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Cornelis van Dorsser

Very Long Term Development of the Dutch Inland Waterway Transport System

Policy Analysis, Transport Projections, Shipping Scenarios, and a New Perspective on Economic Growth and Future Discounting

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Proefschrift

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To my lovely daughter Merel

Wat verschijne,
Wat verdwijne,
't Hangt niet aan een los geval.
In't verleden
Ligt het heden;
In het nu, wat worden zal.

Bilderdijk (1811)

Preface

Dear reader, in front of you lies the result of over 8,000 hours intensive research work. When I started this project in March 2009 the scope was already much larger than that of a standard PhD project, because it concerns many different aspects that need to be integrated into a single policy framework, such as: the very long term development of the world economy; the available options to deal with the evaluation of policies that have a very long term impact; the very long term development of the West-European transport system; the effects of climate change on inland waterway transport; and the modelling of inland waterway transport flows at the network level. However, during the execution of this thesis I had to expand the scope twice. The first expansion was necessary because I concluded that there is something wrong with the prevailing paradigm of ongoing exponential economic growth, and that a different perspective on economic growth is required to obtain realistic projections and sensible policies for issues with a very long term impact. The second expansion followed after this thesis provided input for a broader scenario study of the Dutch Delta Programme.

I first noticed that there could be something wrong with the present views on economic growth in the year 2000, when I started studying Economics at the Erasmus University Rotterdam in addition to my study Naval Architecture at the Technical University Delft. At a certain stage I was simultaneously enrolled in: (1) a technical course on sustainability, in which I was taught that there are limits to technological progress that make it impossible to counter all the negative effects of economic growth by means of technology alone; and (2) an introduction course into macro-economy in which I was taught that economic growth results from technological growth, that can more or less be taken for granted. I couldn’t see how these two views could be united.

At the same time I was a member of student society De Bolk, where I had many interesting discussions on various social topics. I very well remember an evening in which one of my fellow students argued that the only justification for building a nuclear power plant is the fact that economists ‘invented’ future discounting, which allows them to virtually neglect all negative very long term effects. It took me more than a decade before I finally realised, during the writing of this thesis, that this discussion relates to the discussion on economic growth, which implies that it should be considered in conjunction.

In my later work as a transport economist at Royal Haskoning I was further confronted with high economic growth and transport projections that I found unrealistic. I occasionally had a hard time to debate that these estimates were, in my opinion, overestimated and in some cases I even started to develop my own economic growth projections.

During the writing of this thesis I finally discovered that virtually all official long- and very long term economic growth scenarios are more or less based on the assumption of ongoing exponential economic growth. For a several reasons, that will be discussed in this thesis, I think that a different paradigm on economic growth should be adopted when developing very long term scenarios. I felt that I really had to address this issue in order to obtain realistic transport projections and therefore proposed a different paradigm on economic growth, that also turns out to have major implications for the very long term risk free and social discount rates that are to be applied when discounting very long term effects.

When undertaking such a huge complicated research project funding, inspiration, motivation, and support are the most critical elements. I am very grateful to Rijkswaterstaat for providing the necessary funding in various ways. Without this support I would have certainly not been able to bring this thesis to a successful end.

It is impossible to name everybody that has inspired, supported, and motivated me during the writing of this thesis, but I would like to name a few. To start with I want to thank my parents for always motivating and supporting me in undertaking my various studies. Without them I would have not been able to qualify for this project. I am also very grateful to my promotors Han Ligteringen and Bert van Wee for their excellent continuous support. Invaluable have further been the weekly chats with Milou Wolters, my supervisor from Rijkswaterstaat, as well as the meetings with other staff members of Rijkswaterstaat, such as Ernst Bolt, Frank den Heijer, Arjan Hijdra, Bas Turpijn, Onno Miete, Gerra Witting, and Nora Schmorak.

I owe much to TRAIL research school, which offered several courses in which I met quite some interesting people that all seemed to be very willing to support. Warren Walker and Vincent Marchau really helped me to get the right mind-set on policy making. Lori Tavasszy was amongst the few to give me clear directions at the beginning of this project. In addition he provided, together with Mo Zhang, the necessary background on transport modelling at the end of this thesis. The conversations with Henri de Groot, Harry Geerlings, and Bart Kuipers were also very motivating and further inspired me while conducting the research – and in particular Henri's comments on the draft of this thesis turned out to be very valuable.

Within the section Ports and Waterways I thank Henk Verheij for his support in addressing the effects of climate change, Poonam Taneja for her mental support, and Tiedo Vellinga for giving me ample time to complete the work. I further thank Robert Hekkenberg for his support on fuel consumption modelling of inland barges and Niek Mouter for introducing me into the work on future discounting.

I also thank Royal Haskoning (now Royal HaskoningDHV) for enabling my initial steps into this PhD Project and my former colleagues there, Theun Elzinga, Maarten Volgers, and many others for their interest and support. In addition I am also grateful to Robert and Robert-Jan Zimmerman of Mercurius Shipping Group for their interest, flexibility, and ongoing support.

But most off all I thank my loving wife Angelique for supporting me and showing me that there is much more in life than research alone – and my daughter Merel for never letting a day go by without giving me a smile from the very moment she was born in 2012.

Cornelis van Dorsser, April 2015

Contents

1 Introduction

"We frequently find that what is well known is poorly understood, and what is taken for granted is taken without thought. We also disagree with much of the thinking and discussion in academic, intellectual and literary establishments today. Therefore, for both the common and academic wisdom we offer uncommon analysis. The exercise may please some, jar others and perhaps upset more than a few. But we are confident that it will open a new perspective on the issues we discuss."
- Herman Kahn, William Brown, and Leon Martel (The Next 200 Years, 1977, p. ix)

1.1 Introduction

Infrastructures are essential to the well-functioning of modern economies, but once in place they are hard to change due to their high capital intensity and very long technical lifetime. Infrastructure investments therefore need to be carefully planned in order to avoid suboptimal performance and costly adjustments in the future. Infrastructure providers aim to make new infrastructure investments robust against changing user requirements, that will inevitably take place during the very long lifetime of the provided infrastructure.

This also holds for Rijkswaterstaat (RWS), the agency within the Ministry of Infrastructure and Environment that is responsible for the construction, management, and maintenance of hydraulic structures, such as ship locks, weirs, and bridges, on the main inland waterway system in the Netherlands. The technical design lifetime of these structures is typically in the order of 50 to 100 years[1]. Infrastructure investments made today will for a very long period of time define the characteristics of the main inland waterway system. If old hydraulic structures are replaced by similar hydraulic structures at the end of their lifetime, this will eventually result in the development of *'a good as new old timer'*, but the world has changed and will be changing. Rijkswaterstaat therefore desires to develop more visionary proactive integrated infrastructure development strategies, that consider the necessary replacement of the hydraulic structures as an opportunity to improve the network at a systems level.

The evaluation of such strategies does however require insight in the expected very long term development of the main drivers that act on the system as well as a model that is able to define the very long term effects of proposed policies and external developments on the

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[1] Rijkswaterstaat (2002) assumes a technical design lifetime of 50 years for pumping stations, 70 to 75 years for bridges, and 100 years for sluices, locks, weirs, and storm surge barriers.

waterway system. This thesis provides the *'building blocks'* for the development of a new policy evaluation method, that is capable of taking such very long term effects into account for a single sub-system of the waterway system, namely the inland waterway transport (IWT) system. The choice for this sub-system does not imply that other sub-systems are irrelevant, but the scope had to be constrained to keep the project manageable.

The initial and primary objective of this thesis is to investigate how Rijkswaterstaat can develop a workable method for taking the very long term development of the Dutch IWT system into account in the evaluation of integrated infrastructure development strategies with a very long term impact. However, during the execution of this PhD project two important additional research objectives were added. The first additional research objective, of which the scientific and social relevance transcends the original aim of this thesis, followed from the gained insight that there seems to be something wrong with the prevailing paradigm of ongoing exponential economic growth. I aimed to make clear that a different paradigm should be adopted – and addressed the implications of using an alternative economic growth paradigm on the outcome of the very long term transport projections, as well as on the appropriate level of the risk free discount rates that are to be applied when discounting very long term effects. The second additional research objective concerns the development of a set of very long term Shipping Scenarios for the Dutch Delta Programme, up to the year 2100. This objective was added in the year 2012 after a request to contribute to the Delta Scenarios. I responded with a full scenario report (see Van Dorsser, 2012), of which four scenarios are now fully adopted in the official Delta Scenario report (see Bruggeman et al., 2013).

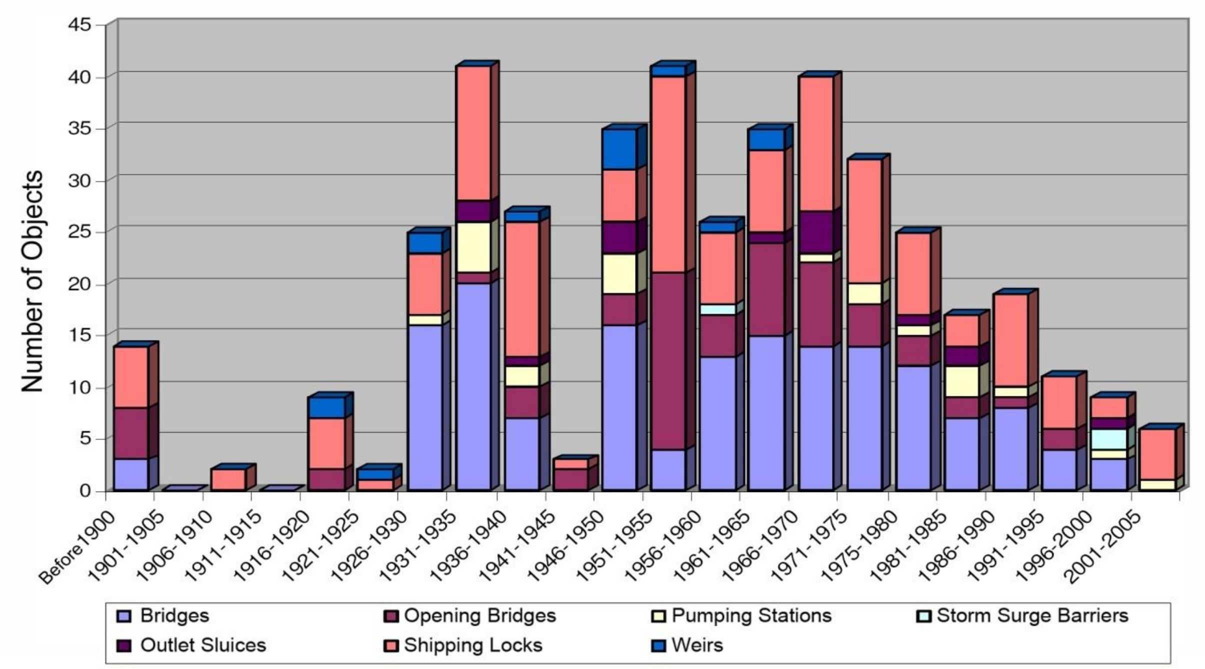
This chapter provides an introduction to this thesis on the very long term development of the Dutch IWT system. Section 1.2 gives the necessary background on the project, from which it becomes clear why Rijkswaterstaat desires to develop a new methodology for taking the very long term effects on the IWT system into account; Section 1.3 places this thesis into its scientific context and elaborates on the scientific gaps that it aims to address; Section 1.4 defines the various research questions and elaborates on the applied methodology; Section 1.5 provides an outline of this thesis that indicates how the various sections are linked; and Section 1.6 concludes with a reading guide for the time critical reader.

1.2 Background

This section provides a discussion on the asset management challenges of Rijkswaterstaat and indicates why Rijkswaterstaat desires to prepare a more visionary and proactive integrated infrastructure development strategy.

1.2.1 The asset management challenges of Rijkswaterstaat

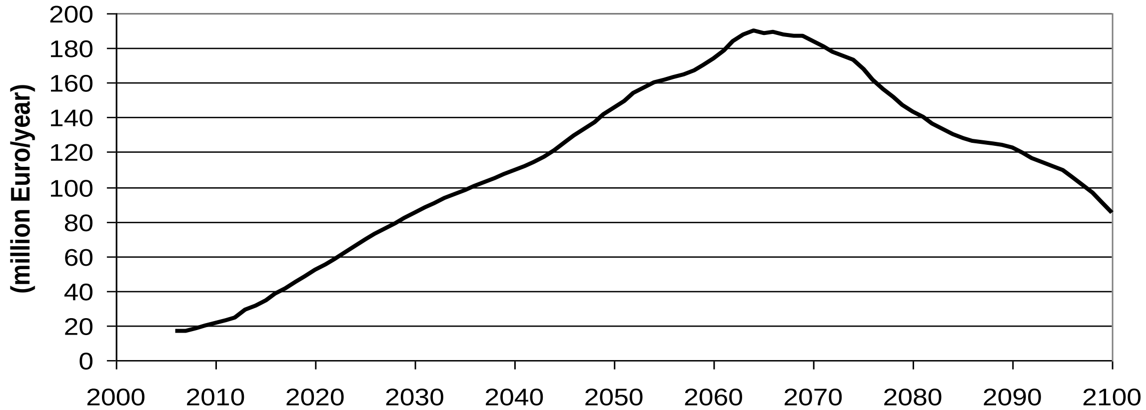
Rijkswaterstaat is responsible for the design, construction, management, and maintenance of the national road- and waterway network in the Netherlands. It is not only responsible for the technical condition of the infrastructure, but also for its operations. Rijkswaterstaat facilitates the smooth and safe flow of traffic; keeps the national water system safe, clean, and user-friendly; and protects the country against flooding (Rijkswaterstaat, 2009, p.10). It aims to maintain and develop the national (road- and) waterway network within the constraints of the available resources, while keeping the stakes of the infrastructure users in mind (Hofstra, 2007, p.5 and 13). This is a difficult task given the fact that the Dutch government runs a tight budget and constantly needs to find new cost savings – while at the same time an ever increasing number of infrastructures is reaching the end of its technical lifetime. The latter implies that large investments will be required to extend the functional lifetime and/or replace the structures. Rijkswaterstaat (2002) investigated the full scope of its replacement challenge throughout the 21st century by making an inventory of the structures for which they are responsible. This inventory listed over 400 hydraulic structures of which the majority is built in the period from 1930 to 1985. The years of construction are indicated in Figure 1-1.



Note: The report states that the infrastructure assessed is frozen on the 2001 situation. The numbers presented for the period 2001 – 2005 are therefore likely to relate to the year 2001.
Source: RWS (2002, p.14), translated and adjusted layout.

Figure 1-1: Hydraulic Structures per Type and Year of Construction

For each individual hydraulic structure an estimate of the replacement costs was made. The total replacement costs were estimated at 13 billion Euros (presumably in constant year 2000 values). Insight in the phasing of the expenditures over time was obtained from combining the age of the structures with their expected lifetime. The expected annual replacement costs for the hydraulic structures managed by Rijkswaterstaat are indicated in Figure 1-2.



Note: Values in constant Euros of a certain base year (year not reported, but most likely the year 2000).
Source: RWS (2002, p.17), modified and translated.

Figure 1-2: Expected Replacement Costs for Hydraulic Structures managed by RWS

Figure 1-2 indicates that future expenditures are likely to rise to a manifold of today's value and can be expected to peak in the 70s of the 21st century. Rijkswaterstaat also analysed the infrastructures on its road network, for which the overall replacement costs were estimated at 12 billion Euros, and for which the peak is expected around the year 2050. One can therefore conclude that the overall replacement costs for the infrastructures managed by Rijkswaterstaat will increase considerable over the next few decades. To cope with these increasing cost levels a well-structured and cost wise replacement strategy will be required.

1.2.2 Desire for a proactive infrastructure development strategy

The previous section indicated that: (1) major repair, renovation, and replacement of the hydraulic structures requires very large capital investments; and that (2) the relatively long design lifetime of about 50 to 100 years implies that investments made today will have a long term impact on the system. After replacement of the hydraulic structures the dimensions and functionalities of the waterways will be fixed for a very long period of time. Current practice is to replace a single hydraulic structure at the end of its lifetime (Den Heijer, 2008, p.7). But by replacing what we have we obtain what we had (about one century ago), while the world has changed and will be changing[2]: new barge types such as container barges have emerged over the past decades; the size of inland barges has increased considerably due to increased transport volumes; the quality of the European IWT network is still improving as a result of European integration; climate change may have an adverse effect on IWT; and so on…

Based on this notion a small group of experts from different knowledge centres within Rijkswaterstaat called for a more visionary and proactive infrastructure development strategy, that is able to consider the necessary replacement of hydraulic structures as an opportunity to improve the network at a system level. The experts argued that such an approach is likely to improve the functionality and reduce the overall cost levels of the waterway system. The main ideas of the experts were outlined in the internal document: *"Networks in the picture, replace with vision"* (Den Heijer, 2008, translated title) and the covering presentation: *"Strategy replacement civil structures - networks in the picture, replace with vision"* (Den Heijer et al., 6 April 2009, translated title). These documents identified a desire for: (1) a methodology for the evaluation of proposed policies with a very long term impact on the waterway network, and (2) a proactive strategy for optimization of (at least parts of) the waterway network.

The development of such a desired new methodology and proactive strategy follows the ADKAR model, that stands for: building *awareness*, creating *desire*, developing *knowledge*, fostering *ability*, and *reinforce* changes in the organization (Hiatt, 2006). At the start of this PhD project (March 2009) the process was still in the phase of building awareness and creating desire. It was time to develop knowledge on the subject and to demonstrate the possibility of taking very long term effects into consideration in the day to day policy making process of Rijkswaterstaat. The perceived path for the full development of the proactive strategy is likely to last a few decades and may ultimately involve the following steps:

1. Demonstrate the feasibility of taking very long term developments (on the waterway system) into account in the decision making process of Rijkswaterstaat.
2. Develop an evaluation model, vision, and proactive strategy for the very long term development of a single (transport) function of the waterways.

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[2] *"If you do what you did, you will obtain what you had. But the world is changing…"* (Den Heijer et al., Presentation of 6 April 2009, translated from Dutch).

3. Develop an evaluation model, vision, and proactive strategy for the very long term development of all identified functions of the waterways.
4. Develop an evaluation model, vision, and proactive strategy for the very long term development of both the road- and waterway infrastructure network.

It was recognised that a PhD project could be an ideal way to develop a knowledge base for implementing the first two steps of the desired very long term asset management approach.

1.3 Scientific Context and Contribution

In general a PhD project should be well placed into its scientific context and provide *"an original contribution to knowledge"* (Phillips at al., 2005, p.33). This section starts with an elaboration on the present desire of infrastructure provides to take longer time horizons into account in their policy formulation – and continues with a discussion that puts this thesis into its broader scientific context, and refers to the knowledge gaps that it aims to address.

1.3.1 Asset management policies desire to take longer time horizons into account

Including very long term developments into asset management policies is a logical next step that has already been identified a decade ago by Plantey (1999), who presented a similar case for the management of the French hydro-agricultural water infrastructure. In this case the annual costs for the concerned infrastructure replacements were expected to grow from 20 million FFR in the year 2000 to 150 million FFR in the year 2060. The study concluded that: *"a long term management strategy cannot really be applied if little effort is made to obtain objective data on the real condition of the system and to ensure its adaptation to the changing needs of its customers. Such efforts need not to be excessive and, if applied consistently and permanently, will prove to be very productive in optimizing the management procedures"*. From this statement one can conclude that integrated long term management strategies are likely to offer substantial benefits – and that the preparation of a very long term management strategy can be expected to require relatively little efforts compared to its potential gains. This conclusion is more or less in line with the opinion of the small group of experts within Rijkswaterstaat, that expect a proactive approach to improve the functionality of the system and to reduce the overall cost levels for maintaining the waterway network.

There are more organisations dealing with the management of large infrastructure networks. The fact that Rijkswaterstaat still needs to learn how to prepare its own integrated very long term infrastructure development strategies does not imply that the required knowledge cannot be obtained from other organisations. Rijkswaterstaat therefore studied the use of long term strategies at eight other Dutch infrastructure providers (Ligtvoet et al., 2011). From this study it was concluded that: *"In general the world of asset management seems to be separated from the world of long term strategies"* (p.12, translated). Nevertheless quite some progress has been made over the past decades. Some companies are already very strong in considering the replacements of the network at a systems level and manage to take the various functions that the network performs into account. Other organisations manage to look further into the future up to the year 2050. However, none of the companies looked as far into the future as the year 2100. Increasing the time horizon up to the year 2100 is still a major challenge.

1.3.2 Lack of credible tools and methods to look far into the future

An important bottleneck in the formulation of very long term policies is the lack of credible tools and methods to look far into the future (Agusdinata, 2008. p.6). Lempert et. al. (2003, p. xi) explain that: *"Powerful analytic tools now exist to help assess risks and improve decision making in business, government, and private life. But almost universally, systematic* *quantitative analysis rarely extends more than a few decades into the future. Analysts and decisionmakers are neither ignorant of nor indifferent to the importance of considering the long term. However, well-publicized failures of prediction – from the Club of Rome's "Limits to Growth" study to the unexpected, sudden, and peaceful end of the Cold War – have done much to discourage this pursuit. Systematic assessments of the long-term future are rare because few people believe that they can be conducted credibly"*. It is therefore important to investigate the available options for looking far ahead and to consider their appropriateness.

The above quote already mentioned that the lacking belief in the *'credibility'* of very long term projections is amongst others caused by the *"Limits to Growth*" study of the Club of Rome, who in 1972 attempted the first quantitative projection on the potential state of the world for a number of important issues towards the year 2100. In their report Meadows et al. (1972, p.27) state that the applied model was: *"the only formal model in existence that is truly global in scope, that has a time horizon longer than 30 years, and that includes important variables such as population, food production, and pollution, not as independent entities, but as dynamically interacting elements, as they are in the real world"*. But the exponential growth functions applied in this study resulted in gloomy results (i.e. doom scenarios) that shocked the world and raised an intense discussion on the validity of quantitative long term projections[3]. Following this discussion long term projections were no longer perceived credible. Rivett (1978, p.35), for instance concluded that: *"according to a number of sources, quantitative methods are only useful up to about 15 years"*. For longer time horizons he suggested the use of scenarios, that could for instance be developed on the basis of Delphi Techniques (i.e. by applying expert judgement). The use of scenarios with a time span of up to about 20 (and later also 40) years ahead became the commonly accepted way of dealing with future uncertainty – and other very long term projection methods were put aside for a considerable period of time. Examples of recent long term scenarios studies are the Dutch WLO scenarios, that provide an outlook up to the year 2040 (Centraal Planbureau et al., 2006)[4]; and the TRANSvisions transport scenarios of the European Commission (Petersen et. al., 2009), that provide an outlook towards the year 2050.

However, by the beginning of the 21st century a few major global issues became so important that they forced the development of a much longer view, and therefore, for some issues such as *population*[5], *energy*[6], *climate change*[7] and the *rise of sea water levels*[8] much longer

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[3] Despite major criticism of their work the Club of Rome continued its modelling activities and presented a 30 year update of their report in 2004 (Meadows et al., 2004).

[4] WLO stands for the Dutch sentence: *"Welvaart en Leefomgeving"*. In English: *"Prosperity and Environment"*.

[5] Examples: Estimate of world population up to 2150 (UN, 1999); Estimate of world population per country up to 2300 (UN, 2003); Four global scenarios up to 2100 by the Working Group for the Millennium Ecosystem Assessment (2005); Four national scenarios for development of population growth in the Netherlands (De Jong, 2008); Probabilistic forecast for the development of the world population divided into 13 regions (IIASA, 2001, and 2007 update).

[6] The Very Long Term Energy and Environmental Model (VLEEM) of the European Union runs up to 2100. Special emphasis of the model is the energy development over one century, worldwide (B. Chateau et al., 2003). Shell International B.V. (2013) published two *"New Lens Scenarios"* (named Mountains and Oceans) for the development of the energy system up to the year 2100.

scenarios and projections up the year 2100 (or even beyond) have now been developed. It is quite interesting to observe that some of these very long term views are once again based on the previously 'rejected' analytical projection methods that systematically explore the very long term development of the system. The *International Institute for Applied Systems Analysis* (IIASA) for instance developed a very long term probabilistic population projection up to the year 2100, on the basis of a system dynamics model, of which the obtained probabilistic output was used as input for the development of a set of very long term population scenarios for the *Intergovernmental Panel on Climate Change* (IPCC). It can therefore be concluded that advanced analytical projection methods are once again gaining acceptance and credibility for dealing with issues that require a very long term view, in particular when the results are presented as plausible scenarios rather than as a definite estimate.

To the best of my knowledge very long term scenarios and projection methods up to the year 2100 have not yet been reported for freight transport; except for a recent study of the Club of Rome for the port of Rotterdam (Van den Akker et al., 2014), and my contribution to the Shipping Scenarios for the Dutch Delta Programme (Van Dorsser, 2012). It seems that very long term projection methods for freight transport still need to be developed.

1.3.3 Policy methods for dealing with a very long time horizon

Very long term policies are generally associated with high or even deep levels of uncertainty. A common way to deal with high uncertainty levels in policy making is to search for policies that perform well across a range of plausible futures. The RAND Corporation[9] developed a new robust *Long Term Policy Analysis* (LTPA) method for dealing with long-time horizons and levels of deep uncertainty[10]. This LTPA method deals with uncertainty by exploring the future in order to find robust solutions amongst large ensembles (hundreds to millions) of scenarios referred to as *"landscapes of plausible futures"* (Lempert et al., 2003). Under harsh conditions of deep uncertainty this approach may however no longer be maintained. Walker et al. (2001) therefore developed a more flexible approach referred to as *Adaptive Policy Making* (APM). Adaptive policy making enables the development of long term policies regardless of the level of uncertainty faced by the policy makers. One may therefore conclude that various methods exist for taking very long term effects into account, but that the policy maker still needs to decide which method suits him best. This also holds for Rijkswaterstaat.

In addition to the selection of the most appropriate policy method there are also a few other issues that need to be addressed. The first issue concerns the evaluation of the various policy

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[7] The IPPC Climate Change Synthesis Report (2007) provides scenarios and bandwidths for CO_2 emissions, the development of greenhouse gasses, and related temperature rise up to 2100.

[8] For the rise of the sea level along the Dutch coast the KNMI provided a bandwidth forecast up to 2100 in 2006. This forecast has been reviewed and extended to 2200 by the Deltacommissie (2008, p. 24).

[9] The RAND Corporation is a non-profit institution that helps to improve policy and decision-making through research and analysis. The name RAND stems from a contraction of the terms research and development.

[10] Deep Uncertainty is defined as a condition in which analysts do not know or the parties to a decision cannot agree upon (1) the appropriate conceptual models to describe interactions among a system's variables, (2) the probability distributions to represent uncertainty about key parameters in the models, and/or (3) how to value the desirability of alternative outcomes (Lempert et al., 2003, p. xii).

outcomes of interest. In some countries, such as the Netherlands and the UK, there exist clear guidelines for the evaluation of infrastructure projects, that amongst others specify the outcomes of interest to be taken into account. The Dutch guidelines were first referred to as the OEEI and later as the OEI methodology (see to Eigenraam et al., 2000; and Spit et al., 2008). The OEI methodology does however require a level of detail that cannot be forecasted at such a very long time horizon. This implies that a different approach will be required for the evaluation of very long term effects. The second issue concerns the value of time. As a result of the fixed discount rates presently prescribed for the OEI methodology, the effects of benefits and disbenefits over about 20 to 30 years are virtually negligible. This implies that project alternatives aiming for long term benefits may (wrongly) be scored too low in a social cost benefit analysis (SCBA). The final issue concerns the applied decision criteria. For policies dealing with higher levels of uncertainty it is no longer appropriate to select the most promising option on the basis of profit maximisation and therefore a different selection criterion should be applied. These are issues that will be addressed in this thesis.

1.3.4 Integration of relatively small and still developing research disciplines

Apart from developments in distinct scientific fields much research is nowadays taking place on the interface between various research disciplines. This PhD project combines several economic, technical, and policy related disciplines under the flag of infrastructural asset management. The involved disciplines amongst others include: *policy making*, *freight transport modelling*, *transport economics*, *intermodal transport*, *civil engineering*, *naval architecture*, *forecasting*, and *econometrics*. Many of the (sub)fields involved are relatively small and/or not yet fully developed. For example: *"Compared to passenger transportation modelling, the field of freight transport modelling is relatively young and developing quickly into different directions all over the World"* (Tavasszy, 2006, p.1); and *"Within the transport literature, inland water transport has received relatively limited attention"* (Jonkeren, 2009, p.13). The field of intermodal (barge) transport is not very developed either. An overview of intermodal barge transport in Flanders is provided by Macharis et al. (2011), but a good standard work is lacking. Within the field of civil engineering the inland waterways are generally perceived less interesting than the international port sector and do not obtain the attention it deserves. The same holds for the field of naval architecture, where inland barges are perceived less interesting than seagoing vessels. Adaptive policies have been discussed by Marchau et al. (2007) for road-, rail-, and airport infrastructures, but not for the inland waterways. The fields of futures research and foresight are still developing and not structured in a coherent way. Though comprehensive books on forecasting are available (e.g. Armstrong, 2001) no standard work on trade-, traffic- and transport forecasting has been found. It should therefore be concluded that many relatively small and/or less developed research disciplines are involved and that these need to be integrated. This thesis is positioned at the forefront of a number of these subfields. Quite a few new contributions to these subfields will therefore be discussed throughout this thesis.

1.4 Research Questions and Methodology

This section defines the research questions that will be addressed in the course of this thesis and elaborates on the applied process and research methodology.

1.4.1 Research questions

This thesis provides the *'building blocks'* for the development of a new very long term policy evaluation method. It aims to investigate how Rijkswaterstaat can develop a workable method for taking the very long term development of the Dutch IWT system into account in the evaluation of integrated infrastructure development strategies with a very long term impact, in order to support decision-making for an integrated part of the waterways with respect to issues such as: how much water depth should be guaranteed on the various river stretches; should the number of weirs and locks at a certain waterway stretch be adjusted; how much hinder will bridge opening cause to other infrastructure users (e.g. road and rail); does it economically pay off to increase the height of fixed bridges as well as the length and width of the locks on the waterways; and how much capacity (e.g. for locks and bridge openings) should be provided to maintain a sufficient quality IWT operation. In line with this objective the following Main Research Question was defined.

Main Research Question (MRQ)

- How can Rijkswaterstaat develop a workable method for taking the very long term development of the Dutch Inland Waterway Transport (IWT) system into account in the evaluation of integrated infrastructure development strategies with a very long term impact?

The required *'building blocks'* for the development of this new policy evaluation method are: (1) insight in the main external drivers that act on the IWT system; (2) methods and models to evaluate the effects of external developments as well as proposed infrastructure policies on the very long term development of the IWT system, in particular with respect to the overall development of the freight transport volumes on the inland waterways; and (3) a plausible set of qualitative and quantitative scenarios for the very long term development of IWT system up to the year 2100.

These three main building blocks are however not readily available and need to be developed. This thesis starts with a preliminary research section in which four General Sub Questions are discussed that contribute to the development of the main building blocks. These four General Sub Questions are indicated in the following text box:

General Sub Questions (GSQ)

1. Concerning the Dutch and West European IWT System:
    a. What is the importance of IWT in the overall freight transport system, how is the relative market share of IWT developing over time, and what are the most important transport flows on the inland waterways?
    b. How has the historical development of the IWT infrastructure and barge fleet affected the present characteristics of the IWT system?
    c. What are the present IWT policies and how can they be expected to effect the future development of the IWT system?
    d. How does IWT interact with other users of the waterway system – and can the IWT system be studied without considering the other users?
2. What can be learned from other regional long term transport scenario studies concerning: the use of scenarios, the applied methodology for quantifying scenarios, the main drivers of the transport system, the presented output parameters, and the obtained long term scenario projections?
3. What are the main trends and drivers for the very long term development of the world economy (i.e. the main driver of the transport system)?
4. What are the most appropriate methods for looking far ahead (i.e. towards the end of the 21st century) and dealing with the inevitable high levels of uncertainty, that are related to such a very long term planning horizon?

The first General Sub Question concerns the development of the Dutch and West European IWT system: GSQ 1a places the development of IWT in the broader perspective of the development of the overall West European inland freight transport volumes over time. These insights do not only provide insight in the development of the overall freight transport volumes but also in the relative share of IWT; GSQ 1b also concerns the development of the IWT system over time, but mainly emphasises the present characteristics of the system as these characteristics will, to a large extent, define the competitiveness of the IWT system and need to be taken properly into account in the applied transport models; GSQ 1c identifies the main policy drivers for the future development of the IWT system, that need to be taken into account; and GSQ 1d examines if it is sensible to develop a methodology that concerns only one sub-system of the waterways, namely the IWT system.

The answer to GSQ 2 provides insight in the main drivers of the transport system as well as in the modelling approaches that are generally applied in long term transport studies. This is useful because similar drivers and modelling approaches may also turn out to be useful in very long term transport studies. In addition this General Sub Question will also provide insight in the prevailing views on the expected long term development of the transport system in general, and the IWT system in particular.

The answer to GSQ 3 addresses the available insights regarding the expected trends and drivers of world economy up to the year 2100. This is important because: (1) the overall very long term transport demand is directly related to the overall level of economic output; and (2) the development of transport infrastructures as well as the use of the transport infrastructures (i.e. the applied modes of transport) turns out to be very much related to the fundamental very long term drivers of the world economy.

The answer to GSQ 4 provides insight in the available options for looking far ahead and dealing with the inevitable high levels of uncertainty, that come with a very long term planning horizon. It provides a clear guideline for the further development of the desired methodology that will be discussed in this thesis.

Having discussed the necessary input from the preliminary research section, the next step is to address the Main Research Question. In order to provide a structured answer to the Main Research Question the following six Methodological Sub Questions were defined:

Methodological Sub Questions (MSQ)

1. How should Rijkswaterstaat structure its policy framework to allow for the ex-ante evaluation of integrated infrastructure development strategies with a very long term impact on the IWT system?
2. How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system, which have been identified as:
    a. the overall development of the demand for freight transport in the larger region covering the West European IWT system;
    b. the possible rise of new infrastructures and their implications for the IWT system as well as the anticipated development of the IWT system itself;
    c. the adverse very long term effects of climate change and morphological changes on the performance of the IWT system; and
    d. the possible major shifts in the mode of transport stemming from major changes to the cost structure of the inland transport modes?

3. What would be a sensible structure for modelling effects of external developments and proposed infrastructure policies on the very long term development of the IWT flows at the network level?
4. What are the options to make efficient use of an existing long term transport model for the implementation of the proposed model structure – and where will additional modelling and/or research efforts be required to obtain a workable model?
5. What would be a plausible set of qualitative storyline scenarios for the very long term development of freight transport on the inland waterways?
6. What would be a sensible quantification of the plausible storyline scenarios for the very long term development of freight transport on the inland waterways?

The six Methodological Sub Questions are intended to jointly provide a preliminary answer to the Main Research Question, but *'the proof of the pudding is in the eating'*. To provide a definite answer to the Main Research Question one has to integrate the findings of all six Methodological Sub Questions into a single model structure and apply it to a real case study. This nevertheless turned out to be *'a bridge too far'*, as it requires an additional amount of research, that is well beyond the time and budget available for this PhD project. This thesis therefore concludes with a provisional answer to the Main Research Question on the basis of the joint answers to the six Methodological Sub Questions.

1.4.2 Process description

The research clearly followed an iterative process in which I continuously shifted from a top down to bottom up approach and vice versa. The first step was to define a provisional outline and working plan for the overall research project, that was based on:

- My personal understanding of the transport system, stemming from former education (as a naval architect and transport economist) and previous experience with long term forecasting of port- and IWT activities (see also CV at the end of this thesis);
- In depth discussions with Han Ligteringen and Bert van Wee (the two promoters of this thesis); Milou Wolters (supervisor from Rijkswaterstaat); a large number of experts within Rijkswaterstaat; and various scientists and researchers that can, in general, be linked to TRAIL Research School.

The next step was to select the most relevant aspect, that had to be studied to get the overall project to the next level; and to conduct the necessary bottom up research to obtain sufficient understanding of this aspect. In general the following approach was applied:

- Contact an expert that knows a lot about the aspect under consideration. Discuss the subject in order to get a head start by asking amongst others: what literature is of particular relevance; what are the present forefront developments; where to find the necessary data; whom to further contact; and what to be aware of;
- Study the aspect by means of: literature research, further discussion with experts and fellow researchers, structured thinking, and/or modelling activities;
- Report the findings and, where necessary, add a refection section to address the issues that were encountered. Where possible, try to put the insights in a broader perspective and indicate the relevance of the findings for this thesis (by eventually providing a formal answer to the various sub questions discussed in Section 1.4.1);
- Share the findings with a select number of experts and organise feedback by either publishing the work as a journal paper (this was done once) or asking at least one expert (often the ones contacted before) to comment on the work;

- Take sufficient time to discuss the comments and leave the subject for at least a couple of months to contemplate the remarks before writing a new version. If necessary ask the experts to comment on the changes made.

Each time when the study of a detailed bottom up subject was completed I shifted my mind set back to the top down approach, in order to sharpen my view on how to structure the overall thesis and what to study next. I continued this approach until a full draft of all chapters was completed. At that stage I wrote a comprehensive summary report (Van Dorsser, 2013) that was reviewed by my promoters, as well as by a substantial number of experts within Rijkswaterstaat. I then revised the chapters in the thesis to bring them in line with the overall discussion in the summary report.

1.4.3 Research methodology

The obtained results are based on: (1) literature research; (2) personal working experience; (3) discussions with and comments by experts; and (4) analysis of existing trends and future developments, for which I prepared my own models and developed my own insights.

With respect to the applied literature research I made use of: books available at the libraries of the Technical University Delft (TU-Delft) and the Erasmus University Rotterdam; books that have been purchased via the internet; PhD studies that were available at TRAIL Research School and several university repositories; scientific journals to which the TU-Delft has access; articles, reports, data, and web text that are available on the internet; as well as reports that have been obtained from the various experts with whom I discussed the research.

From experience as a transport consultant at Royal Haskoning I already had a background in transport forecasting as well as in financial- and economic project evaluations. I re-joined the Mercurius Shipping Group in 2011, to improve my understanding of IWT.

During the research I had weekly meetings with Milou Wolters, frequent meetings with Han Ligteringen and Bert van Wee, as well as substantial meetings with many experts from various disciplines. In general I either contacted these experts to: (1) orientate myself, obtain input, and further discuss the subject; or (2) to validate/review parts of the work, such as: a chapter or a part of a chapter, a note on a conceptual idea, an appendix, a draft of a paper, the background report on the Shipping Scenarios for the Delta Programme (Van Dorsser, 2012), or the draft summary report of this thesis (Van Dorsser, 2013). Of particular relevance is to note that the Shipping Scenarios, that were prepared for the Delta Programme (but also directly address MSQ 5 and 6), were commented on by a number of experts from Rijkswaterstaat, Deltares, the Port of Rotterdam Authority, and the Ministry of Economic Affairs (EL&I). A list containing most of the consulted experts is provided in Appendix E.

The models and data sets that were used to answer the various research questions are made available on the internet. Reference to these files is made in Appendix F.

1.5 Outline of the Thesis

This thesis contains the following seven subsequent sub-sections: *Introduction* (Chapter 1), *Preliminary research* (Chapter 2 to 5); *Policy framework* (Chapter 6); *External developments* (Chapter 7 to 10); *Transport model* (Chapter 11 and 12); *Scenario output* (Chapter and 13 and 14); and *Conclusions* (Chapter 15). Figure 1-3 provides an outline of the thesis.

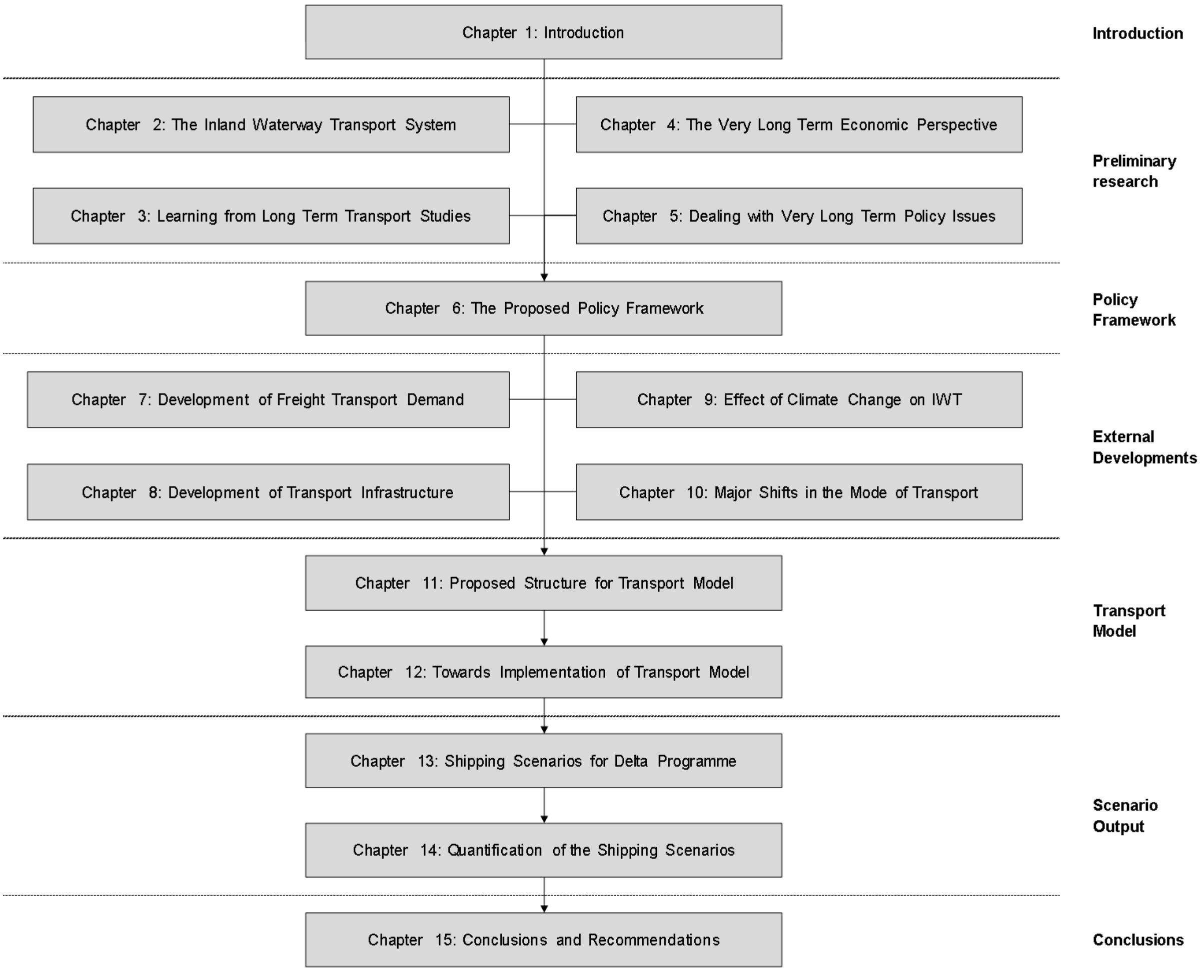

Figure 1-3: Outline of the Thesis

The section below discusses the various topics that will be addressed in each of the seven sub-sections of this thesis:

1. The **first sub-section** concerns the discussion in this chapter.

2. The **second sub-section** addresses the outcome of the preliminary research efforts by providing an answer to the four General Sub Questions. Chapter 2 (related to GSQ 1) provides an introduction to the IWT system that covers: (a) the historical development and market share of IWT; (b) the present characteristics of the IWT infrastructure and the inland barge fleet; (c) the possible effect of prevailing IWT policies on the future development of the IWT system; and (d) the interaction with other user functions of the waterway system. Chapter 3 (related to GSQ 2) elaborates on the lessens that can be learned from other long term transport studies; Chapter 4 (related to GSQ 3) continues with a discussion on the very long term development of the economy (i.e. the main transport driver); and Chapter 5 (related to GSQ 4) provides a guideline for taking the uncertainties stemming from applying a very long term planning horizon into account in the policymaking process.

3. The **third section** relates to the structure of the proposed policy framework. Chapter 6 (related to MSQ 1) introduces a general policymaking framework and shows how this

framework can be used for the evaluation of infrastructure development strategies with a very long term impact on the IWT system.

4. The **fourth section** deals with the primary very long term external drivers that act on the IWT system. Chapter 7 (related to MSQ 2a) provides probabilistic projections for the development of the overall transport demand in the larger West European region; Chapter 8 (related to MSQ 2b) addresses the possible development of new transport infrastructure networks, as well as the anticipated development of the IWT network itself; Chapter 9 (related to MSQ 2c) covers the adverse effects of climate change and morphological changes on the transport performance of the IWT system; and Chapter 10 (related to MSQ 2d) provides an analysis of the possible effects of major changes to the cost structure of the various transport means on the modal share for IWT.

5. The **fifth section** addresses the options to develop a modelling approach, that is able to define the very long term effects of proposed policies and external developments on the performance of the IWT system at the network level. Chapter 11 (related to MSQ 3) proposes an sensible structure for the modelling of the very long term effects that act on the IWT system – and addresses a number of outstanding issues that need to be resolved. Chapter 12 (related to MSQ 4) addresses the options to develop the proposed very long term transport model on the basis of an existing long term transport model – and concludes with a research agenda for the further implementation of this model.

6. The **sixth section** deals with the development of six very long term shipping scenarios for the throughput volumes in the Dutch seaports as well as for the transport volumes on the Dutch inland waterways. Chapter 13 (related to MSQ 5) provides an outline and qualitative description of the six Shipping Scenarios that were developed. Chapter 14 (related to MSQ 6) shows how the scenarios have been quantified.

7. **Chapter 15** summarises the conclusions from the preliminary research section; provides an answer to the Main Research Question; and elaborates on the finding that a different paradigm on economic growth and future discounting should be applied. Finally, on the basis of these conclusions, a number of recommendations is made.

The fact that this thesis is structured along the lines of the primary research objective, does not imply that the two additional research objectives are irrelevant (see Section 1.1). These two objectives could very well be covered within the structure, that was put in place to address the primary research objective. The first additional research objective is covered by the various reflection sections in Chapter 3, 4, 6, and 14, Appendix B and C, as well as Section 7.5. In addition I have added a specific section to Chapter 15, in which I discuss how the various findings provide a joint argument that a different paradigm on economic growth should be applied. The second additional research objective that concerns the development of the Shipping Scenarios for the Dutch Delta Programme is addressed as an integral part of the discussion in Chapter 13 and 14.

1.6 Reading Guide

This PhD project combines a large number of topics into a single framework. The broad scope and considerable size of this thesis implies that readers may not have the time to read through the entire document. I have therefore prepared a corresponding *"Extended Summary Report"* (Van Dorsser, 2015) and included a concluding summary section at the end of Chapter 2 to 14 that one can read instead of reading the entire chapter. In addition I have further aimed to make each individual chapter stand-alone readable and listed the relevant background reading for the individual chapters in Table 1-1.

Table 1-1: Recommended Background for Proper Understanding of the Chapters

Chapter	Recommended background
1	N/A
2	Chapter: 1
3	Chapter: 1
4	Chapter: 1, 3
5	Chapter: 1
6	Chapter: 1, 2, 3*, 4*, 5
7	Chapter: 1, 2, 3*, 4*
8	Chapter: 1, 2*, 3, 4*
9	Chapter: 1, 2*
10	Chapter: 1, 2*, (4), 8
11	Chapter: 1, 2, 3*, (4*), 5, 6*, 7, 8*, 9, 10
12	Chapter: 1, 2, 3*, (4*), 5, 6*, 7, 8*, 9, 10, 11*
13	Chapter: 1, 2, 3, 4, 5, (6), 7, 8, 9, 10
14	Chapter: 1, 2, 3, 4*, 5, (6), 7*, 8, 9, 10, (11), 12, 13*
15	Chapter: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

Note: Chapters indicated with an asterisk (*) are necessary for the proper understanding of the chapter. Numbers between brackets are required for the proper understanding of referred chapter.

The items listed with an asterisk* are necessary for the proper understanding of the chapter under consideration. The other chapters are suggested to improve the reading. Chapters listed between brackets are required for the proper understanding of chapters to which reference is made. Chapter 4 is for instance placed between brackets in the list of Chapter 11, because it is required for the proper understanding of Chapter 6. To illustrate the use of the table: if you are interested in the very long term effects of climate change on the IWT system (i.e. Chapter 9), you can look up that background is required from Chapter 1 (optional) and Chapter 2* (recommended). In this case you are advised to read at least the concluding summary section at the end of Chapter 2 prior to reading Chapter 9.

Literature:

Agusdinata, B. (2008) *Exploratory Modeling and Analysis: A promising method to deal with deep uncertainty*, TRAIL Thesis Series Volume T2008/17, Trail Research School, Delft, The Netherlands.

Armstrong, J.S. (2001) *PRINCIPLES OF FORECASTING, A Handbook for Researchers and Practioner*s, Kluwer Academic Publishers, Boston/Dordrecht/London.

Bruggeman, W., E. Dammers, G.J. van den Born, B. Rijken, B. van Bemmel, A. Bouwman en K. Nabielek, J. Beersma, B. van den Hurk, N. Polman, Vincent Linderhof, C. Folmer, F. Huizinga, S. Hommes, and A. te Linde (2013) *Deltascenario's voor 2050 en 2100, Nadere uitwerking 2012-2013*, Deltares, KNMI, PBL, CPB, and LEI.

Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau (2006) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040.*

Chateau, B., N. Quercia, and the VLEEM consortium (2003) *Assessment of the Very Long Term Development of the Needs For Energy Services: The VLEEM Methodology,* International Energy Workshop jointly organized by the Energy Modeling Forum (EMF), International Energy Agency (IEA) and IIASA. 24-26 June 2003 at IIASA Conference Center, Laxenburg, Austria.

De Jong, A. (2008) *Vier scenario's voor de zeer lange termijn.* Bevolkingstrends: Statistisch kwartaalblad over de demografie van Nederland, Jaargang 56-4e kwartaal 2008, Centraal Bureau voor de Statistiek, Den Haag, pp. 72-81.

Deltacommissie (2008) *Samen werken met water: Een land dat leeft, bouwt aan zijn toekomst, Bevindingen van de Deltacommissie 2008.*

Den Heijer, F. (2008) *De netwerken in beeld: Vervangen met visie, Versie 1,* Bouwdienst, Waterdienst en Dienst Verkeer en Scheepvaart, Ministerie Verkeer en Waterstaat.

Den Heijer, F., M.A. Wolters, J.C.M. van Dorsser, H.E.J. Berger, and A.C.L. Hijdra (2010) *Developing a substitution strategy for hydraulic structures to meet the challenges of a new century,* PIANC MMX Congress, Liverpool, UK.

Eigenraam, C.J.J., C.C. Koopmans, P.J.G. Tang, and A.C.P. Verster (2000) *Evaluatie van infrastructuurprojecten, Leidraad voor kosten-batenanalyse,* Ministerie van Verkeer and Waterstaat en Ministerie van Economische Zaken.

Hiatt, J. (2006) *ADKAR: A Model for Change in Business, Government and the Community,* Learning Center Publications, Loveland, CO.

Hofstra, M. (2007) *Watermanagement van de grote wateren: De wateropgave van Rijkswaterstaat (basisdocument van de RWS-watermanagers),* Rijkswaterstaat RIZA, Rijswijk. Report number 2007.018.

IPCC (2000) *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change,* [Nakicenovic, N. and R. Swart (eds.)], Cambridge University Press: Cambridge, UK and New York. 570 p.

IPCC (2007) *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Pachauri, R.K, and A. Reisinger (eds.)], IPCC, Geneva, Switzerland.

Jonkeren, O. (2009) *Adaptation to Climate Change in Inland Waterway Transport,* Vrije Universiteit Amsterdam, Amsterdam, The Netherlands.

Kahn, H., W. Brown, and L. Martel (1977) *The Next 200 Years, A Scenario for America and the World,* The Hudson Institute, Associated Business Programmes Ltd., 17 Buckingham Gate, London, United Kingdom.

Ligtvoet, A., T. van der Lei, and P. Herder (2011) *Leren van andere organisaties: lange-termijn investeringsvraagstukken buiten Rijkswaterstaat,* Faculteit Techniek, Bestuur en Management, Technische Universiteit Delft, Delft, The Netherlands.

Lempert, R.J., S.W. Popper, and S.C. Bankes (2003) *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis.* RAND, Santa Monica.

Macharis, C., T. van Lier, E. Pekin, and A. Verbeke (2011) *Intermodaal Binnenvaartvervoer, Economische en ecologische aspecten van het intermodaal binnenvaartvervoer in Vlaanderen,* Uitgeverij VUBPRESS, Brussels, Belgium.

Marchau, V.A.W.J., W.E. Walker, and Wee G.P. van (2007) *Innovative long-term transport policymaking: from predict and act to monitor and adapt,* Proceedings European Transport Conference, Association for European Transport, pp. 1-17,

Meadows, D.H., D.L. Meadows, J. Randers, and W.W. Behrens III (1972) *The Limits to Growth,* Universe Books, New York.

Meadows D.L., J. Randers, D.H. Meadows (2004) *Limits to Growth, The 30-Year Update,* Chelsea Green Publishing Company, White River Junction, Vermont.

Petersen, M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, A. Ulied (2009) *TRANSvisions: Report on Transport Scenarios with a 20 and 40 year Horizon, Final Report,* Funded by DG TREN, Copenhagen, Denmark.

Phillips, E.M., and D.S. Pugh (2005) *How to get a PhD, A handbook for students and their supervisors,* Open University Press, Berkshire, England.

Plantey, J. (1999) *Sustainable management principles of French hydro-agricultural schemes,* Irrigation and Drainage Systems, vol. 13, pp. 189-205.

RWS (2002) *Vervangingskosten Kunstwerken, Versie 1.1,* Directoraat-Generaal Rijkswaterstaat, Document number 6931.0002.

Rijkswaterstaat (2009) *Annual Report 2008.*

Rivett, B.H.P. (1978) *Futures Literature and Futures Forecasting – A critical Review, The International Journal of Management Science,* vol. 7, no. 1, pp. 33-41.

Shell International B.V. (2013) *New lens scenarios, a shift in perspective for a world in transition,* http://www.shell.com/global/future-energy/scenarios/new-lens-scenarios.html.

Spit, W., E. Devillers, K. Vervoort, and J. Nuesink (2008) *Werkwijzer OEI bij MIT-planstudies,* Ministerie van Verkeer en Waterstaat.

Tavasszy, L.A. (2006) *Freight Modelling: an overview of internal experiences,* TRB Conference on Freight Demand Modelling: Tools for Public Sector Decision Making, September 25-27, Washington DC.

United Nations (1999) *The World at Six Billion,* ESA/P/WP.154, Population Division, Department of Economic and Social Affairs, United Nations Secretary, New York.

United Nations (2003) *Population, Education and Development: The Concise Report,* ST/ESA/SER.A/226, United Nations, New York, 56 pp.

Van den Akker, J., M. Betsema, T. Oegema, G. Wurpel (2013) *Updating the future: The next steps in becoming the sustainable global port, using scenarios from Limits to Growth,* IMSA Amsterdam, The Netherlands.

Van Dorsser, J.C.M. (2012) *Scheepvaartscenario's voor Deltaprogramma, 100 jaar later...,* Rijkswaterstaat, https://deltaprogramma.pleio.nl/file/download/15938322.

Van Dorsser, J.C.M. (2013) *Very Long Term Development of the Dutch Inland Waterway Transport System – Draft Summary Report,* Rijkswaterstaat, The Netherlands.

Van Dorsser, J.C.M. (2015) *Very Long Term Development of the Dutch Inland Waterway Transport System – Policy Analysis, Transport Projections, Shipping Scenarios, and a New Perspective on Economic Growth and Future Discounting – Extended Summary Report,* Rijkswaterstaat, The Netherlands.

Walker, W.E., S.A. Rahman, and J. Cave (2001) *Adaptive policies, policy analysis, and policy-making,* European Journal of Operational Research, Elsevier, vol. 128, no. 2, pp. 282-289, January.

Working Group, Millennium Ecosystems Assessment (2005) *Ecosystems and Human Well-being: Scenarios, Volume 2,* [Charpentier, S.R. (ed.)] ISLANDPRESS, Washington, DC.

Presentations:

Den Heijer, F., M. Wolters, and H. Berger (6 April 2009) *Strategie vervanging kunstwerken – De netwerken in beeld,* Vervangen met visie, Rijkswaterstaat.

Websites:

IIASA (accessed: 2009) *World Population Program, 2007 IIASA Probabilistic World Population Projections,* [www.iiasa.ac.at/Research/POP/]

IPCC (accessed: 2009) *Climate Change Scenarios* [www.ipcc.ch]

RAND Corporation (accessed: 2009) *RAND Corporation* [www.rand.org]

2 The Inland Waterway Transport System

"Nowhere else in the world are freight flows concentrated as massively as on the Rhine. This made it possible for the Netherlands to become the gateway to Europe. The Rhine's reserve capacity (700%) and that of the other waterways (100%) will ensure that significant increases in transport volumes over the waterways network can be handled without difficulty for many years to come."
Bureau Voorlichting Binnenvaart (The power of inland navigation, 2010-2011, p.20)[11]

2.1 Introduction

This chapter starts with a discussion on the available literature on inland waterway transport (IWT) and continues with a specific introduction into the IWT system, that addresses the first general sub question (GSQ 1) concerning the Dutch and West European IWT system (see Section 1.4). The aim of this chapter is to provide a clear answer to the four sub questions of GSQ 1. It is not intended to offer a broad general introduction into the subject of IWT, but I will provide some references to other literature on IWT in this introduction section.

IWT is generally *'unknown, unloved'*. In most countries IWT plays only a very modest role. The Dutch are the main exception to this rule. In the Netherlands about 40% of the freight transport volume (measured in tonne kilometres) takes place over water, but even in the Netherlands this is still hardly noticed. China follows with a market share of about 28%. Belgium, Germany, Luxembourg, Romania and Bulgaria are the only remaining countries that I know of with a two digit market share of 10 to 15%[12]. Taking into account the fact that IWT generally receives little attention and the fact that none of the above listed countries is native English speaking it is not very surprising that Jonkeren (2009, p.2) concluded that *"Within the transport literature, inland waterway transport has received relatively limited attention"*. There do however exist a few Dutch books that provide an introduction to IWT (and similar books may also be available in for instance Chinese, German or French). With respect to the Dutch books reference can be made to Hengst (1995), De Vries (2000), Schweig (2006), and Macharis et al. (2011). In addition quite some information is available on the internet, in reports, and in press articles, but this information is often not available in English. One can therefore conclude that sufficient information on the IWT system exists, but that in general non-English (often Dutch) sources will have to be included in the analysis. I do however observe a growing interest for IWT in academic literature, which is written in English. In this

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[11] Bureau Voorlichting Binnenvaart (BVB) is the Dutch Inland Shipping Promotion Bureau.

[12] An overview of IWT throughout the globe is provided by Buscher et al. (2010) and RHDHV (2014).

respect it worth mentioning the appraisal of Sys and Vanelslander (eds., 2011) and the recent dissertations of Jonkeren (2009), Platz (2009), Konings (2009), Demirel (2011), Beelen (2011), Van Hassel (2011), and Hekkenberg (2013).

Knowing that sufficient information on the IWT system exists it is now time to address the four sub questions of GSQ1 concerning the development of the Dutch and West European IWT system, which are defined as follows:

a. What is the importance of IWT in the overall freight transport system, how is the relative market share of IWT developing over time, and what are the most important transport flows on the inland waterways?
b. How has the historical development of the IWT infrastructure and barge fleet affected the present characteristics of the IWT system?
c. What are the present IWT policies and how can they be expected to effect the future development of the IWT system?
d. How does IWT interact with other users of the waterway system – and can the IWT system be studied without considering the other users?

GSQ 1a concerns the historical development and present structure of the West European freight transport system as well as the development of freight transport on the inland waterways. These issues are addressed in Section 2.2. GSQ 1b concerns the historical development and present characteristics of the West European IWT infrastructure and barge fleet. These issues are discussed in Section 2.3. GSQ 1c concerns the various legislative institutions and IWT policies that may affect the future development of the IWT system. These issues are discussed in Section 2.4. GSQ 1d concerns the interaction of IWT with other user functions of the inland waterways. These issues are discussed in Section 2.5. Section 2.6 contains a concluding summary that provides an answer to GSQ2.

2.2 Freight Transport on the European Inland Waterways

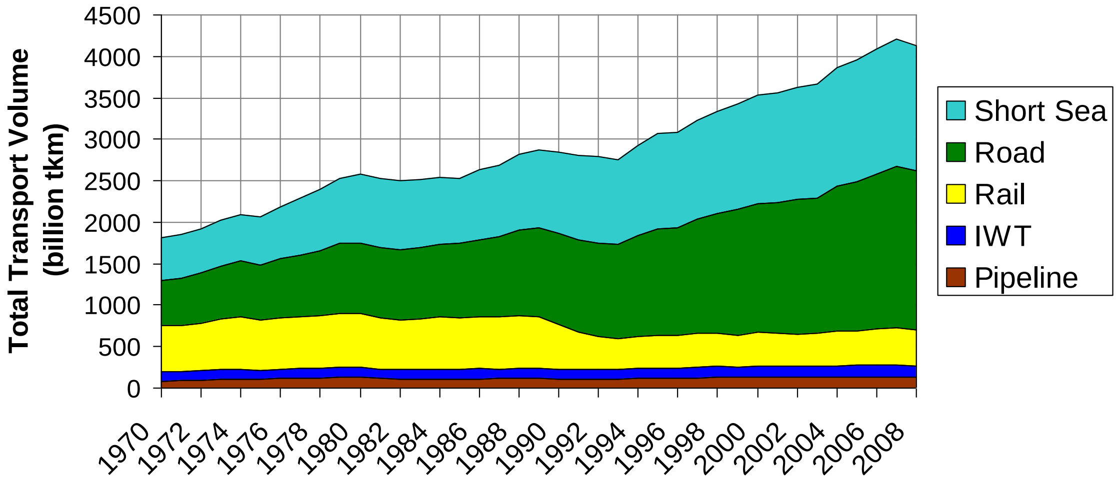
This section addresses GSQ 1a: *'What is the importance of IWT in the overall freight transport system, how is the relative market share of IWT developing over time, and what are the most important transport flows on the inland waterways?'*. It starts with a broad discussion on the importance of IWT in the overall freight transport system; continues with a section on the development of the relative market share of IWT over time; and concludes with a discussion of the most important transport flows on the inland waterways.

2.2.1 The importance of IWT in the overall freight transport system

At a European level the freight volumes shipped by IWT are rather small. Only 3.3% of the intra EU-27 transport volumes (measured in tonne kilometre) takes place by IWT (Eurostat, 2009, p.58)[13]. This used to be different in the past. The inland waterways played an important role in the transport of passengers and goods in the course of history. The waterways were the dominant transport system until the first half of the 19th century, but from about 1850 onwards the relative share of IWT has considerably declined due to the rise of the new rail- and road transport networks. These faster and more flexible modes of transport took over the majority of the fast growing higher valued goods segment while inland shipping retained a strong

[13] When excluding short sea shipping (considering inland modes only) this percentage is slightly higher (about 5.4% measured in tonne kilometre and 3% measured in tonnes).

market position in the slow moving low valued bulk products. By the second half of the 20th century IWT was generally perceived as a slow, old fashioned, and little service oriented mode of transport that was bound to face a long gradual decline[14]. This gradual decline in the relative market share for the slower less flexible modes of transport can also be observed from the European transport statistics.



Source: Various EU Publications (2000, 2001a, 2003, 2010), ITF/OECD Database (2010), UNECE Database (2010). The adjusted and consolidated data is discussed in Appendix A.

Figure 2-1: Total Freight Transport Volumes by Mode of Transport in the EU-27

Figure 2-1 indicates the historical development of the total freight transport volumes in the EU-27 by mode of transport since the year 1970. Apart from the inland modes the figure also includes short sea shipping. In the year 1970 the railways were still the largest mode of transport, but shortly thereafter (in 1971) road transport took over. Road transport showed an impressive growth with an average annual growth rate of 3.4% over the period from 1970 to 2008. Short sea shipping showed an almost similar impressive growth of 2.9%. The other modes of transport lagged behind and lost market share. Rail transport, which is the primary mode of transport in Russia, declined in the East European countries after the disintegration of the Soviet Union (1985-1991); IWT showed a very modest growth rate of just 0.6% per year; and pipeline transport increased at a moderate growth rate of 1.2%. Air transport is not included in the figure as the market share for air transport is less than 0.1% (Eurostat, 2009, p.58). Air transport is however still important in terms of economic value.

The fact that only a relatively small part of the overall transport volumes is shipped by IWT does not imply that the inland waterways have had little effect on the structure of the West European transport flows. In the course of time the inland waterways provided a strong socio-economic backbone that connected many of Europe's most important economic and industrial centres. This held in particular for the river Rhine that connected the economic centres of Venice, Genoa, Florence and Milan with those of Antwerp, London and Amsterdam. Brunet (1989) refers to the broader Rhine corridor as the *'Blue Banana'* (see Figure 2-2, left side). This corridor represents the metropolitan heart of Europe (see Figure 2-2, right side).

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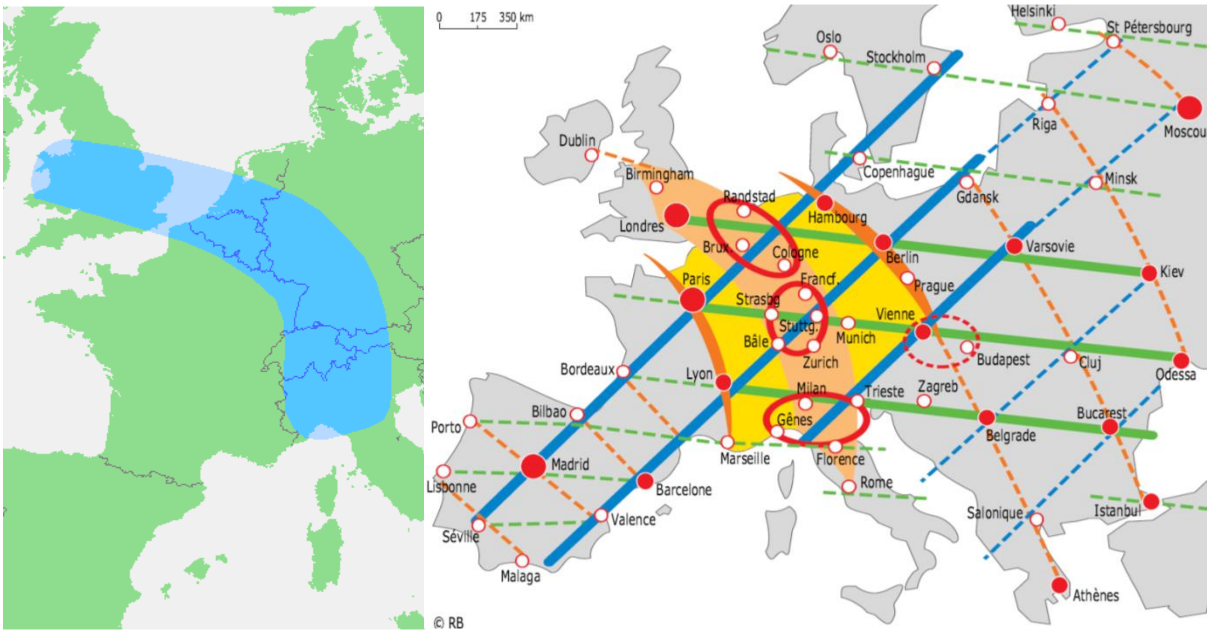
[14] In this respect reference can be made to Grübler (1990, p.235), see also Chapter 8.



Source: Left: Wikipedia (accessed: 2010, reduced content), Right: Brunet (2002, p.17).

Figure 2-2: The Blue Banana and the Socio-Geographic Structure of Europe

Social geographers sometimes refer to a classical ‘law’ (or at least a geographical model) that postulates that in an ideal homogenous space cities of the same order tend to be spread at regular distances. Brunet (2002) investigated how well this ‘law’ fits with the actual situation in Europe. His analysis is illustrated by the orange, green and blue lines in Figure 2-2 (right side). It is quite interesting to observe that the Rhine corridor imposes a strong curved effect on the main grid structure. This curved shape once again points out the impact of the river Rhine on the historical development of the major economic and industrial sites in Europe.

The dominant role of the Rhine corridor can also be observed from European port statistics. About 70% of the external and 40% of the internal freight volumes to and from the EU-27 are shipped by sea (Eurostat, 2009, p.58 and 63). The Dutch and Belgium seaports are located at the intersection of the international seaways and the Rhine corridor. Due to this unique location the ports of Antwerp, Rotterdam and Amsterdam (ARA) developed into a main access point for the central European hinterland. Other ports serving the central European hinterland are located at the outskirts of the so called Le-Havre – Hamburg range (i.e. Le-Havre, Dunkirk, Bremen, Wilhelmshaven, and Hamburg), in the south of France (i.e. Marseilles), and in the north of Italy (i.e. Genoa, and Trieste). In 2006 the total throughput of the European ports (EU-27) reached a volume of 3.8 billion tonnes (Eurostat, 2009, p.60). The Le-Havre – Hamburg range (LHR) handled about 1.0 - 1.1 billion tonnes[15]. The ARA ports, that are connected to the Rhine by IWT, handled 0.6 to 0.7 billion tonnes. This is about 60% of volume handled by the LHR.

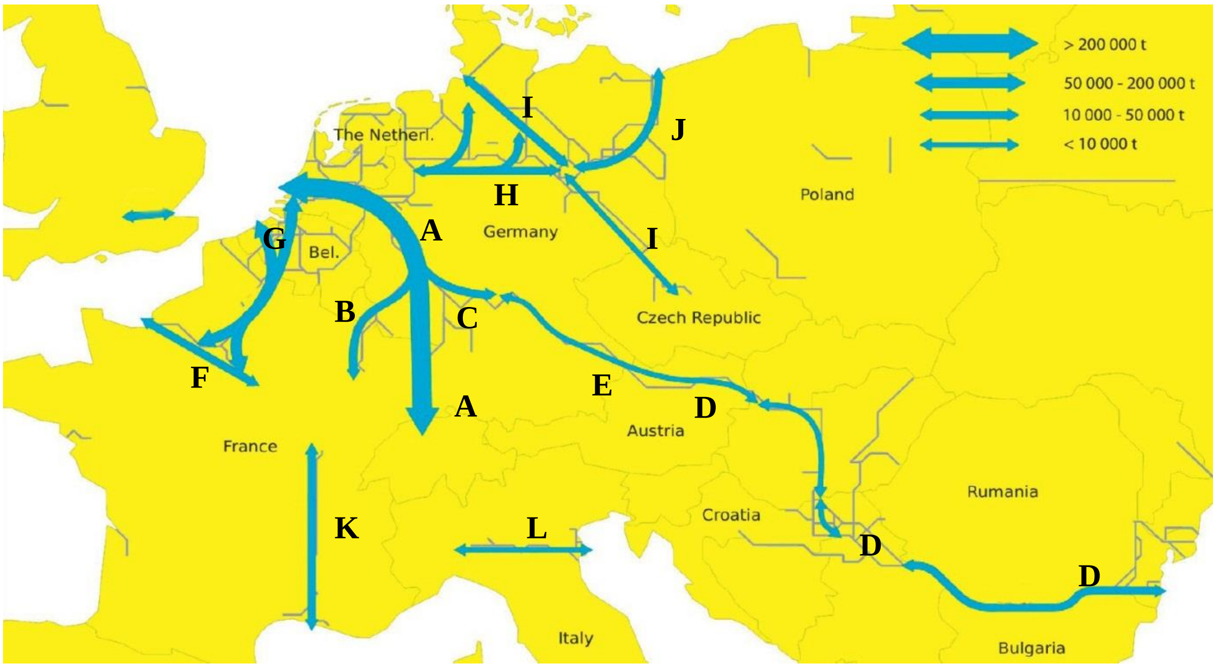
[15] Estimates of the port throughput in the LHR and ARA range are based on country and port data from the Eurostat (2009, p.60) and the port of Antwerp.

The major effect of the Rhine corridor on the European transport system becomes even more clear from a visual representation of the European inland transport flows. Figure 2-3 shows the size of the overall transport flows for all inland transport modes combined (as reported by the Dutch promotion bureau for inland shipping). The figure clearly points out how strong the transport flows are concentrated around the Rhine corridor.

Note: Original figure based on data from VROM/RPD.
Source: Bureau Voorlichting Binnenvaart (2009, p.20), edited and reduced content.

Figure 2-3: Main European Transport Flows for all Inland Transport Modes combined

The use of IWT differs substantially throughout Europe. IWT is highly concentrated in a few member states located around the Rhine and the Danube; plays a minor role in North Germany, France, and North Italy; and is virtually absent in the remaining parts of Europe.



Note: figures in legend should be regarded as 1000 tonnes. 10 000 stands for 10 million tonnes.
Source: CCNR (2009, p.7), edited and reduced content.

Figure 2-4: Main European Waterway Connections and IWT Flows

Figure 2-4 shows the main European waterway connections and the corresponding size of the transport flows. The largest IWT flows are concentrated around the Rhine (A). The Rhine origins in the Alps and is navigable over a length of about 900 km from Rotterdam to Basel. The river remains free flowing over a distance of about 700 kilometre up to Rastatt from where it becomes a weired river. A more specific map that shows the various sections of the river Rhine is provided in Figure 2.5. The main tributaries of the Rhine are the Moselle (B) and the Main (C), which are both weired rivers. The Rhine is connected to the Danube (D) by the Main-Danube Canal (E), but this connection still requires an upgrade as suggested in the framework of the TEN-T projects (EC, 2005). Apart from the Rhine and Danube the IWT flows are mainly concentrated in the area between the Seine (F) and the Scheldt (G), and in the northern part of Germany on the Mittellandkanal (H), Elbe (I) and Oder (J). The waterway connection between the Rhine and the North German waterways is only accessible for medium sized barges with a rather low air draft. This low air draft prohibits the cost effective transport of containers on these waterways. Navigation on the canals between the Seine and Scheldt basin is restricted to even smaller barges, but there are advanced plans to dig a new much larger waterway connection that is referred to as the Canal Seine – Nord Europe. The construction of this new canal almost commenced, but has now been postponed for budgetary reasons after the election of president Hollande in the year 2012 (see also Chapter 8). There finally exist two remote rivers on which IWT takes place. These are the river Rhône (K) and the river Po (L). The Canal du Rhône au Rhine connects the Rhône directly to the Rhine, but the canal is only navigable for the smallest size barges which are no longer cost effective. The river Po has no connection to the main West European waterway system.

Source: Ullrich (2005), http://commons.wikimedia.org/wiki/File:Rhein-Karte.png), adjusted.

Figure 2-5: Map showing the various Sections of the River Rhine

2.2.2 The size and development of the relative market share of IWT

Table 2-1 indicates the absolute IWT volumes for countries within the EU-27. For only 12 of the 27 countries the reported volumes were significant. Flows over 5 million tonnes have been marked bold. From the bold figures it can be observed that the majority of the IWT flows in Western Europe takes place in the Netherlands, Germany, Belgium, and France. In Eastern Europe the main flows take place in Romania. Table 2-2 shows that similar conclusions can also be drawn from the relative share of IWT in the EU-27 member states.

Table 2-1: National and International Intra-EU-27 IWT (measured in million tonnes)

IWT in EU-27		Unloading Countries												
		BE	BG	CZ	**DE**	**FR**	LU	HU	**NL**	AT	PL	**RO**	SK	**Total**
Loading Countries	**BE**	**37.5**	-	0.0	**12.9**	4.9	0.2	0.0	**29.4**	0.0	0.0	-	0.0	**85.0**
	BG	-	2.0	-	0.2	-	-	0.0	-	0.0	-	0.2	0.0	2.5
	CZ	0.0	-	0.4	0.4	-	-	-	0.0	-	-	-	-	0.8
	DE	**15.0**	0.1	0.3	**57.2**	2.2	0.4	0.1	**34.1**	0.7	0.2	0.0	0.0	**110.3**
	FR	4.5	-	-	**5.2**	**30.6**	0.1	-	**7.0**	-	-	-	-	**47.3**
	LU	0.0	-	-	0.1	0.0	-	-	0.1	-	-	-	-	0.2
	HU	0.0	0.0	-	0.6	0.0	-	0.1	0.4	0.5	-	0.5	0.0	2.2
	NL	**38.1**	-	0.0	**76.5**	4.3	0.3	0.2	**90.2**	0.8	0.0	-	0.0	**210.5**
	AT	0.1	0.0	-	0.5	0.0	-	0.4	0.1	1.1	-	0.1	0.2	2.5
	PL	0.0	-	-	1.8	0.0	-	-	0.0	-	4.5	-	-	**6.3**
	RO	-	0.5	0.0	0.0	-	-	0.2	0.0	0.5	-	**23.6**	0.0	**24.7**
	SK	0.0	0.1	-	0.3	-	-	0.0	0.1	1.1	-	0.0	0.1	1.7
Total		**95.3**	2.7	0.8	**155.6**	**41.9**	1.0	1.0	**161.4**	4.8	4.7	**24.4**	0.3	**493.9**

Note: Transport flows to/from other countries are not included; abbreviation DE stands for Germany.

Source: De La Fuente Layos (2007, p.3-5), combined figures for the year 2006.

Table 2-2: Relative share of IWT in the EU-27 member states (measured in tonne km)

Rank	Country \ Year	1970	1980	1990	2000	2008
1	The Netherlands	56%	51%	47%	42%	46%
2	Belgium	24%	18%	14%	13%	15%
3	Bulgaria	7%	8%	5%	4%	13%
4	Luxembourg	21%	19%	14%	12%	12%
5	Germany (including DDR)	17%	15%	14%	13%	11%
6	Romania	2%	3%	3%	8%	11%
7	Hungary	6%	5%	5%	4%	7%
8	France	6%	4%	3%	3%	3%
9	Austria	5%	5%	4%	4%	3%
10	Czech & Slovak Republic	3%	3%	5%	2%	2%
11	Poland	2%	1%	1%	1%	1%
12	Other EU-27	<0.5%	<0.5%	<0.5%	<0.5%	<0.5%
N.A.	**Total EU-27**	**8.8%**	**6.9%**	**6.5%**	**6.1%**	**5.4%**

Source: Various EU Publications (2000, 2001a, 2003, 2010), ITF/OECD Database (2010), UNECE Database (2010). The adjusted and consolidated data is discussed in Appendix A.

Table 2-2 indicates that 46% of the Dutch freight transport volumes take place over water (measured in tonne kilometres). Nowhere else in the world is the market share of IWT this large. Other European countries with a reasonable 10 to 15% share are Belgium, Bulgaria, Luxembourg, Germany, and Romania. Hungary follows with a market share of 7%. IWT plays only a minor role in France, Austria, Czech Republic, Slovak Republic, and Poland (though France may catch up after the construction of the Canal Seine-Nord Europe). In the remaining EU-countries IWT is virtually non-existent. Outside Europe there are only some 28 counties in which IWT occurs (RHDHV, 2014), though IWT is gaining interest all over the world (see e.g. River of Information #3, 2013). IWT has a large market share in China (28% measured in tonne kilometres) and a reasonable market share in the USA (8% measured in tonne kilometres). Despite its large waterway network IWT accounts for only 1% in Russia[16].

Table 2-2 presents my best interpretation of the available EU, ITF/OECD, and UNECE data. For the Netherlands these numbers differ from those reported by other sources. Buscher et al. (2010, p.8) report a market share of about 39% in tonne kilometre for both the year 2000 and the year 2008, and a market share of respectively 31.9% and 34.7% in tonnes for the years 2000 and 2008 based on Eurostat data (excluding pipeline transport); Chapter 12 shows numbers of about 29% in tonnes and 35% in tonne kilometres based on Dutch transport data for the year 2004 (excluding pipeline transport); and CBS data presented in Chapter 14 shows that the market share in tonnes (including pipeline transport) has gradually declined from 34% in the year 1994 to 27% in the year 2003, after which it more or less remained stable (except for the crisis year 2009 in which it dropped to 23%). One can therefore conclude that the reported numbers differ considerably amongst the various sources[17].

The analysed data shows a possible increase in the market share of the Dutch IWT system since the year 2000. This indicates that a very long term period of decline, since the introduction of the railroads, may now have, at least temporarily, come to a hold. There are some good reasons for the recent improvement of the relative performance of the Dutch IWT system. One of the most obvious reasons is the liberalisation of the inland shipping market in the year 2000, but I think that there are more fundamental drivers acting on the system. In my opinion the main explanation should be sought in the development of international deepsea container transport since the year 1966 and the development of inland container barge lines since the year 1974 (see also Chapter 8). The Dutch national fraction of containers that is transported by barge increased from 15% in 1994 to 33% in 2002 (Policy Research Corporation, 2007). A further increase of these numbers may be expected after the commissioning of the Second Maasvlakte in 2014, as the Rotterdam Port Authority prescribes a modal split of 45% for IWT and 20% for rail in the concession agreements with new terminal operators (Port of Rotterdam, 2011, p.52). For the Netherlands and Belgium the strong growth in the relative market share of containers shipped by IWT now seems to outweigh the gradual decrease in the market share of bulk products. I would argue that the IWT system in Rhine-Meuse-Scheldt Delta has now developed itself into a self-reinforcing system in which the growing container transport volumes create economies of scale, reduce costs, and attract even more cargoes. In addition national and European transport policies also pursue a shift from road transport to IWT (see Section 2.4). The future for inland shipping therefore looks much brighter than one may have expected a few decades ago.

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[16] The original numbers provided by Eurostat (2009, p.57) indicate 15% for China, 8% for the USA, and 1% for Russia, but these numbers include short sea shipping in the total. The reported numbers relate to the share of IWT as a fraction of the inland transport volumes excluding short sea shipping.

[17] One of the reasons that the numbers differ amongst the various sources is the fact that the EU shifted in 2001 (following the opening of the internal EU borders) from road transport measurements based on haulage by national territory to haulage of companies registered within the member states. This makes it hard to compare road transport numbers on a like for like basis with other transport modes, that are still reported by haulage on national territory. I have therefore applied a correction to the road transport volumes in Appendix A.

2.2.3 The most important transport flows on the inland waterways

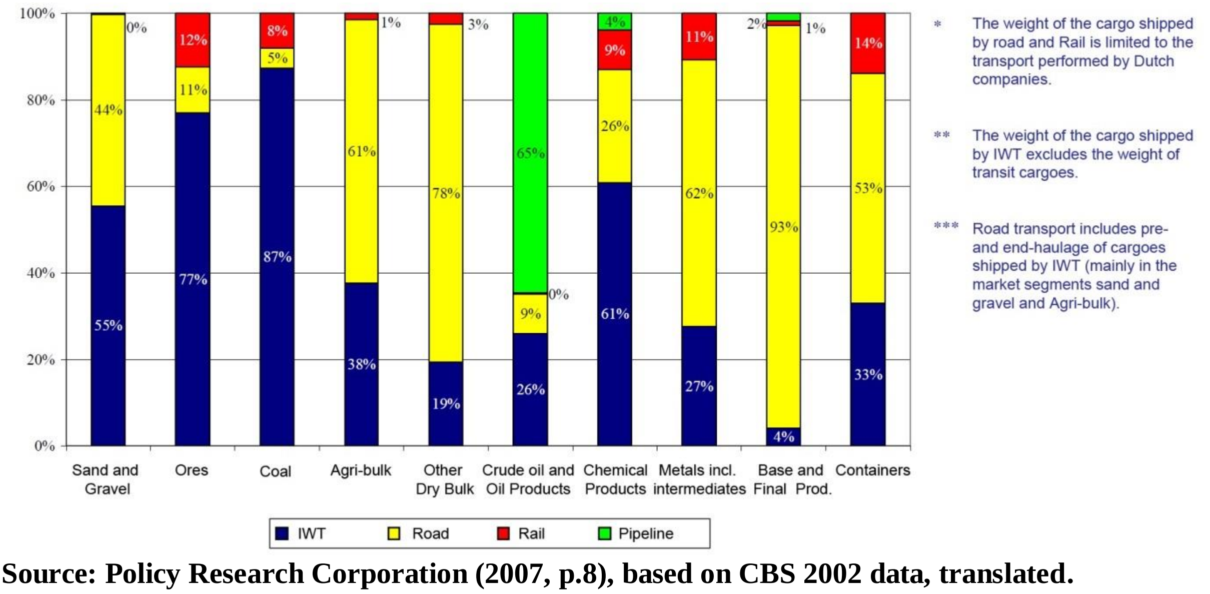
Additional insight in the functioning of the IWT system can be obtained from a more detailed analysis of the most important transport flows on the inland waterways. Though there exist many different ways to categorise the IWT flows into different segments I have limited the analysis to: (1) a distinction between IWT flows with a national- and an international character; (2) a distinction according to the type of commodity that is shipped; and (3) a distinction between port related-, continental-, and river-sea transport flows. Each of these different segmentations provide valuable insights in the functioning of the system.

<u>The international character of the Dutch IWT flows</u>

The Dutch IWT system has a very international character. Measured in tonnes about 60% of the international transport volumes take place by IWT and about 70% of all goods shipped by IWT have an international origin or destination. Measured in tonne kilometres some 80% of the Dutch IWT performance concerns international transport[18].

<u>The share of IWT in the transport of various types of commodities</u>

The competitiveness of IWT differs considerable amongst various types of commodities. The vast majority of the commodities shipped by IWT are bulk products. Figure 2-6 shows the relative market share of IWT for a range of different commodities. It can be observed that IWT is market leader in the transport of ore, coal, sand, gravel, chemical products, and oil products (if these are not transported by pipeline). In addition IWT has also gained an important market share in the hinterland transport of deepsea containers.



Source: Policy Research Corporation (2007, p.8), based on CBS 2002 data, translated.

Figure 2-6: Market Share of Inland Modes for the Netherlands (measured in tonnes)

There are several explanations why IWT has a relatively strong position in the low valued bulk segment and a rather poor position in the transport of higher valued half fabricates and final products. The first explanation is that IWT requires certain economies of scale which are easily obtained in the transport of bulk products, but much harder to realise for non-

[18] Refer to Policy Research Corporation (PRC, 2007) and Verberk (2010).

containerised half fabricates and final products, that are generally shipped in much smaller parcel sizes. The second explanation is that the producing and/or receiving companies tend to be located close to the waterfront for bulk products and farther away from the waterside when it concerns higher valued goods. This implies that IWT of half fabricates and final products still requires expensive pre- and end-haulage by truck to reach the final destination (this also holds when the goods are shipped in containers). In general the absence of *'wet'* transport connections makes it hard to compete with road transport (PRC, 2007, p.21). The third and final explanation is that the higher valued goods tend to operate in an overall supply chain that is organised in such a way that it minimises the lead time (e.g. by demanding a short notice delivery in combination with a built to order process). These logistical processes are not in favour of IWT, that is relatively slow and inflexible compared to road transport.

Port related, continental, and river-sea transport flows

When studying IWT it is sensible to distinguish between port related-, continental-, and river-sea transport flows. The first category relates to the import and export of cargoes via the seaports. It is characterised by large cargo volumes, large inland barges and large economies of scale. The second category is related to the transport of continental goods (i.e. goods shipped within the same geographical land area such as on the European mainland). This category still mainly concerns bulk materials that are shipped in smaller barges between two waterborne locations, but it should be noted that present transport policies are also aiming for the development of continental container transport on the inland waterways (see Section 2.4). One should therefore realise that continental container flows may be developed in the future and that this could have a serious impact on the overall transport volumes (see also Chapter 8, 10, and 14). The third category finally concerns coastal vessels that connect two river ports or a seaport and a river port via the sea. These transport flows tend to be rather small.

Port related inland waterway transport flows

The development of the ports and waterways has historically gone hand in hand since the waterways have always provided a primary access route to the European hinterland. For the Netherlands about 60% of IWT has an origin or destination in the seaports and for some bulk products (ores, coal, crude oil, and chemical products) this is even more than 90% (PRC, 2007, p.7). The importance of the main West European seaports for the European IWT flows can be evaluated by comparing the port statistics with EU statistics on IWT. In 2006 and 2007 the total volumes transported on the inland waterways were respectively 503 and 515 million tonnes (De La Fuente Layos, 2007 and 2009). The total freight volume loaded and unloaded in barges in the ports of Rotterdam, Amsterdam, and Antwerp as well as their share in the total IWT volume shipped in the EU is listed in Table 2-3.

Table 2-3: Barge loading/unloading in main ports compared to EU figures for IWT

Port Data	Loaded on Barges		Unloaded from Barges	
	million tonnes	% of IWT in EU	million tonnes	% of IWT in EU
Rotterdam (2007)	133.0	25.8	55.4	10.8
Amsterdam (2006)	37.8	7.5	21.6	4.3
Antwerp (2007)	49.4	9.6	39.9	7.7
Total		42.9		22.8

Source: Eurostat bulletin 132/2007 and 27/2009; Port of Rotterdam Website (accessed: 2010); Port of Amsterdam Website (accessed: 2010); Port of Antwerp Statistical Yearbook 2008.

Table 2-3 indicates that about 50% of the IWT flows in the EU are likely to be port related[19]. If other ports such as Constanta, Marseilles, and other French, German, and Italian ports are included this number will be larger, probably also in the order of 60% (as for NL). The opposite question: *"How large is the modal share for IWT in the seaports"* is difficult to answer due to a lack of unambiguous statistics on this subject. Based on Haezendonck (2001, p.87) it can be expected that 10 to 20% of the Dutch port throughput relates to transhipment cargoes (i.e. sea-sea transport). The share of IWT in the remaining 80 to 90% of the goods imported or exported via the seaports is likely to be in the order of 40 to 50% percent[20].

Continental inland waterway transport flows

From a European perspective the market share of IWT in the transport of continental cargoes is relatively small, probably in the order of 1 to 2% of the total intra-EU inland transport flows measured in tonnes. The European continental IWT flows are therefore almost negligible, but for some countries such as the Netherlands the market share can still be considerable. It is interesting to know the relative share of IWT in the continental (non-port related) transport flows for the Netherlands, but this number is not reported. I have therefore estimated the share of IWT in the Dutch non-port related inland transport flows on the basis of year 2006 data. The details of the calculation are presented in Figure 2-7.

2006 Data (million tonnes)

	NL Transport	National	Int. Loaded	Int. Unloaded	Total	Source
A	Road	475	93	85	654	Eurostat (2009) *Panorama of transport* p.66-67
B	Rail	6	18	5	29	Eurostat (2009) *Panorama of transport* p.66-67
C	IWT	90	120	71	282	Eurostat (2009) *Panorama of transport* p.66-67
D	Pipe	-	52	-	52	CBS
E	Total	572	284	162	1,017	Calculated (A+B+C+D)
F	Total IWT loaded/unloaded in the Netherlands				282	Eurostat (2009) *Panorama of transport* p.66-67
G	Percentage of IWT with origin/destination in seaports			60%	169	PRC (2007) *Beleidsstrategie Binnenvaart* p.7
H	Total IWT not related to seaports				113	Calculated (F-G)
I	Total Throughput of the Dutch Seaports				477	Eurostat (2009) *Panorama of transport* p.90
J	Assumed Transhipment Volumes			15%	72	Haezendonck, E. (2001) *Essays on strategy analysis for seaports* p.87
K	Import/Export Volumes via the Seaports				406	Calculated (I-J)
L	Domestic Transport not related to seaports				611	Calculated (E-K)
M	Average modal share of IWT in the Netherlands				28%	Calculated (F/E)
N	Modal share continental non-port related IWT in the Netherlands				18%	Calculated (H/L)

Figure 2-7: Estimate of Modal Split for Continental IWT flows in the Netherlands

It follows from the calculation that IWT has a market share of about 18% in the Dutch continental non-port related inland transport flows (measured in tonnes).

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19 Exact figures cannot be given without knowing the amount of the cargo volumes shipped between the ports. The assumed 50% lays somewhere between 42.9% and 42.9 + 22.8 = 65.7%.

20 The 40% low estimate can be calculated as G/L in Figure 2.6. This estimate does however not include the inter-port shipments that should appear twice in the calculation. The 50% high estimate is derived from CBS data provided by the Port of Rotterdam Authority. In 2008 IWT shipped 165,594 out of the 340,406 tonnes of inland transport to/from Rotterdam. This is equal to 49%. The CBS data is not compatible with the port throughput data as it lacks data on the national use of pipelines and does not include Schiedam and Vlaardingen.

River-Sea Transport
River-sea transport is a special kind of short-sea shipping in which transhipment costs at the seaport are avoided. River-sea transport directly connects two river ports or a seaport and a river port via the sea (Konings and Ladema, 2000, p.221)[21]. Coastal vessels sailing on the inland waterways have to comply with national and European regulations for IWT as well as with international regulations for seagoing vessels. *"Nowadays short-sea vessels can reach the Rhine up to Duisburg, the Meuse up to Maastricht, and elsewhere up to smaller places like Rhenen, Zwartsluis, Kampen, and Doesburg. If river-sea transport saves on transhipment costs from the inland barge to the seagoing vessel it can be economically very attractive; even though the limited water depth reduces the available draft of the vessel. The volumes shipped by river-sea transport are nevertheless rather small"* (Schweig, 2009, p.54, translated). It is not only the draft that restricts the use of coastal vessels on the inland waterways. Equally important are the length, width, and height restrictions, that are imposed by the locks and bridges, as well as the applied regulations. In particular the height restrictions in combination with the low available draft are often quite a challenge. River-sea transport therefore uses dedicated *'low air draft coasters'* that are often able to sail worldwide (Hengst, 1990).

2.2.4 Answer to sub-question 1a
In answer to sub-question 1a, I conclude that in general IWT plays only a minor role in the overall transport system, but for some countries that have a large waterway system, such as the Netherlands, the market share can be considerable. In the Netherlands about 25% to 35% of the total transport volume (measured in tonnes) and about 35% to 45% of the transport performance (measured in tonne kilometres) takes place by IWT. The IWT system has played an important role in the Dutch (and to a lesser extent also the West European) transport system throughout history, but from about the year 1850 onwards the market share of IWT declined considerably due to the rise of the rail- and road transport networks. These new transport modes took over the majority of the higher valued goods segment and left IWT with the gradually declining lower valued bulk products. However, following the introduction of intermodal container barge transport, IWT is now regaining market share in the higher valued goods segment. IWT is market leader in the transport of ore, coal, sand, gravel, chemical products, and oil products (if not transported by pipeline) and IWT is becoming increasingly important for the transport of containers. IWT flows can be subdivided into port related-, continental-, and river-sea transport. About 60% of all IWT in the Netherlands has an origin or destination in the seaports, the remaining volumes are related to continental transport. The volumes shipped by river-sea transport are rather small compared to the total IWT volumes.

2.3 Historical Development of the present IWT System

This section addresses GSQ 1b: *'How has the historical development of the IWT infrastructure and barge fleet affected the present characteristics of the IWT system?'*. It starts with a discussion on the historical development and classification of the IWT infrastructure and continues with a discussion on the development of the West European barge fleet.

2.3.1 Historical development and classification of the IWT infrastructure
The historical development and classification of the European IWT infrastructure is discussed in the Dutch guidelines for the development of the inland waterways (Rijkswaterstaat 2011,

[21] In case of two river ports a connection is for instance made between a port in the UK and a port in Germany.

p.13, translated): *"Europe's rivers have traditionally formed the backbone of its waterway network, connected over the years by canals. The locks in the canals dictated the maximum size of the barges that the waterway could accommodate. International coordination was virtually non-existent. In 1879 the French minister of public works, Charles de Freycinet, launched legislation to upgrade and construct 9000 km of canal. The legislation prescribed a standard barge with dimensions of 38.5 x 5.05 meter. As a result, the péniche, which at the time had a cargo capacity of 300 tonnes, was designated the standard barge on the French canal network. The Dortmund-Ems Canal and Rhine-Herne Canal, both built in the early 20th century, were so important for shipping in the Rhine basin that barges with a cargo capacity of 1000 and 1350 tonnes respectively were developed, based on the locks in these two canals. In the Netherlands, the Ringers Commission issued recommendations for the dimensions of the waterways in the west of the country in 1932, and in 1950 the Kloppert Commission produced recommendations for the northern Netherlands.*

It was not until 1954 that the Conférence Européenne des Ministres des Transports (CEMT) accepted an international classification system which divided waterways into five classes, depending on their horizontal dimensions. The system was based on the dimensions of five barge types that were common in Western Europe at the time. The class to which a waterway belongs depends on the largest standard barge that it can accommodate. The CEMT recommended the class IV barge, the Rhine-Herne Canal type, to be used as the standard for waterways of European importance, which is why it was often referred to as the 'Europe barge'. The CEMT also set out guidelines for the dimensions of canals, bridges and locks on class IV waterways. The first pushed convoy travelled along the Rhine in 1957, and push-towing soon took off. The CEMT responded in 1961 by adding a class VI to its classification. After a time, however, this classification turned out to be inadequate. PIANC, the World Association for Waterborne Transport Infrastructure, took charge of revising the system. A working group specially set up for the purpose produced a report in 1990, and later published a supplement in the form of a study on class Vb waterways. This prompted the CEMT and the United Nations Economic Commission for Europe (ECE) to produce a uniform new classification, known as CEMT1992 after the year it was adopted. This classification takes account of East European waterways, which generally have slightly smaller dimensions than similar waterways in Western Europe". The classification system for the West European waterways (i.e. west of the Elbe) is shown in Figure 2.8. Figure 2.9 provides a map that shows the European inland waterways according to their CEMT class.

The original CEMT-1992 table contains a number of footnotes. Where two numbers are provided, the first number covers the current situation and the second number provides a guideline for the future. For container transport it was argued that the recommended waterway dimensions are sufficient for the transport of 8½ foot (or 2.60 meter) high containers under the condition that at least 50% of the containers is loaded or sufficient ballast is taken. The reported minimum height underneath the bridges includes a safety margin of 30 cm between the highest point of the ship and the lower end of the bridge. The following minimum vertical clearances were recommended:

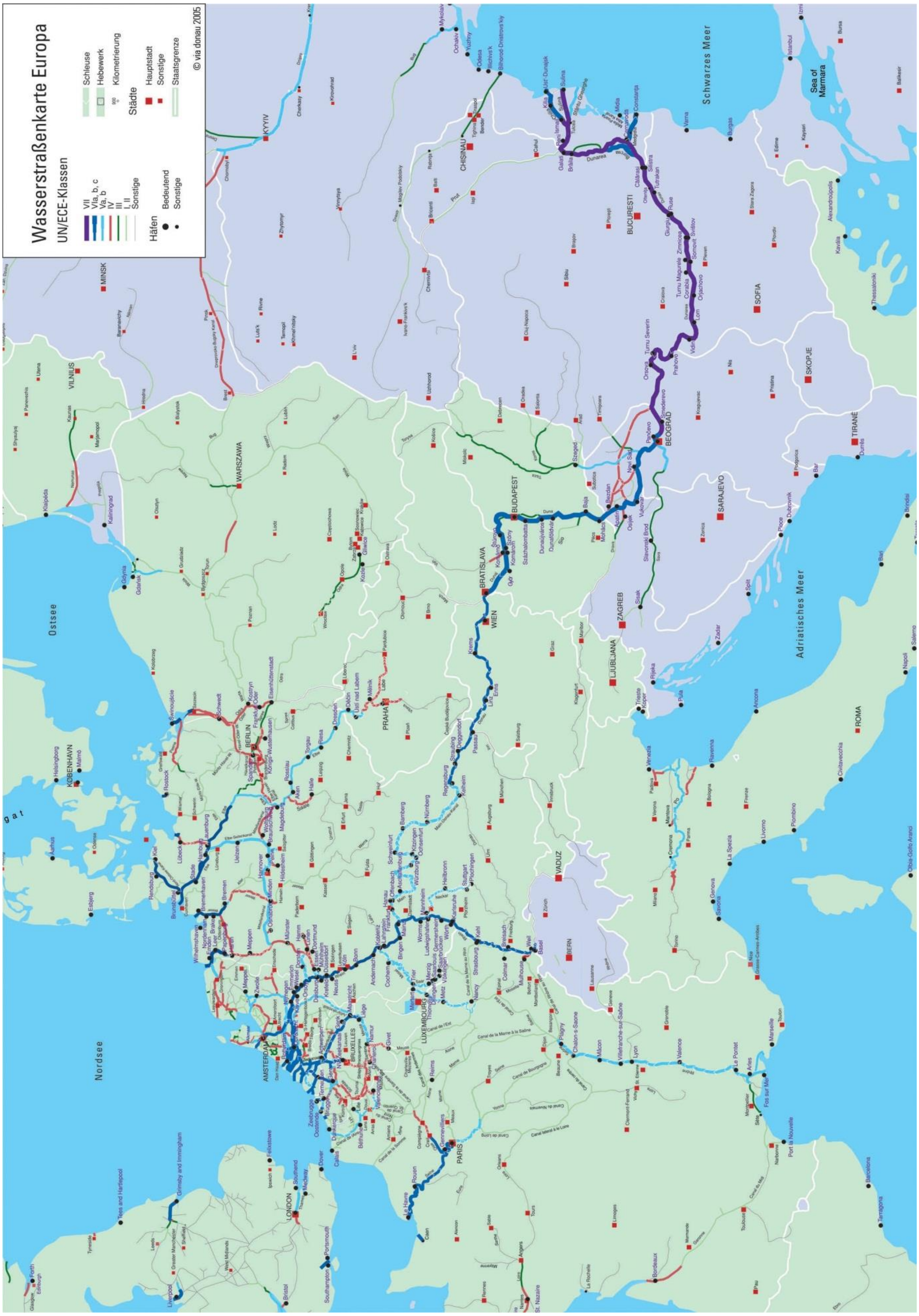
- 5.25 m for barges with two layers of containers;
- 7.00 m for barges with three layers of containers;
- 9.10 m for barges with four layers of containers.

When taking into account the required safety margin of 30 cm the maximum height of the barge above the waterline is limited to 4.95 m, 6.70 m, and 8.80 m.

	Type de voies navigables / Type of Inland waterways	Classe de voies navigables / Classes of navigables waterways	Automoteurs et chalands / Motor vessels and barges — Type de bateaux: caractéristiques générales / Type of vessel: générales characteristics					Convois poussés / Pushed convoys — Type de convoi- Caractéristiques générales / Type of convoy- Générales characteristics					Hauteur minimale sous les ponts / Minimum height under bridges
			Dénomination / Designation	Longueur / Length	Largeur / Beam	Tirant déau / Draught	Tonnage / Tonnage		Longueur / Length	Largeur / Beam	Tirant déau / Draught	Tonnage / Tonnage	
				m	m	m	t		m	m	m	t	m
D'INTERET REGIONAL	OF REGIONAL IMPORTANCE	I	Péniche / Barge	38.50	5.05	1.80-2.20	250-400						4.00
		II	Kast-Caminois / Campine-Barge	50-55	6.60	2.50	4.00-650						4.00-5.00
		III	Gustav Koenings	67-80	8.20	2.50	650-1000						4.00-5.00
D'INTERET INTERNATIONAL	OF INTERNATIONAL IMPORTANCE	IV	Johan Welker	80-85	9.50	2.50	1000-1500		85	9.50	2.50-2.80	1250-1450	5.25/or 7.00
		Va	Grand bateaux Rhenands/Large Rhine Vessels	95-110	11.40	2.50-2.80	1500-3000		95-110	11.40	2.50-4.50	1600-3000	5.25/or 7.00/or 9.10
		Vb							172-185	11.40	2.50-4.50	3200-6000	
		VIa							95-110	22.80	2.50-4.50	3200-6000	7.10/or 9.10
		VIb		140	15.00	3.90			185-195	22.80	2.50-4.50	6400-12000	7.10/or 9.10
		VIc							270-280 193-200	22.80 33.00-34.20	2.50-4.50 2.50-4.50	9600-18000	9.10
		VII							285 195	33.00 34.20	2.50-4.50	14500-27000	9.10

Source: Rijkswaterstaat (2006, p. 14), originally based on CEMT - Resolution No. 92/2.

Figure 2-8: CEMT-1992 Classification for Inland Waterways West of the Elbe



Source: www.inlandnavigation.org (accessed: 2010).

Figure 2-9: European Inland Waterways according to their CEMT Waterway Class

Class Vb is nowadays recommended as the minimum standard for international European waterway connections, with a minimum headroom of 7.0 m for container transport. When existing waterways are upgraded or new ones are built, the CEMT stipulates that efforts should be made to achieve at least Class Va (Rijkswaterstaat 2011, p.15).

The original CEMT-1992 classification is still applicable but no longer representative for the characteristics of the present IWT fleet. Roelse (2002) studied the present dimensions of the West European fleet and concluded that many barges have been lengthened. This implies that the average length and tonnage of the barges has increased over time. In addition the barges are now also loaded at greater draft than in the past. Rijkswaterstaat therefore developed a new so called RWS 2010 classification system that can be regarded as a refinement of the CEMT-1992 classification. The RWS 2010 classification system contains a larger number of categories and also covers the use of coupled units (in Dutch: Koppelverband). For a further discussion of the RWS 2010 classification system reference is made to the present waterway guidelines of Rijkswaterstaat (2011, p.16-p.23).

In addition to the abovementioned changes there are a few other recent developments in the container sector that yet call for another major revision of the applied classification system (see also Brolsma, 2014). The standard container used to be 20 or 40 foot long, 8 foot wide, and 8½ foot high. Nowadays 9½ foot high, so called high cube containers (which are 30.48 cm higher) are becoming the new standard. These containers require more bridge height than accounted for by the CEMT-1992 and RWS 2010 classification. The use of pallet wide containers (having a width of 2.50, 2.56 or even 2.60 instead of 2.44 meter) is also becoming more common in Europe. These containers do not fit (properly) into the holds of a standard 11.45 meter (used to be 11.4 meter) wide Class Va barge[22]. Solving this problem for the widest containers would ideally require the width of the locks to be increased.

Finally there is a strong increase in the use of high cube, pallet wide, 45 foot containers that offer a similar loading volume as a European lorry truck. These containers will be further referred to as continental 45 foot containers. The continental 45 foot container is already booming in European short sea shipping and intermodal rail transport. It has become the new standard for intermodal transport in Europe, but unfortunately it is not fully compatible with the dimensions of the inland waterways. One can therefore argue that the efficient transport of continental 45 foot containers requires an upgrade of the dimensions (mainly headroom and width) of the inland waterways (see also Chapter 8).

The notion that it is necessary to upgrade the inland waterways in order to comply with the requirements for the efficient transport of continental 45 foot containers is not yet fully recognised, but the Dutch Minister of Infrastructure and Environment has recognized the fact that higher bridge heights will be required to support the efficient transport of the growing number of high cube containers (Schultz van Haegen, 2014).

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[22] It should be noticed that some 11.45 meter wide barges (hold 10.10 meter wide) sometimes manage to load four of the slimmest 2.50 meter wide pallet wide containers next to each other (having 2 cm margin between each container). The loading of these containers is however problematic as hardly any heeling of the barge is allowed during the loading process, the containers cannot be bulging, and damages occur more frequent. The present width of 11.45 meter is therefore too slim to load four pallet wide containers properly next to each other.

2.3.2 Historical development and present state of the inland barge fleet

The development of the West European barge fleet is closely related to the development of the West European IWT infrastructure. This section provides an introduction to the barges sailing on the European waterways.

Class I and Class II barges

The smallest Class I and II barges were built according to the dimensions of French and Belgium waterways. An example of these barges is indicated in Figure 2-10.

Source: www.shipphoto.nl (accessed: 2010).

Figure 2-10: Class I Barge (Left) and Class II Barge (Right)

Class I barges (Dutch: Spits; French Péniche) were built for the nine thousand kilometre late 19th century waterway system in France that prescribed a maximum barge dimension of 38.5 by 5.05 meter. Nowadays the French Class I waterway system is falling into disrepair and Péniche barges have difficulties to compete with road transport. Despite an overall growth of total transport volumes the use of the system has been decreasing for decades. Very few new Péniche barges have been constructed since the late 1960s.

Class II barges (Dutch: Kempenaar) were built according to the size of the locks on the *Kempenskanaal* in Belgium. This canal connects Antwerp to Liège and functioned as a main IWT hinterland connection until the construction of the *Albertkanaal*. The barges on the Kempenskanaal were originally limited to a length of 50 meters and a width of 6.6 meters. Later, around the 1930s some locks on the canal have been upgraded to 55 by 7.5 meters (De Kotter, 1999, p.23). Only a few Kempenaars have been constructed since the 1960s.

The connection between the Seine and Scheldt passes through the *Canal du Nord*. This canal is indicated on some maps as a Class II waterway as its dimensions are larger than those of most French waterways. The locks are however only 6 meter wide. The Canal du Nord is therefore too small to be called a Class II waterway. Special barges with a length of up to 70 meters and a width of 5.7 meters were built to operate on this waterway (Dutch: Superspits). To some extent the Canal du Nord was already outdated the moment it became operational in the late 1960s, because at that time barges of 110 by 11.4 meters became standard on the Rhine (De Kotter, 1999, p.22). A new *Canal Seine – Nord Europe* is planned for push barges with a length of 185 meter, a width of 11.4 meter, a draft of 3 meter, and 7 meter headroom under the bridges (VNF, 2006). It is unclear if larger barges will be permitted, but the planned canal dimensions suggest that it should be possible to allow slightly wider and deeper barges on the canal as the design width of the locks is 12.5 meters and the design depth of the canal is 4 meter. The go-ahead decision for the construction of the canal is however still pending.

Once the project gets a definitive green light it will take at least eight years before it becomes operational (Reuters, 2013).

Class III barges

Class III barges (Dutch: Dortmunders) find their origin in the construction of the *Dortmund-Ems Canal* between 1886 and 1899 and the connection to the Rhine that followed 14 years later. The Dortmund-Ems Canal provided a direct connection between North Germany and the quickly developing Ruhr area. At that time the canal provided access to barges of 67 by 8.2 meter, but nowadays it has been upgraded to a Class IV waterway. Figure 2-11 indicates that there are not many Class III waterways left in Western-Europe.

Source: www.shipphoto.nl (accessed: 2010).

Figure 2-11: Old Class III Barge (Left) and New Class III Barge (Right)

The older Class III barges (see Figure 2-11, left) have a length of 67-80 meters and a beam of 8.2 meters. They were built for transport of dry bulk and general cargoes and are not very efficient for the transport of containers (2 wide, 2 high). A 72 meter long Dortmunder that is converted for the transport of containers carries just 28 TEU[23].

In the period between 2000 and 2005 a few new Class III barges of 63 x 7.2 meter were constructed that are now referred to as the *Neokemp* or *Hopper* type barges (see Figure 2-11, right). These smaller barges are able to carry 32 TEU at 2 layers. The relatively smaller size of these Neokemp (or new Kempenaar) barges implies that it may be useful to consider a new intermediate waterway class. The RWS 2010 classification system therefore introduced the *M3 Hagenaar* subclass for Class III waterways (Rijkswaterstaat, 2011, p.22).

There is not much interest from barge operators to invest in new Class III – M3 barges. Due to the relatively small economies of scale, high levels of competition with old and fully depreciated barges (i.e. a difficult business case), low comfort levels for the barge crew (i.e. small accommodations), and *"uncertainty with respect to possible future waterway upgrades to Class IV the private sector is still reluctant to invest in new Class III barges"* (PRC, 2007, p.37). Apart from the few barges that were constructed between 2000 and 2005 hardly any new Class III barges have been constructed since the late 1960s.

[23] A TEU stands for the volume required for a standard twenty foot container with a length of 6.1 meters.

It should be noted that a number of new business concepts are now being proposed for the smaller waterways, but that these concepts are still on the drawing board or in the first stage of a subsidised pilot. Van Hassel (2011) presented a new system in which use is made of small barges that can sail on their own on the smaller inland waterways and are coupled and pushed on the larger waterways to obtain sufficient economies of scale. A similar concept is proposed by the Watertruck project (www.watertruck.eu) that applies small dumb barges in combination with a small pusher unit on the smaller waterway, and a larger pusher unit on the larger waterways. The Watertruck project also suggests a completely different operational regime. It no longer works with a fixed crew that lives on board, but allows the sailors to drive home at the end of their shift. It is still too early to tell how successful these concepts will be. The future use of the smaller waterways is therefore still very uncertain.

Class IV barges

Class IV barges are built according to the locks of *Rhein-Herne Canal*. The Rhein-Herne Canal was constructed in 1914 and connects Duisburg to Dortmund. It is a short, but important canal that used to allow for barges with a size of 80 by 9.5 meters. Rhein-Herne Canal barges were very popular and many of the older barges have been lengthened or converted into a tanker. Class IV barges are still intensely used for general cargo, chemical products, and containers (3 wide, 3 high). The small beam allows the barge to sail on most of the important inland waterways in Europe. The Rhein-Herne Canal barge is now replaced by the Europaship which is officially five, but in practice often six meters longer (85 or 86 meter). These barges are now also frequently constructed with a slightly wider beam of 9.6 meter to increase the loading capacity for bulk products. The length of just below 86 meters is not only driven by the locks in the canals. It is also the maximum allowed length for sailing with just two people according to the Police Regulations for Navigation on the Rhine (CCNR, 2010b). Figure 2.12 shows two Class IV barges with a length of almost 86 meters. The capacity of a Class IV container barge is about 90 TEU at 3 layers.

Source: www.shipphoto.nl (accessed: 2010).

Figure 2-12: Class IV Dry Bulk Barge (Left) and Tanker (Right)

Upgraded Class IV barges / Small Class V barges

"*Some, existing waterways have to be considered as class IV waterways due to a restriction on the maximum length of the barge despite higher allowable maximum widths and drafts of 11.4 and 4.0 meter"* (Rijkswaterstaat, 2006, p.15, translated). On these waterways a wider ship is more efficient. Some barges therefore have a length of 86 meters and a width of 11.4 (or 11.45) meters (see Figure 2-13). In container transport the additional width does not only allow for an additional row, but also for an additional layer of containers[24]. This results in a 78% higher capacity compared to a standard 9.5 (or 9.6) meter wide barge.

Source: www.shipphoto.nl (attended 2010).

Figure 2-13: Upgraded Class IV Tanker (Left) and Container Barge (Right)

<u>Class V barges</u>

Class V barges are designed according to the infrastructure dimensions on the upper Rhine and the main tributaries of the Rhine (i.e. Moselle, Neckar and Main). These barges are therefore referred to as large Rhine barges (Dutch: Groot Rijnship). The locks on the upper parts and main tributaries of the Rhine were initially constructed with a length of 112 meter and a width of 12 meters. The maximum allowed barge size on these waterways used to be 110 x 11.4 meter, but the width has now been increased to 11.45 meters. Many locks have been lengthened to allow for longer push barge combinations. In that case the waterways are referred to as Class Va. Class V container barges are able to transport containers four wide and four high. The total capacity of a 110 x 11.45 meter container barge is about 200 TEU. Examples of a Class V container and dry bulk barge are presented in Figure 2-14.

Source: www.shipphoto.nl (accessed: 2010).

Figure 2-14: Class 5 Containership (Left) and Class 5 Dry Bulk Barge (Right)

[24] A rule of thumb in container transport is that due to stability restrictions (against capsizing) a barge is able to carry as many (full) containers high as wide. In other words: 1 x 1, 2 x 2, 3 x 3, …, n x n. However, at a certain stage the draft becomes a restriction. During low water it may not be possible to sail further upstream the Rhine with more than 4 layers of loaded containers, though empties may then still be loaded as an additional fifth layer.

The flat bow of the Class V barges can be used to push an additional dumb barge. A pusher barge combination is referred to as *‘koppelverband’* (Dutch and German). A proper English word is lacking, but Rijkswaterstaat (2011, p.23) applies the word *‘coupled unit’*. The push barge can either be located next to the barge (side-by-side) or in front of the barge. Placement in front of the barge is more fuel efficient while taking the barge aside increases the manoeuvrability. Therefore upstream sailing push barges are placed in front of the pusher barge while downstream sailing push barges are placed aside (see Figure 2.15).

Source: www.shipphoto.nl (attended 2010).

Figure 2-15: Class V coupled unit with dumb barge aside (Left) and in front (Right)

<u>Class VI barges</u>

In the 1970s the first Rhine-max barges with a length of 135 meter (CCNR, 2010a, p.75) appeared on the waterways, but these barges were still 11.4 meter wide. The size of the barges changed completely with the construction of the Jowi, a 135 x 16.9 meter Rhine-max barge delivered in 1998. The Jowi was the first Rhine-max barge with a width over 11.45 meters. It sparked the construction of a new wave of large container barges that are able to carry containers five or six wide (barge widths of 14.2 to 14.3 and 16.9 to 17.4 meters). These barges have a capacity of about 330 and 390 TEU respectively (based on four layers high). Due to draft restrictions the fifth layer is mainly used for the transport of empties. Including the fifth layer increases the capacity of the largest barge from 390 to 470 TEU (De Vries, 2000, p.49). An example of both barge types is given in Figure 2-16.

Source: www.shipphoto.nl (accessed: 2010).

Figure 2-16: Class VI Container barges with 5 (Left) and 6 (Right) Containers Wide

There are plans for even larger barges: *“Some considerations are under discussion to build a future super-container-ship for operation on the river Rhine with a capacity of 640 TEU. The dimensions could be about 135 meters x 20 meters”* (Müller, 2003, p.32). Under the present regime the maximum barge size for container barges would be 135 x 22.8 meters. Such a barge would be able to carry a load of 8 containers wide.

Closely after the introduction of large container barges the liquid bulk sector followed with the construction of large tankers[25]. Amongst the first inland ‘super tankers’ built in 2002 were the *Compromis* of 135 x 16.8 meter, and the *VT Vlissingen* of 135 x 21.6 meter (see Figure 2-17, right). The capacities of these barges are 5700 and 9300 tonnes respectively. Intense new building followed in the period thereafter (2003-2010). Schuttevaer (6/11/2008) reported the ordering of a shipload of hulls structures in China with sizes ranging from 110 x 11.45, 110 x 16.20, 135 x 16.20, 135 x 17.5, and 135 x 22.8, up to 150 x 22.80 (should be 147 x 22.80) meters. According to Deen Shipping (personal communication in 2010) about 70% of these barges is used for bunkering of seagoing barges. The remaining barges are mainly used for the transport of oil products in the (V)ARA area (Vlissingen, Amsterdam, Rotterdam and Antwerp). Only a hand full of large tankers sails on the Rhine to Germany. The largest 147 x 22.8 barge (the *VT Vorstenbosch*) is not allowed to sail further up the Rhine than Gorinchem, as the Regulations for Navigation on the Rhine (RPR) prohibit single hull barges longer than 135 meter. Figure 2-17 shows two Class VI oil product tankers of 15 and 22 meter wide.

Source: www.shipphoto.nl (accessed: 2010).

Figure 2-17: Class VI Oil Product Tankers of 15 meter (Left) and 22 meter wide (Right)

<u>Push barges</u>

For many centuries barges have been towed over the waterways by man- and horsepower. Not surprisingly towing was originally adopted after the introduction of the ship engine and propeller. Figure 2-18 shows a historical towing convoy on the Rhine. For each barge a separate towing line was provided by the towing barge.

[25] The development of these large tankers was partly enabled by the development of a new Y-shaped hull structure generally referred to as the “Scheldt Skin” (Damen Shipyard, 2006). The Scheldt Skin provided much more safety against collision and allowed for a strong reduction in the number of cargo tanks. For the largest tanker (of 150 x 22.8 meter) the number of tanks was allowed to be reduced from 40 to 16. This made the barge cheaper, safer, and easier to operate (Schuttevear 6/11/2008).

Source: www.vaartips.nl/extra/sleepboot.htm (accessed: 2014).

Figure 2-18: Convoy of Towed Barges on the Rhine

In 1953 a delegation of the French national shipping agency visited the United States to study the operations of push barges on the Mississippi. Following this visit a pilot with a push barge was undertaken. On the 21st of October 1957 the Wasserbüffel (1260 HP) with four barges of 1250 tonnes each made her first trip on the Rhine. Push barges turned out to increase productivity considerable between Rotterdam and the Ruhr area and reduced the required number of staff by a factor five. Shortly thereafter a swift transition from towing to pushing of barges followed (Brolsma, 2010, p.11).

Push convoys consist of a tugboat and a number of dumb barges. The connection between the tugboat and the barges is made with tightened steel cables. The most common dumb barge applied in Europe is the Europe II barge. This barge has a length of 76.5, a width of 11.4 meters and is available for various drafts. The largest push convoys in Europe consist of nine such barges, but they are only allowed on the Danube up to Belgrade. On the Rhine push barge combinations are allowed up to six barges. Figure 2-19 shows an example of a push barge combination with one (Class Va), two (Class Vb), four (Class VIb) and six (Class VIc) dumb barges. If two barges are allowed next to each other instead of behind each other the waterway is referred to as Class VIa in the CEMT-1992 classification.

<u>River-sea-ships</u>

In addition to the barges for which the sailing area is restricted to the inland waterways, there also exist some barges that are able to sail offshore. With respect to these so called river-sea-ships a distinction should be made *"between <u>inland going sea ships</u> and <u>seagoing inland ships</u>. The first are sea ships of which the draught also allows sailing on inland waterways. At sea they must be able to resist a heavy seaway (Baltic Sea, North Sea, Biscay etc.). The last are inland ships where the equipment, the strength, the stability and the freeboard allow the operation on maritime waterways up to a certain seaway status"* (Müller, 2003, p.18). In general the use of inland going sea ships is more expensive than the use of seagoing inland barges (that are also referred to as estuary barges). Figure 2-20 provides an example of an inland going sea ship (left) and a seagoing inland ship leaving the port of Zeebrugge (right).

Source: www.shipphoto.nl (accessed: 2010).

Figure 2-19: Examples of Push Barges Class Va, Vb (Top), VIb, and VIc (Bottom)

Source: www.shipphoto.nl (accessed: 2010), www.scheepvaartwest.be (accessed: 2010).

Figure 2-20: An inland going Sea Ship (left) and a seagoing Inland Barge (right)

2.3.3 Answer to sub-question 1b

In answer to sub-question 1b, I conclude that the West European IWT infrastructure has been developed by the construction of various canals since the 19th century – and that the size of the barges followed the available canal dimensions. It took until 1954 before a European (CEMT) waterway classification was adopted, that was updated to include the East European waterways as well as the use of larger push barge combinations in 1992. The dimensions of most waterways are however still stemming from the period before the introduction of the container. Initially, when the first containers were shipped by barge, the available height underneath the bridges turned out to be just sufficient for (partly) loaded standard 20 or 40 foot deepsea containers – and for deepsea containers the width also turned out to be just sufficient to load four containers next to each other into the holds of a standard Class V barge. For this reason there was no need to make costly adjustments to the inland waterways. Nowadays, use is increasingly made of higher so called high cube containers and wider so called pallet wide containers, as well as longer-, wider-, and higher continental high cube pallet wide 45 foot containers. For these containers the present waterway dimensions are however not fully compatible with the requirements for cost effective container transport.

2.4 Policies related to Inland Waterway Transport

This section addresses GSQ 1c: *'What are the present IWT policies and how can they be expected to effect the future development of the IWT system?'*. IWT Policies are in place to regulate issues that mainly relate to: access to the waterways, rules for inland navigation, technical requirements of the barges, minimal crew standards, transport of hazardous materials, as well as issues related to maximum emission levels and taxation. Policies affecting IWT are developed at various institutional levels. The Central Commission for Navigation on the Rhine (CCNR) has the highest international legislatory status as it is based on a supra-national treaty between member states inside and outside the European Union[26]. At the next level regulation takes place by the European Union, for which the regulation has to comply with the regulations of the CCNR for IWT on the Rhine. Finally, policies are also implemented on a national or even a local level by the responsible waterway authorities.

2.4.1 Central Commission for Navigation on the Rhine

The Central Commission for Navigation on the Rhine (CCNR) is the primary legislative institution dealing with IWT on the Rhine. The commission comprises five member states being: Germany, Belgium, France, The Netherlands, and Switzerland. The existence of the CCNR dates back to the Congress of Vienna (1815) in which the organisation was founded to secure the principle of freedom of navigation on the major international rivers of Europe. Its current legal status is based on the Revised Convention for Navigation on the Rhine – referred to as *'Mannheim Act'* – of 17 October 1868. The aim of the CCNR is to implement any initiative intended to guarantee freedom of navigation on the Rhine and promote navigation on the Rhine. Individual member states are not authorised to develop policies regarding issues affecting IWT on the Rhine independently, but need to do this in line with the policy of the CCNR. This guarantees that the favourable conditions for navigation on the Rhine are maintained and continuously improved. In addition member states are not allowed to impose any taxes or other constraints to inland navigation. For this reason there still exists a fuel tax exemption for gasoil used by inland barges.

The CCNR is responsible for legislation of a vast number of issues regarding IWT, such as: technical requirements of barges, environmental standards, inland navigation laws, manning requirements, and the requirements for transport of hazardous materials. Due to the important position of the Rhine in the European IWT system the CCNR has a strong influence on the development of European and national IWT legislation (also outside the Rhine basin). It therefore works in close cooperation with other states and international organisations. The CCNR has provided ten states an observer status (i.e. Austria, Bulgaria, Luxembourg,

[26] In addition to the CCNR there is also a commission that deals with navigation on the Danube which is referred to as the Danube Commission. The importance of the Danube for West European and Dutch IWT is however limited. Further information on this committee can be obtained from www.danubecommission.org.

Hungary, the Slovak Republic, the Czech Republic, Romania, the United Kingdom, the Ukraine, and Poland). The participation of these states does not depend on any financial contribution, but merely on acceptance of the CCNR's rules. A special agreement is made with the European Commission in which the CCNR accords observer status to the European Commission and conversely, the European Commission accords observer status to the CCNR within the Joint Committee on Inland Navigation.

The CCNR and European Commission work in close cooperation. The CCNR provides the member states of the European Union access to the Rhine under similar conditions as its own members. To this end, the CCNR and the European Community have adopted identical regulations for navigation of barges on the Rhine and on the other European waterways. With respect to the technical requirements for barges used in inland navigation, the CCNR and the EU have adopted identical regulations and have agreed to mutually recognise their barge certificates. For the purpose of ensuring identical requirements as well as a common safety policy in the long term, a Joint Working Group (JWG) has been established with the mandate of preparing proposals for amending the technical requirements[27].

The policies of the CCNR are likely to enhance the further development of the European IWT system. They provide some guarantee that the inland waterways will remain accessible for inland barges – and that the quality of the waterway connection will not be deteriorated. In addition they set new regulations for safer and cleaner barges and barge operations. If, for some reason, the fuel tax exemption on gasoil is abandoned, this may have a considerable effect on the competitiveness and market share of IWT (see also Chapter 10).

2.4.2 European inland waterway transport policy

The views of the European Commission on the European transport policy are discussed in the *'White papers'* on transport of 1993, 2001, 2006 (mid-term review), and 2011. The primary aim of the EU policy is to support a swift integration of the common European market by eliminating any restrictions or distortions as rapidly as possible, while taking into account the new challenges to transport such as emissions, safety and congestion (EC, 1993, p.5). In line with the conclusions of the Gothenburg European Council (June 2001) it was recognised that *"A modern transport system must be sustainable from an economic and social as well as an environmental viewpoint"* (EC, 2001b, p.10). The white paper of 2001 indicates that in order to obtain a sustainable system *"This will involve greater efforts in order to break the link gradually between transport growth and economic growth and make for a modal shift"* (EC, 2001b, p.14). In practice it appeared to be impossible to break the link between transport growth and economic growth, and in addition the shift towards cleaner modes of transport cannot be imposed by European and/or national transport regulations[28]. The 2006 mid-term review of the European Commission's 2001 transport White Paper therefore indicates that: *"Mobility must be disconnected from its negative side-effects using a broad range of policy tools. Therefore, the future policy will have to optimise each mode's own potential to meet the objectives of clean and efficient transport systems. The potential for technology to make*

[27] The text on this subject is based on information obtained from the websites of the CCNR (www.ccr-zkr.org), the EICB (www.informatie.binnenvaart.nl/binnenvaartorganisaties/98-ccr.htm), and Wikipedia.

[28] In this respect it is interesting to note that the Rotterdam Port Authority now prescribes the modal split in its concession agreements with new terminal operators (see also Section 2.2.2).

transport more environmentally friendly must be enhanced, in particular in relation to greenhouse gas emissions. A number of major infrastructure projects will help to alleviate environmental pressure on specific corridors. Shifts to more environmentally friendly modes must be achieved where appropriate, especially long distance, in urban areas and on congested corridors. At the same time each transport mode must be optimised. All modes must become more environmentally friendly, safe and energy efficient. Finally, co-modality, i.e. the efficient use of different modes on their own and in combination, will result in an optimal sustainable utilisation of resources" (EC, 2006, p.7).

The EU white paper of 2011 (EC, 2011) stresses that the European Union aims for decarbonising of transport by *"improving the energy efficiency performance of vehicles across all modes; developing and deploying sustainable fuels and propulsion systems; optimising the performance of multimodal logistic chains"* and *"using transport and infrastructure more efficiently through use of improved traffic management and information systems"* (p.6 – p.7). Important is to realise that in order to reduce greenhouse gasses *"New transport patterns must emerge that, according to which larger volumes of freight and greater numbers of travellers are carried jointly to their destination by the most efficient (combination of) modes. Individual transport is preferably used for the final miles of the journey and performed with clean vehicles"* (p.6). This multimodal transport system requires *"a 'core network' of corridors, carrying large and consolidated volumes of freight and passengers traffic with high efficiency and low emissions"* (p.14). The EU therefore intends to provide *"A fully functional and EU-wide multimodal TEN-T 'core network' by 2030, with a high-quality and capacity network by 2050 and a corresponding set of information services"* (p.9). This TEN-T network should: *"ensure that all core seaports are sufficiently connected to the rail freight and, where possible, inland waterway system"* (p.9).

The European Commission (2011, p.9) aims that: ***"Thirty per cent of road freight over 300 km should shift to modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors"*** (p.9). It therefore aims to shape the right conditions to *"align market choices with sustainability needs (and to reflect the economic costs of non-sustainability)*" (p.16). This implies that the policies of the European Union are intended: (1) to focus on improving the environmental performance of all transport modes on their own; (2) to improve the quality of the more environmental transport networks, such as IWT network; (3) to enhance the development of sustainable intermodal transport networks; and (4) to reduce greenhouse gas emissions by enhancing environmental taxes (e.g. imposed via road pricing), which should eventually be in favour of IWT.

2.4.3 Dutch transport frameworks and policy documents

The Dutch transport policy is discussed in the *"Vision on Infrastructure and Spatial Development"* (Ministry of Infrastructure and Environment, 2012, translated title), that replaces the *"Note on Mobility (NoMo)"* (Ministerie van Verkeer en Waterstaat and VROM, 2004, translated title). The main objective of the NoMo was to keep the main transport network operational and have the primary bottlenecks removed by 2020. The related infrastructure investments were listed in the MIRT Programme (Multi-year programme on Infrastructure, Spatial development and Transport) and the annual state budget. The new structural framework aims for flexible and sustainable use of all modes of transport combined. This new policy framework enhances the growth of freight transport by means of intermodal rail- and inland waterway transport and supports the development of intermodal nodes. It aims to improve the service level of the waterways and stimulates the development of new waterborne business areas.

The policy document *"Sailing to a vital economy: safe and sustainable inland shipping"* (Ministerie Verkeer en Waterstaat, 2007, translated title) also mentions the intention to maintain a balanced mix of large and small barges. It draws special attention to safeguarding the use of the smaller inland waterways by securing quay facilities and supporting initiatives in favour of small inland barge operations. As these intentions have not been noticed in the new structural vision on infrastructure and spatial development their current status is unclear.

The infrastructure providers (Rijkswaterstaat and local authorities) have to comply with a wide range of guidelines, policies, and regulations. The functional dimensions and design of the waterways are defined in the *"Waterway Guidelines 2011"* (Rijkswaterstaat, 2011). The planned development of the main waterways is framed in the *"Maintenance and development plan of the national waterways 2010 – 2015"* (Rijkswaterstaat, 2008, translated title). This plan has to comply with the regulations imposed by the EU *"Water Framework Directive"*, the EU *"Bird Directive/Nature 2000 Directive"*, and the *"National Waterplan"*[29]. In addition to the above frameworks the infrastructure provider should also comply with the CCNR directives as well as with the directives of other waterway commissions, such as the commission for IWT on the Scheldt, Eems-Dollard, and Meuse[30], and the ratified directives of the IMO and other international organisations related to IWT[31].

It can therefore be concluded that Dutch transport- and infrastructure policies also aim to enhance the use of IWT, but that they have to comply with a wide range of other guidelines, policies, and regulations. Future policies affecting IWT can be expected to be related to the development of waterfront business areas, as well to maintaining and/or improving the quality of the many inland waterway connections within the Netherlands.

2.4.4 Answer to sub-question 1c

In answer to sub-question 1c, I conclude that IWT policies are in place to regulate issues such as: access to the waterways, rules for inland navigation, technical requirements of the barges, minimal crew standards, transport of hazardous materials, as well as issues related to maximum emission levels and taxation. Policies affecting IWT are developed at various institutional levels. The Central Commission for Navigation on the Rhine (CCNR), has the highest international legislatory status as it is based on a supra-national treaty between member states inside and outside the European Union (i.e. the Mannheim treaty of 1868). On the next level regulation takes place by the European Union (that has to comply with the regulations of the CCNR for IWT on the Rhine). Finally, IWT policies are also developed at a national or even local level by a number of responsible authorities. Some of these policies may have a large effect on future IWT. As a consequence of the Mannheim treaty IWT is still exempted from fuel taxes on gasoil. If, for some reason, the fuel tax exemption on gasoil will be abandoned, this may have a considerable effect on the competitiveness and market share of IWT. European and national transport policies aim for a modal shift from unimodal road transport towards more sustainable intermodal transport means such as IWT. This may, at a certain stage, enable the future development of intermodal continental container transport.

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[29] In Dutch: Richtlijnen Vaarwegen; Beheer- en Ontwikkelplan voor de Rijkswateren (BPRW); Waterwet en Kaderrichtlijn water (KRW); Vogelhabitat Richtlijn / Natura 2000; Nationaal Waterplan.

[30] In Dutch: Scheldecommissie; Eems-Dollard Commissie; Grensmaasoverleg.

[31] The policy framework has been discussed on the basis of a presentation by Huub Cramer, Staf DG of RWS.

2.5 Interaction with other functions of the waterways

This section addresses GSQ 1d: *'How does IWT interact with other users of the waterway system – and can the IWT system be studied without considering the other users?'*. It addresses the interaction with other users of the waterway system in order to judge whether it is sensible to develop a policy evaluation methodology, that takes only one sub system of the waterways (i.e. the IWT system) into account, instead of considering the effects on a broader range of inland waterways users.

2.5.1 Discussion of interaction with other functions of the waterways

The IWT system does not stand on its own as the inland waterway system serves many other functions as well. In the present *"Management and development plan 2010-2015 for the national waters"* (Short: BPRW)[32] the functions are grouped and prioritized into three categories (Rijkswaterstaat, 2008, p.22). The first category, that has the highest priority, contains the basic functions of the waterways, such as security against flooding and the provision of adequate clean and ecologically healthy water. The second category is related to the IWT function of the waterways for which speed, reliability, and safety are the main objectives. Finally the third category contains the remaining user functions such as recreation, fishing, and swimming. The objective for these functions is to support them as long as they do not conflict with the objectives imposed by the first and second category.

A more detailed discussion of seventeen recognised waterway functions prioritised into four categories was provided in the previous version of the BPRW (Rijkswaterstaat, 2005, p.60). Despite the fact that the applied categorisation is outdated, it still provides a useful discussion framework from which the interaction between IWT and the other functions of the waterways becomes clear. The outdated categorisation is therefore presented in Table 2-4.

Table 2-4: Outdated Categorisation of Core Activities and Functions of the Waterways

No.	Core Activity	Function
1	Protection against flooding	Water retaining Water discharge
2	Providing clean and sufficient water	Commercial fishing Drinking water Cooling water (River)bank recreation Regional water supply Sport fishing Hydropower Water quality and ecology Bathing and swimming water
3	Providing smooth and safe waterway transport	Main transport axis Main waterway Other waterways Recreational use of waterways
4	Other	Surface mining and quarrying Other outside the dike activities

Note: The outdated numbering of the categories (BPRW 2005) differs from the new one (BPRW 2008).
Source: Rijkswaterstaat (2005, p.60, translated).

[32] Dutch: Beheer- en Ontwikkelplan voor de Rijkswateren 2010-2015.

Schweig (2006, p.119-124) studied the extent to which the above functions are conflicting with and/or complementary to the IWT function. To start with the *water retaining* function: ever since the 11th century dikes have been constructed and riverbeds have been shaped and normalised. This is generally beneficial for IWT. It provides better accessibility and results in less fluctuation of water levels. The normalised flow also reduces the occurrence of ice dams and uncontrolled sedimentation. However, under some (extreme) high water conditions the flood protection system may become an obstruction to shipping. Sometimes flood gates are closed, but on the main waterways locks are available to keep the ships going. During some rare events shipping was banned to reduce wave impacts on potentially unstable dikes, but often many years go by without such a ban taking place. In general the interaction between the water retaining function and shipping is small, but positive. This also holds for the water *discharge function* of the waterways. When bottlenecks in riverbeds are removed and buffer capacity is created this results in a stabilised flow and improved river navigability.

The items in the second category (related to the core activity of providing clean and sufficient water) also show few conflicts of interests with the transport function. There is synergy with respect to the provision of *hydropower* as the dams required for shipping also provide an opportunity for hydropower and vice versa. The *regional water supply* has also benefited considerably from the canals once laid-out for shipping. For example the *Amsterdam Rhine Canal* now replaces a complex structure that was in place for local water management. Some canals have even lost their shipping function but are still in place for water management. The *cooling water* function shows hardly any interaction as long as the intakes and outfalls are designed in such a way that strong side currents are avoided. *Water quality and ecology* may impose some restrictions on barge pollution, but pollution should be avoided anyway. Inland shipping puts some restrictions on the use of the waterways for *bathing and swimming*. It is for example not allowed to swim in the Amsterdam-Rhine Canal. However, there is also a lot of positive interaction as shipping berths often provide a nice platform for swimmers. There is also not much interaction with *drinking* water, except that barge pollution should be avoided. *Riverbank recreation* is not conflicting with inland shipping and vice versa. *Sport fishing* needs to take shipping into account but is still possible. The same holds for *commercial fishing* activities, though fishermen are also part of shipping traffic themselves.

The functions of *main transport axis*, *main waterway* and *other waterways* reflect to the shipping function itself. Only *recreational use of the waterways* is in some cases conflicting with inland shipping, particularly with respect to safety. Some additional measures will therefore be required. However waterway recreation and inland shipping reinforce each other more than they hamper. The economic importance of water recreation almost equals the economic importance of shipping and therefore there is mutual interest with respect to political influence and budget allocation. In addition, waterway recreation benefits from the supply sector and facilities, that are put in place for inland shipping and vice versa.

Other functions such as *surface mining and quarrying* are also mutually beneficial. The quarrying industry uses barges to transport their material while at the same time they deepen the waterways or create new water recreation areas. Other functions that were not included in the list of Table 2-4 are *defence*, *cultural heritage*, and *living areas outside the dikes*. In principle there is no reason why these functions could not be combined with IWT, but they can be expected to impose some restrictions on the use of the inland waterways for IWT (e.g. limited access to waterways that are of strategic military importance, difficulties to upgrade the dimensions and capacity of the waterways due to the existence of monumental locks and bridges, and local speeds restrictions near residential waterfront areas).

According to Schweig (2006, p.124, translated) the interaction between IWT and other functions of the waterways is quite limited and mainly positive: *"On balance, the general impression is that the waterway functions pretty much reinforce each other and are not often conflicting. Formally shipping does not receive the highest priority, but in practice shipping does not often have to give way to other functions. If for some reason shipping has to give way the hinder is usually temporary"*. In my opinion the conclusion of Schweig holds quite well for the use of existing waterways, but one should be careful when planning major changes to the water system, such as reducing the number of weirs on the river Meuse (Den Heijer et al., 2010). The various user functions are closely related. Changes made to improve the performance for one of the user functions will also have an effect on others.

2.5.2 Answer to sub-question 1d

In answer to sub-question 1d, I conclude that the IWT system is a subsystem of the larger inland waterway system that also serves a wide variety of other functions. Waterway managers give highest priority to the protection against flooding and availability of sufficient clean water supplies, followed by the use of the waterways for IWT. In theory the various functions may be conflicting, but in practice the IWT system and the other functions of the waterways do not seem to hinder each other much, unless major changes to the water system are made. This implies that it is still sensible to study the effects on the IWT system without considering other users as long as no major changes to the water system are proposed. When major changes are concerned (e.g. resulting in completely different water levels) additional methods will be required to include these effects in the evaluation.

2.6 Concluding Summary

This chapter addresses the first general sub question (GSQ 1) *"Concerning the Dutch and West European IWT System"*, that consists of four open ended sub-questions. As the answer to an open ended question is in fact the discussion itself, I will start with a summary of the issues discussed in this chapter. On the basis of this summary the main conclusions will be drawn. For those who have read the entire chapter it is not necessary to read the summary part of this section. They can go directly to the conclusions in Section 2.6.5.

2.6.1 Answer to sub-question 1a

This section addresses the answer to Sub-question 1a: *"What is the importance of IWT in the overall freight transport system, how is the relative market share of IWT developing over time, and what are the most important transport flows on the inland waterways?"*. The discussion in this section is more elaborate than in Section 2.2.4, in order to provide sufficient background for those reading only the concluding summary.

In answer to sub-question 1a, I conclude that inland shipping is nowhere in the world so well developed as on the river Rhine. The Dutch IWT system is located in the heart of the Rhine Delta. It contains the world's most advanced fleet of inland barges and the relative share of goods shipped by means of IWT is unequalled. In the Netherlands about 25% to 35% of the total transport volume (measured in tonnes) and about 35% to 45% of the transport performance (measured in tonne kilometres) takes place by IWT. The vast majority of these flows has an international origin or destination. IWT is market leader in the transport of ore, coal, sand, gravel, chemical products, and oil products (if not transported by pipeline). IWT flows can be subdivided into port related-, continental-, and river-sea transport. About 60% of all IWT in the Netherlands has an origin or destination in the seaports. There is no clear data on the overall share of IWT in the hinterland transport of the Dutch ports, but I expect this share to be in the order of 40% to 50% (measured in tonnes). In addition I estimated the average market share of continental (non-port-related) IWT at almost 20% for the Netherlands (measured in tonnes). River-sea transport refers to waterway transport in which two river ports or a seaport and a river port are directly connected by a small coaster or a sea-going barge. There is no data available on the relative share of river-sea transport, but volumes are indicated to be rather small.

The inland waterways have played an important role in the transport of passengers and goods throughout history. The waterways have always provided a strong socio-economic backbone that connected many economic centres in Europe. IWT used to be the main mode of transport until the first half of the 19^{th} century. Free access to the Rhine and its main tributaries is provided ever since the Mannheim treaty of 1868, which is still in place. Many industrial sites have been developed and are still located near the waterfront. However, from about the year 1850 onwards the relative share of IWT has considerably declined due to the rise of the rail- and road transport networks. These faster and more flexible modes of transport took over the majority of the fast growing higher valued goods segment while inland shipping retained a strong market position in the lower valued bulk products. By the second half of the 20^{th} century IWT was generally perceived as a slow, old fashioned, and little service oriented mode of transport, that was bound to face a long gradual decline.

The future for IWT now looks much brighter than one may have expected a few decades ago. Recent statistics indicate that the very long term decrease in the market share of IWT may have now, at least temporarily, come to a hold from about the year 2000 onwards. The main reasons for this improvement should not only be sought in the liberalisation of IWT market in the year 2000, but mainly in the development of international deepsea container transport (since the year 1966), and the development of inland container barge lines (since the year 1974). The Dutch national fraction of containers that is transported by barge increased from 15% in 1994 to 33% in 2002. A further increase in the market share of inland container barge transport is expected after the commissioning of the Second Maasvlakte in 2014, because the Rotterdam Port Authority now prescribes a modal split of 45% for IWT in their concession agreements with new terminal operators. European and national policies also pursue a shift from road to IWT. The European Commission (2011) states its white book on transport a policy goal to shift 30% of road freight over 300 km to more sustainable rail and waterborne transport by 2030, and more than 50% by 2050.

2.6.2 Answer to sub-question 1b

This section addresses the answer to Sub-question 1b: *"How has the historical development of the IWT infrastructure and barge fleet affected the present characteristics of the IWT system?"*. The discussion in this section is more elaborate than in Section 2.3.3.

In answer to sub-question 1b, I conclude that the IWT system stems from the age before the development of the container. The characteristics of the container have never been taken into account in the standard CEMT classification for inland waterways. The initial classification of the Conférence Européenne des Ministres des Transport (CEMT) stems from the year 1954. In 1992 an update was made to include push barges as well as the East European waterways. This CEMT-1992 classification is still in place, but Rijkswaterstaat now applies a new RWS 2010 classification (that is a refinement of the CEMT-1992 classification).

Barges have always been built to meet the size of the available infrastructure. The smaller Class I, II, and III barges were built according to the locks of the Péniche in France, the Kempens-Canal in Belgium, and the Dortmund-Ems Canal in Germany. Almost no new Class

I, II, and III barges have been built since the 1960s. The use of the smallest waterways is therefore phasing out. A few Class III barges have been constructed between 2000 and 2005, but due to relatively low economies of scale, high competition with old and depreciated barges, low comfort levels in the rather small accommodation, and uncertainty with respect to future upgrades of the waterways, the private sector is still reluctant to invest in new Class III barges. New barge concepts are now being proposed to address this issue, but the viability of these concepts still needs to be proved. The future use of the smaller waterways for transport is therefore still uncertain. Class IV barges were originally built according to the dimensions of the Rhein-Herne Canal that was constructed in 1914 to connect Duisburg to Dortmund. This canal allowed for barges of 80 by 9.5 meters. Due to upgrades of the canals the Rhein-Herne barge is now replaced by the Europaship (European barge) which is about 86 meters long and 9.5 (or 9.6) meter wide. Class IV waterways are regarded the minimum standard for waterway connections of international importance. Class IV barges are still competitive and newly constructed. Class V barges are designed according to the maximum allowable ship dimensions on the upper Rhine. They have a length of 110 meter, a width of 11.45 meter, and are able to carry about 200 TEU. Class V barges used to be the standard on the entire Rhine, but since the construction of the Jowi (in the year 1998) larger Class VI barges are now increasingly used in the lower Rhine Delta. Class VI barges are generally 135 meter long and 14.3 or 17.4 meter wide. The maximum allowed barge dimensions for a single hull barge on the Rhine are 135 x 22.8 meter. Push barge combinations are allowed up to 6 barges on the Rhine. These combinations have a length up to 280 meters and a width up to 22.8 meters.

Purely by coincidence the available height underneath the bridges turned out to be just sufficient for (partly) loaded standard 20 or 40 foot deepsea containers. In a similar way intercontinental deepsea containers fitted just four rows wide into the holds of a standard Class V barge (in fact the allowable width was increased from 11.40 to 11.45 meters). However, the past few decades a clear trend can be observed towards an increasing share of higher so called high cube containers and wider so called pallet wide containers. Pallet wide containers are mainly developed for the European market as they allow for the efficient loading of two European pallets (Euro-pallets) next to each other. For continental transport the high cube pallet wide 45 foot container has now become the standard intermodal loading unit. This container, that will be referred to as the continental 45 foot container, has similar inner dimensions as a lorry truck but the outer dimensions are not fully compatible with the dimensions of the IWT network. In this respect one can argue that the future development of efficient continental container barge transport requires an upgrade of the IWT system.

2.6.3 Answer to sub-question 1c

This section addresses the answer to Sub-question 1c: *“What are the present IWT policies and how can they be expected to effect the future development of the IWT system?”*. The text in this section is identical to that of Section 2.4.4. and repeated for convenience.

In answer to sub-question 1c, I conclude that IWT policies are in place to regulate issues such as: access to the waterways, rules for inland navigation, technical requirements of the barges, minimal crew standards, transport of hazardous materials, as well as issues related to maximum emission levels and taxation. Policies affecting IWT are developed at various institutional levels. The Central Commission for Navigation on the Rhine (CCNR), has the highest international legislatory status as it is based on a supra-national treaty between member states inside and outside the European Union (i.e. the Mannheim treaty of 1868). On the next level regulation takes place by the European Union (that has to comply with the regulations of the CCNR for IWT on the Rhine). Finally, IWT policies are also developed at a national or even local level by a number of responsible authorities. Some of these policies may have a large effect on future IWT. As a consequence of the Mannheim treaty IWT is still exempted from fuel taxes on gasoil. If, for some reason, the fuel tax exemption on gasoil will be abandoned, this may have a considerable effect on the competitiveness and market share of IWT. European and national transport policies aim for a modal shift from unimodal road transport towards more sustainable intermodal transport means such as IWT. This may, at a certain stage, enable the future development of intermodal continental container transport.

2.6.4 Answer to sub-question 1d

This section addresses the answer to Sub-question 1d: *"How does IWT interact with other users of the waterway system – and can the IWT system be studied without considering the other users?"*. The text is identical to that of Section 2.5.2. and repeated for convenience.

In answer to sub-question 1d, I conclude that the IWT system is a subsystem of the larger inland waterway system that also serves a wide variety of other functions. Waterway managers give the highest priority to protection against flooding and availability of sufficient clean water supplies, followed by the use of the waterways for IWT. In theory the various functions may be conflicting, but in practice the IWT system and the other functions of the waterways do not seem to hinder each other much, unless major changes to the water system are made. This implies that it is still sensible to study the effects on the IWT system without considering other users as long as no major changes to the water system are proposed. When major changes are considered (e.g. resulting in completely different water levels) additional methods will be required to include these effects in the evaluation.

2.6.5 Answer to General Sub Question 1

In answer to the first three sub questions of GSQ 1, I conclude that the IWT system has played an important role in the Dutch (and to a lesser extent also the West European) transport system throughout history, but from about the year 1850 onwards the market share of IWT declined considerably due to the rise of the new rail- and road transport networks. These new transport modes took over the majority of the higher valued goods segment and left IWT with the gradually declining lower valued bulk products. Recent statistics indicate that the very long term decrease in the market share of IWT may have now, at least temporarily, come to a hold from about the year 2000 onwards. The main reasons for this improvement should not only be sought in the liberalisation of IWT market in the year 2000, but mainly in the development of inland container barge lines (since the year 1974). The increased use of intermodal barge transport is likely to be continued in the future as it is supported by many policies that aim for a modal shift from unimodal road transport towards more sustainable intermodal transport solutions. If successful these policies may eventually enhance the development of continental container barge transport on the inland waterways, but the development of continental container transport still remains a major challenge, as the cost effective transport of pallet wide high cube continental 45 foot containers (i.e. the standard intermodal loading unit in European continental transport), amongst others, requires an upgrade of the present IWT system.

In answer to the last sub question of GSQ 1, I conclude that there is only limited interaction between IWT and the other users of the inland water system. This implies that it is still sensible to study the effects on the IWT system without considering other users as long as no major changes to the water system are proposed. When major changes are concerned additional methods will be required to include these effects in the evaluation.

Literature:

Beelen (2011) *Structuring and modelling decision making in the inland navigation sector*, Universiteit Antwerpen, Belgium.

Brolsma, J.U. (2010) *Historische ontwikkeling van de binnenvaart*, DVS Rijkswaterstaat, paper prepared as course material for PAO course on inland shipping.

Brolsma, J.U. (2014) *Rapportage containerhoogtemetingen*, DVS Rijkswaterstaat.

Brunet, R. (1989) Les villes europeénnes: Rapport pour la DATAR. Montpellier: RECLUS.

Brunet, R. (2002) *Lignes de force de l'espace Européen, Mappemonde*, vol. 66, no. 2, pp. 14-19, http://www.mgm.fr/PUB/Mappemonde/M202/Brunet.pdf.

Bureau Voorlichting Binnenvaart (2010) *The Power of Inland Navigation,* Dutch Inland Shipping Information Agency (BVB), Rotterdam, www.inlandshipping.com.

Buscher, I, H. Blaauw, M. De Gier, B. Kelderman, J. Kiel, H. de Leijer, H. Maurer, S. van Putten, M. Quispel, R.J. Zimmerman (2010) *Rivers of the World Atlas,* NEA, the Netherlands.

CCNR (2009) *Inland Navigation in Europe, Market observation 2008-I,* CCNR.

CCNR (2010a) *Rijnvaartpolitieregelement*, http://www.ccr-zkr.org/13020500-nl.html.

CCNR (2010b) *Regelement betreffende het scheepvaartpersoneel op de Rijn (RSP)*, http://www.ccr-zkr.org/files/documents/reglementSTF/stf1_102011_nl.pdf.

Damen Shipyard (2006) *Introduction of Y-shape patent ('Schelde Skin')*, Damen Shipyard, Damen News 7, April 2006.

De Kotter, M.L., and R. de Kotter (1999) *Binnenvaart wat vaart waar*, De Alk, Alkmaar, The Netherlands.

De la Fuente Layos, L. (2007) *Inland Waterways Freight Transport in Europe in 2006, EU transport static*, Eurostat: Statistics in Focus, 132/2007.

De la Fuente Layos, L. (2009) *Inland Waterways Freight Transport in Europe in 2007 remains stable*, Eurostat: Statistics in Focus, 27/2009.

Demirel (2011) *Economic Models for Inland Navigation in the Context of Climate Change*, Vrije Universiteit, Amsterdam.

Den Heijer, F., M.A. Wolters, J.C.M. van Dorsser, H.E.J. Berger, and A.C.L. Hijdra (2010) *Developing a substitution strategy for hydraulic structures to meet the challenges of a new century*, PIANC MMX Congress, Liverpool, UK.

De Vries, C.J. de (2000) *Goederenvervoer over water: Achtergronden bij een bedrijfstak in beweging*, Van Gorcum, Assen, The Netherlands.

European Commission (1993) The future development of the common transport policy, A global approach to the construction of a Community framework for sustainable mobility, Bulletin of the European Communities, Supplement 3/93, Office for Official Publications of the European Communities, Luxembourg.

European Commission (2000) *EU Transport in Figures: Statistical Pocketbook 2000*, Directorate General for Energy and Transport, Brussels. Related data: *pb pt2 July 2000.xls* obtained from DG MOVE - Directorate-General for Mobility and Transport.

European Commission (2001a) *Transport and Environment: Statistics for the transport and environment reporting mechanism (TERM) for the European Union – 2001 edition*, Office for Official Publications of the European Communities, Luxembourg.

European Commission (2001b) *White Paper, European transport policy for 2010: time to decide*, Office for official publications of the European Communities, Luxembourg.

European Commission (2003) *European Union Energy & Transport in Figures 2003*, Directorate General for Energy and Transport, Brussels. Related data: *ETIF_2003 _tran_tonkm.xls* obtained from DG MOVE - Directorate-General for Mobility and Transport.

European Commission (2005) *Trans-European Transport Network: TEN-T priority axes and projects 2005*, Office for Official Publications of the European Communities, Luxembourg.

European Commission (2006) Keep Europe Moving, Sustainable mobility for our continent, Office for Official Publications of the European Communities, Luxembourg.

European Commission (2010) *EU energy and transport in figures: Statistical Pocketbook 2010*, Publications Office of the European Union, Luxembourg. Related data: pb_2010_32_ tkm.xls obtained from http://ec.europa.eu/transport/publications/statistics/statistics_en.htm.

European Commission (2011) White Paper on transport, roadmap to a single European transport area – towards a competitive and resource-efficient transport system, Office for Official Publications of the European Communities, Luxembourg.

Eurostat (2009) *Panorama of Transport, edition 2009*, European Commission, Office for Official Publications of the European Communities, Luxembourg.

Grübler, A. (1990) *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport*, Physica-Verlag Heidelberg.

Haezendonck, E. (2001) *Essays on strategy analysis for seaports*, Garant, Leven, Belgium.

Hekkenberg (2013) *Inland ships for efficient transport chains*, Delft, The Netherlands.

Hengst, S. (1995) *Binnenvaart in Beeld*, Delft Universitaire Pers, Delft, The Netherlands.

Jonkeren, O. (2009) *Adaptation to Climate Change in Inland Waterway Transport*, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands.

Konings, J.W. (2009) *Intermodel Barge Transport: Network Design, Nodes and Competitiveness*, TRAIL Thesis Series Volume T2009/7, Trail Research School, Delft.

Konings, R., and M. Ludema (2000) *The competitiveness of the river-sea transport system: market perspectives on the United Kingdom – Germany corridor*, Journal of Transport Geography, vol. 8, no. 3, pp. 221-228.

Macharis, C., T. van Lier, E. Pekin, and A. Verbeke (2011) *Intermodaal Binnenvaartvervoer, Economische en ecologische aspecten van het intermodaal binnenvaartvervoer in Vlaanderen*, Uitgeverij VUBPRESS, Brussels, Belgium.

Ministerie van Infrastructuur en Milieu (2012) *Structuurvisie Infrastructuur en Ruimte, Nederland concurrerend, bereikbaar, leefbaar en veilig*. www.rijksoverheid.nl.

Ministerie van Verkeer en Waterstaat and VROM (2004) *Nota Mobiliteit, Naar een betrouwbare en voorspelbare bereikbaarheid*, www.notamobiliteit.nl.

Ministerie van Verkeer en Waterstaat (2007) *Varen voor een vitale economie, Een veilige en duurzame binnenvaart*. Drukkerij Albani, Den Haag.

Müller, E. (2003) *Innovative Transport Vehicles – Rhine, Working Paper for* project: *European Strategies to Promote Inland Navigation, WG3 Intermodality & Interoperability*.

Platz, T.E. (2009) *The Efficient Integration of Inland Shipping into Continental Intermodal Transport Chains: Measures and Decisive Factors,* TRAIL Thesis Series Volume T2009/11, Trail Research School, Delft, The Netherlands.

Policy Research Corporation (2007) *Beleidsstrategie Binnenvaart, Een landelijke markt- en capaciteitsanalyse*, Ministerie van Verkeer en Waterstaat, The Netherlands.

Port of Antwerp (2009) *Yearbook of statistics 2008*, Gemeentelijk Havenbedrijf Antwerpen, Havenhuis, Entrepotkaai 1, 2000 Antwerpen, Belgium.

Port of Rotterdam (2011) *Port Vision* 2030, http://www.portofrotterdam.com/en/Port/port-in-general/port-vision-2030/Documents/Port-Vision-2030.pdf

Reuters (2013, 11 December) *Seine canal project could be 3 bln euros cheaper –report,* http://uk.reuters.com/article/2013/12/11/france-canal-idUKL6N0JQ3O520131211.

RHDHV (2014) *Verkenning exportmogelijkheden overcapaciteit Nederlandse binnenvaartschepen*, in opdracht van het Ministerie van Infrastructuur en Milieu.

Rijkswaterstaat (2005) *Beheerplan voor de Rijkswateren 2005 – 2008 (Ontwerp), Balanceren tussen ambities en middelen*, Ministerie van Verkeer en Waterstaat.

Rijkswaterstaat (2006) *Richtlijnen Vaarwegen,* 2nd edition, Ministerie van Verkeer en Waterstaat, Rijkswaterstaat Adviesdienst Verkeer en Vervoer, Rotterdam, The Netherlands.

Rijkswaterstaat (2011) Richtlijnen Vaarwegen 2011, Rijkswaterstaat, Dienst Verkeer en Scheepvaart, Brolsma J.U. and K. Roelse (eds.).

Rijkswaterstaat (2011) Waterway Guidelines 2011, English translation of Dutch Version, Rijkswaterstaat, Centre for Transport and Navigation, Brolsma J.U. and K. Roelse (eds.).

Rijkswaterstaat (2008) *Beheer- en Ontwikkelplan voor de Rijkswateren 2010-2015 (Ontwerp), Werken aan een robust watersysteem*, Ministerie van Verkeer en Waterstaat.

River of Information (2013) *Binnenvaart als Exportproduct*, River of Information (bulletin), Vol. 3, pp. 4-5, provided by Bureau Telematica Binnenvaart.

Roelse (2002) *Classificatie en kenmerken van de Europese vloot en de actieve vloot in Nederland*, Rijkswaterstaat, Adviesdienst Verkeer en Vervoer, Rotterdam, The Netherlands.

Schultz van Haegen (2014) *Rapport hoogtes containerbinnenvaartschepen*, aanbiedingsbrief, http://www.rijksoverheid.nl/documenten-en-ublicaties/kamerstukken/2014/06/12/aanbieding-rapport-hoogtes-containerbinnenvaartschepen.html.

Schuttevaer (2008) *Deen Shipping creëert met Apollo nieuwe klasse*, Schuttevear, Zwijndrecht, 6 November 2008.

Schweig, J.C. (2006) *Beste Stuurlui! Overdracht van kennis en inzicht betreffende transport, scheepvaart en vaarwegen*, Aprilis, Zaltbommel, The Netherlands.

Sys C., and T. van Elslander eds. (2011) *Future Challenges for Inland Navigation, A Scientific Appraisal of the Consequences of Possible Strategic and Economic Developments up to 2030,* UPA University Press Antwerp.

Van Hassel, E. (2011) *Developing a Small Barge Convoy System to reactivate the use of the small inland waterway network*, Universiteit van Antwerpen, Belgium.

Verberk, A. (2010) *Advies Binnenvaartambassadeur*, Ministerie van Verkeer en Waterstaat & Ministerie van Economische Zaken.

VNF (2006) *Enquiry prior to the Declaration of Public Interest, Seine-Nord Europe Canal*, voies navigables de France.

Presentations:

H. Cramer (3 November 2010) *Binnenvaart en Vaarwegennetwerk*, PAO cursus: Binnenscheepvaart en Vaarwegen, Rotterdam.

Websites:

CCNR (accessed: 2011) *Central Commission for Navigation on the Rhine*, [www.ccr-zkr.org]

Danube Commission (accessed: 2011) *Danube Commission*, [www.danubecommission.org]

EICB (accessed: 2011) *Central Commission for Navigation on the Rhine*, [www.informatie. binnenvaart.nl/binnenvaartorganisaties/98-ccr.htm]

Inland Navigation Europe (accessed: 2010) *Map of Waterways*, [www.inlandnavigation.org]

International Transport Forum of the OECD (accessed: 2010) *Historic data on Inland Freight Transport in tonne kilometres*, [www.internationaltransportforum.org]

Port of Amsterdam (accessed: 2010) *IWT volumes in the port*, [www.portofamsterdam.com]

Port of Rotterdam (accessed: 2010) *IWT volumes in the port*, [www.portof rotterdam.com]

Scheepvaartwest (accessed: 2010) *Picture of Estuary Barge*, [www.scheepvaartwest.be]

ShipPhoto (accessed: 2010) *Pictures of Inland Barges*, [www.shipphoto.nl]

UNECE Statistical Database (accessed: 2010) *Transport Statistics for Inland Transport Modes in tonne kilometres*, [http://w3.unece.org/pxweb/]

Vaartips (accessed: 2012) *Picture of Towing Convoy on the Rhine*, [www.vaartips.nl]

Watertruck (accessed: 2014) Background on Watertruck project, [http://www.watertruck.eu/]

Wikimedia (accessed: 2014) Ullrich’s Map of the Rhine, [http://commons.wikimedia.org/wiki /File:Rhein-Karte.png]

Wikipedia (accessed: 2010) *Blue Banana*, [http://en.wikipedia.org/wiki/Blue_Banana]

Wikipedia (accessed: 2011) *Central Commission for Navigation on the Rhine*, [http://en. wikipedia. org/wiki/CCNR]

3 Learning from Long Term Transport Studies

“Scenarios are not predictions. It is simply not possible to predict the future with certainty.”
- Peter Schwartz (The Art of the Long View, 1991, p.6)

3.1 Introduction

Transport scenarios provide a logical starting point for an investigation into the very long term development of the inland (waterway) transport system. This chapter addresses the second general sub question (GSQ 2): *‘What can be learned from other regional long term transport scenario studies concerning: the use of scenarios, the applied methodology for quantifying scenarios, the main drivers of the transport system, the presented output parameters, and the obtained long term scenario projections?*’. From analysing existing transport scenarios one can expect to learn: how transport scenarios are generally used; what methodologies are generally applied to quantify the scenarios; what main drivers of the transport system are taken into account; which output parameters are considered relevant for policy analysis; and what the prevailing views on the long term development of the inland transport volumes are. This chapter therefore analyses four recent transport scenario studies that were: (1) available at the start of this PhD project; and (2) provide an indication of the development of the inland transport flows in the Netherlands or in its surrounding regions. The analysed scenario studies are: (1) the Dutch WLO scenarios; (2) a single German transport scenario; (3) the European TRIAS scenarios; and (4) the European TRANSvisions scenarios. For each of these transport studies an analysis of the identified scenarios, applied methodology, main scenario drivers, and relevant output parameters was made.

It is worth mentioning a few other transport scenarios that have not been included because they relate to a single port instead of a geographical region. These are: the *“Port Vison 2030”* scenarios of the Port of Rotterdam Authority (2011) and the *“Updating the future”* scenarios that were prepared by the Club of Rome Climate Programme for the Port of Rotterdam up to the year 2100 (Van den Akker et al., 2014).

The nature of forward looking projections is such that ex-ante validation of the output by means of obtaining additional sample data is not possible. The only option to validate the quality of scenario quantifications is to analyse the quality of the applied methodology and the applied input data (e.g. the socio-economic scenario input). This chapter therefore includes a reflection section that addresses my concerns with the applied methodology for modelling long term and very long term effects as well as my concerns with the long- and very long term scenario input that was used for the quantification of the transport scenarios.

Section 3.2 to 3.5 report the findings from each of the four analysed scenario studies; Section 3.6 combines the lessons learned into a joint discussion; Section 3.7 addresses my concerns with the applied methodology and scenario input; and Section 3.8 contains a concluding summary that provides an answer to GSQ2.

3.2 Dutch WLO Scenarios up to the year 2040

The Dutch WLO scenarios were developed as a joint effort of the Central Planning Agency (CPB), the Netherlands Environmental Assessment Agency (MNP, now PBL) and the Spatial Planning Agency (RPB, now also PBL). They are intend to take into account the effects of long term trends, such as: the decreasing household size, the ageing population, international migration, economic growth, and increasing personal welfare on the Dutch natural and built environment. The scenarios combine the impact of these trends on various aspects of the urban and rural landscape, including residential and industrial land use, traffic and transport, energy, agriculture, nature and landscape, water safety, and environment and health. WLO stands for *'Welfare, Prosperity and Quality of the Living Environment'*.

3.2.1 Identified scenarios

The Dutch planning agencies generally apply an even number of scenarios in order to avoid abuse of the middle scenario as *'the most likely one'* (CPB, 2011). The Dutch WLO scenarios were developed around two key drivers formerly applied in the *'Four Futures of Europe'* scenario study, which are: (1) the extent to which nations and international trade blocks cooperate and exchange; and (2) the way governments will balance between market forces and a strong public sector[33].

On the basis of these two dimensions the following four scenarios were developed:

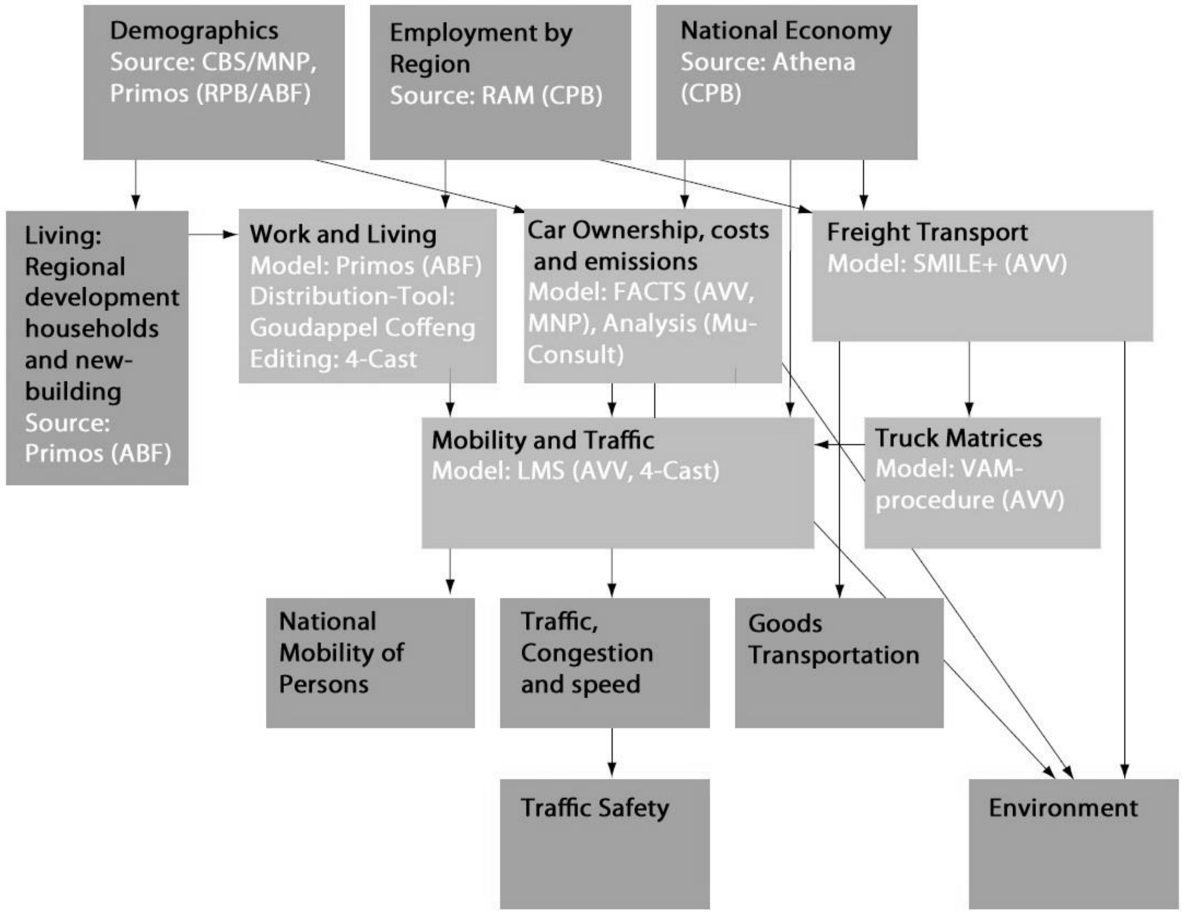
- Global Economy: emphasis on international cooperation and private responsibilities;
- Strong Europe: emphasis on international cooperation and public responsibilities;
- Transatlantic Markets: emphasis on national interests and private responsibilities;
- Regional Communities: emphasis on national interests and public responsibilities.

3.2.2 Applied methodology

The applied methodology for quantifying the transport scenarios is indicated in Figure 3-1. It can be observed that the applied methodology is based on a chain of linked models in which the output of high level models is used as input to more specific models.

The applied model structure avoids unnecessary complexity by omitting feedback loops (such as the effect of transport on economic output). Freight transport flows were estimated with the SMILE+ model on the basis of presumed economic developments. Assumptions with respect to the development of international trade were made in dialogue with the central planning agency (CPB) and the Port of Rotterdam Authority. Manual corrections were applied to account for decoupling (between economic growth and growth of the transport volumes) and increased levels of containerization in international trade.

[33] See De Mooij and Tang (2003), Lejour (2003), and Bollen, Manders, and Mulder (2004) for a discussion of the 'Four futures of Europe' scenario study.



Note: For an explanation of applied models and abbreviations reference is made to the source document.
Source: Janssen et al. (2006b, p.183), translated.

Figure 3-1 Methodology applied in the Dutch WLO Scenario Study

3.2.3 Scenario drivers

The WLO scenarios consider internal and external policy drivers (Janssen et al., 2006b). Internal policy drivers lie within the political sphere of influence of the Dutch government. They include spatial policy, supply of infrastructure and public transport, regulations on safety and living environment, cost levels for use of infrastructure, and the structure of the transport market. External drivers are those on which the government has little or no influence. These include socio-demographic factors, economic output, income and living patterns, technological development, and broader EU policies.

The overall demand for freight transport is mainly driven by the size and composition of the economy (measured by GDP) and the international trade volumes. The relation between economic output and transport is expected to change over time as a result of decoupling. Decoupling implies that the transport volumes per unit of GDP output will drop as a result of an increased level of services in the economy. On a disaggregated level (i.e. looking into specific transport flows) a shift from import of raw materials to import of low-grade intermediate and finished products is expected. This results in a strong growth of containerized goods and a relatively slow growth of bulk materials.

The effect of high oil prices on economic output and transport is argued to be almost negligible[34]. High oil prices are expected to have little effect on the overall level of freight transport, but they do affect the relative cost levels and competitiveness of the inland modes of transport and thereby affect the way goods are shipped. High oil prices can for instance be expected to enhance: speed reductions; economies of scale, such as larger carriers or different modes of transport[35]; and the use of more fuel efficient technologies, such as new propulsion systems or alternative fuels. The use of more fuel efficient technologies is further expected to reduce the noise- and emission levels of the inland transport means.

3.2.4 Scenario output

The scenario output of the WLO study addresses the total transport performance, as well as the external effects of transport on the living environment.

The total transport performance is measured in tonnes and tonne kilometres. Figure 3-2 (left) shows the expected transport performance in tonnes per type of freight flow (i.e. transit[36], international import/export, and domestic cargoes). Figure 3-2 (right) shows the expected transport performance by mode of transport (i.e. pipe, rail, road, and IWT) measured in tonne kilometres. The WLO scenarios also include the expected performance of the Dutch seaports. Figure 3-3 (left) shows the expected total throughput volumes of the Dutch seaports measured in tonnes. Figure 3-3 (right) shows the expected growth of the container throughput volumes, that are also measured in tonnes.

The effects of mobility on the living environment are defined on the basis of the expected developments of both freight and passenger transport. They include positive welfare effects as well as negative external effects, that are mainly related to issues like: unsafety, emissions, noise hinder, space required for infrastructure and parking areas, crossing of residential and nature areas, and congestion. Safety is measured by the number of victims from traffic accidents as well as by the number of casualties. Pollution refers to emission of carbon dioxide (CO_2), nitrogen oxides (NO_x), and fine dust particles (PM_{10}). Sulphur emissions were not reported. Several definitions were applied for congestion, such as: (1) increased travel time; and (2) length and duration of traffic jams on national motorways. Congestion can be regarded as both an external effect as well as a negative internal driver for transport. The development of the total transport performance on the Dutch motorways is indicated in Figure 3-4 (left). Figure 3-4 (right) shows that the level of congestion may stabilise or even decrease on the long term as a result of demographic factors and infrastructure improvements.

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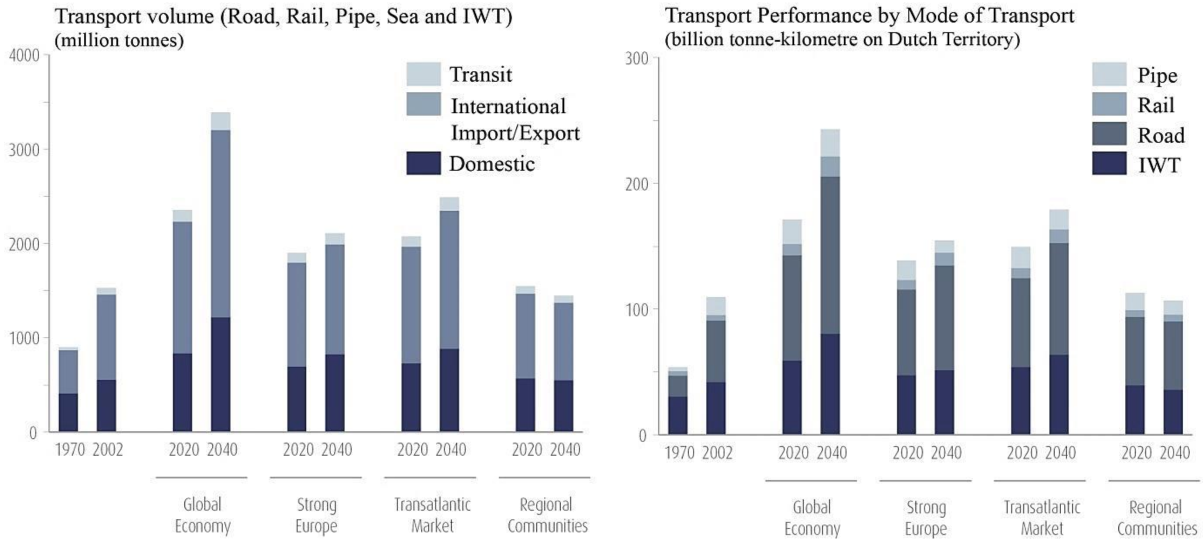
[34] Reference is made to Barrell and Pomerantz (2004), Jiminez-Rodriguez and Sanchez (2004), and Meijermans and Van Brusselen (2005).

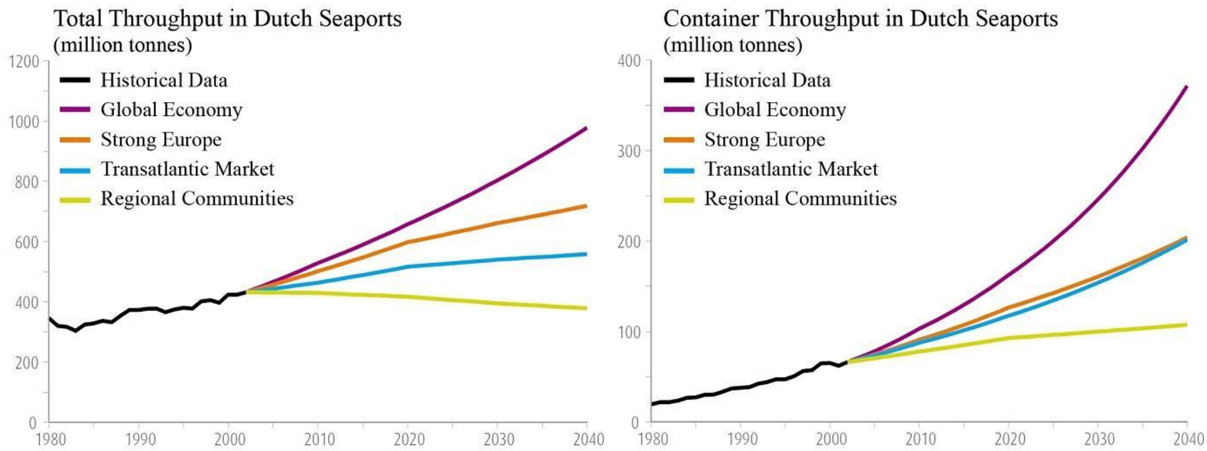
[35] The effect of higher fuel prices on the competitiveness and modal share of IWT can be observed indirectly from the elasticities for IWT, that are reported at the end of Chapter 9 (for which higher fuel prices result in a relative decrease of the cost of barge transport compared to road transport and thereby in an increase of the volumes shipped by IWT) – as well as directly from the reported effect of higher fuel prices on the break-even-distance for intermodal continental container barge transport in Chapter 10).

[36] Transit cargo refers to cargo shipped over national territory, but not loaded or discharged within the country.



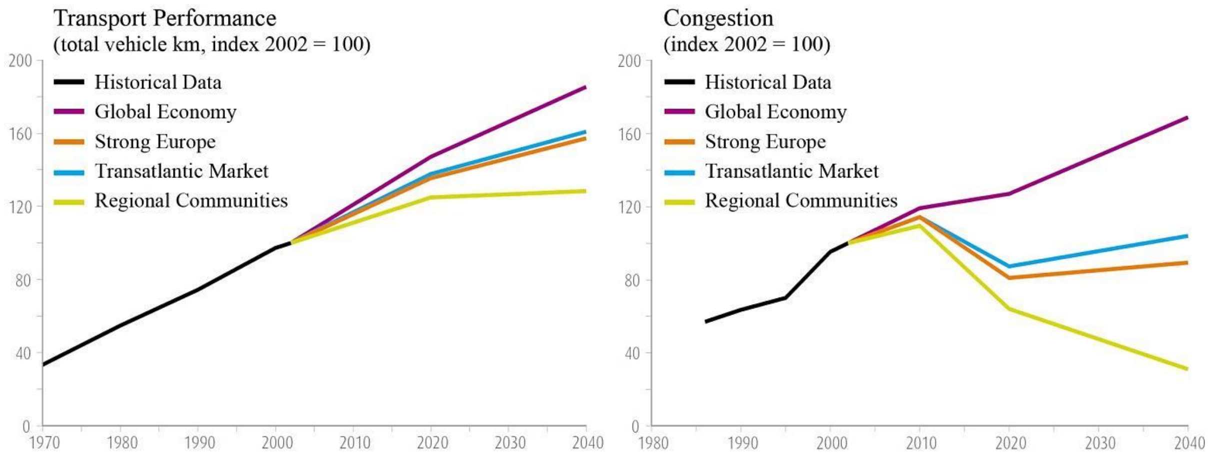
Source: Janssen et al. (2006b, p.151 and 153), translated, adjusted size and layout.

Figure 3-2: Transport Volumes and Performance in the WLO Study



Source: Janssen et al. (2006b, p.149 and 150), translated, adjusted size and layout.

Figure 3-3: Total Throughput for Dutch Seaports in the WLO Study



Source: Janssen et al. (2006b, p.155-156), translated, adjusted size and layout.

Figure 3-4: Transport Performance and Congestion in the WLO Study

3.3 German Transport Scenario up to the year 2050

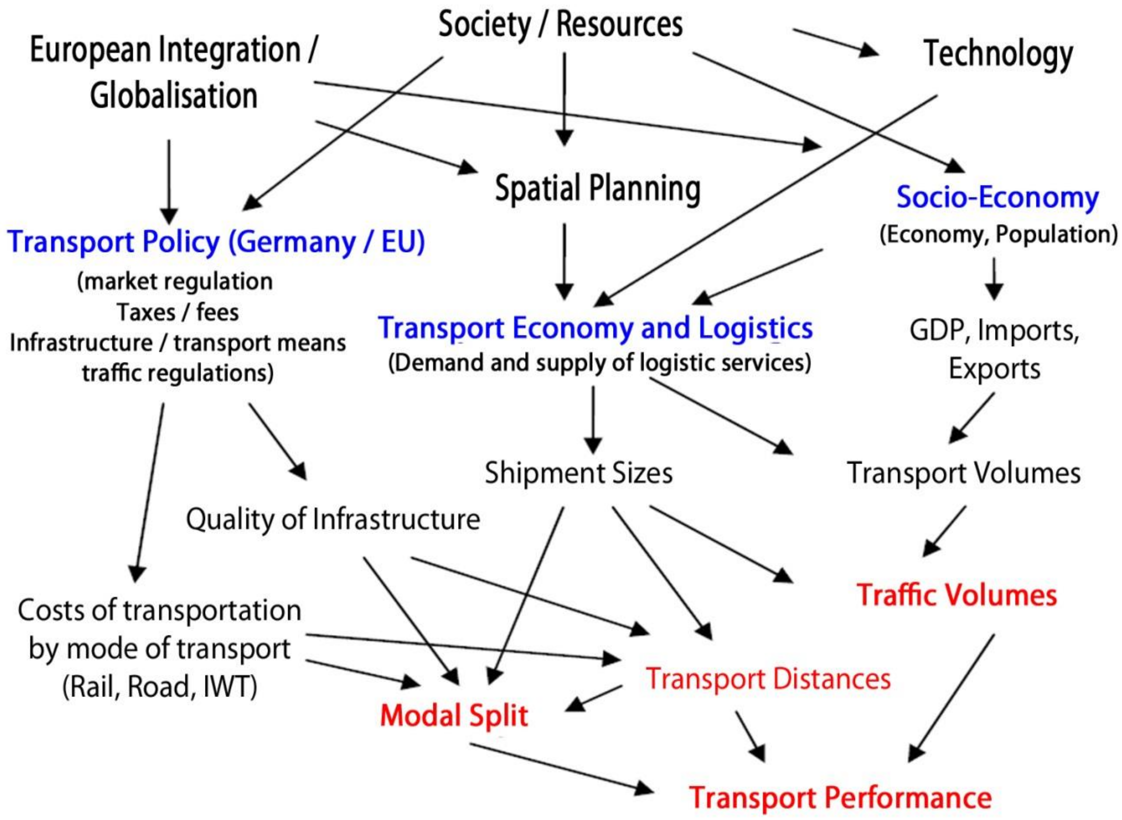
Ickert et al. (2007) developed a long term scenario for German freight transport up to the year 2050, that was used for the preparation of a *'Masterplan for goods transport and logistics'* by the German *'Federal Department of Transport, Construction, and Urban Development'*[37].

3.3.1 Identified scenarios

The German transport study provides a single forecast for the most likely development of German freight transport towards the year 2050, that is based on extrapolation of historical trends and expert judgement. However, due to the uncertain nature of very long term forecasts the word *'forecast'* was avoided and the forecast was presented as *'a possible scenario'*. The study considers two distinct time periods to deal with changes to fundamental drivers over time. The applied time periods range from 2005 to 2030 and from 2030 to 2050[38].

3.3.2 Applied methodology

For the development of this scenario a conceptual framework was used that combines the effects of four decisive factors into three major scenario drivers (see Figure 3-5).



Source: Ickert et al. (2007, p.18), translated.

Figure 3-5: Conceptual Model applied in the German Transport Study

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[37] In German: 'Bundesministerium für Verkehr, Bau, und Stadtentwicklung' (BMVBS).

[38] Note that the applied time periods are chosen in line with the expected downswing and upswing periods of the very long Kondratieff waves that will be discussed in Chapter 4.

The four decisive factors relate to: (1) European integration and globalisation; (2) societal changes related to future constraints on resources (i.e. energy, water, land use, and environmental impact); (3) spatial planning; and (4) technological developments. The main drivers are: (I) socio-economic developments, (II) transport policy, and (III) transport economic and logistical trends. On the basis of the identified drivers the overall transport volume (in tonnes) and performance (in tonne kilometre) for a number of trade relations (domestic, export, import, and transit), modes of transport (road, rail, IWT, and pipeline), and types of cargo (10 one digit NSTR[39] categories) were defined.

3.3.3 Scenario drivers

The German scenario is developed around the following three main drivers:

- Socio-economic developments (population, economy, and trade);
- European as well as German transport policies;
- Transport economic and logistical developments.

Each driver is applied in a different part of the model. Socio-economic developments are used to estimate the total demand for freight transport; European and German transport policies are used to define the spatial integration of freight transport; and transport economic and logistical trends are used to define the modal split. European and German transport policies tend to move towards further enhancement of strong interrelated urban areas (at a European level) while at the same time the rural areas will become less populated. This enhances the development of integrated European infrastructure-, transport- and trade networks, that finally result in an increased average transport distance. The main transport economic and logistical trends indicate an enhanced focus on environmentally friendly modes and means of transport (e.g. by internalising external costs) as well as an increased share of intermodal container transport. It was noticed that road transport emissions were reduced considerably over the past few decades while other modes of transport are still lagging behind. Road transport is now relatively clean, but over the next decades rail- and inland waterway transport may bridge the gap and improve their performance vis-à-vis road transport. Rail transport is expected to gain from ongoing harmonization of the rail system and use of multi-system locomotives. Climate change may have a negative effect on IWT due to an increased variation in water levels.

3.3.4 Scenario output

The scenario output provides detailed information on the anticipated transport volumes (in tonnes) and performance (in tonne kilometres) for each of the four trade relations, four modes of transport, and ten different NSTR commodity classes. Table 3-1 and Table 3-2 provide an aggregated summary of the results (in which the commodity details are summarised).

On the basis of the presented scenario output it can be concluded that the total transport volumes are expected to increase from 3.7 billion tonnes in 2005 to 5.5 billion tonnes in 2050. The total transport performance over the same period is expected to double, from almost 600 billion tonne kilometres to over 1,200 billion tonne kilometres. Domestic demand for freight transport flattens after 2030 while international trade remains a strong driver for international freight transport. Transport distances are increased due to an ongoing integration of the EU. Growth of transport performance is therefore stronger than growth in transport volumes.

[39] The *'Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée'*, short *'NSTR'* is a commonly used classification system for the registration of imported and exported goods.

Table 3-1: Total Transport Volumes reported by the German Transport Study

Volume (million tonnes)	1995	2000	2005	2010	2020	2030	2040	2050
Domestic	3,446	3,198	2,911	2,997	3,266	3,442	3,444	3,497
Export	201	244	290	349	413	480	546	640
Import	331	356	399	469	559	644	759	889
Transit	58	88	127	184	265	331	391	442
Total	4,016	3,886	3,727	3,999	4,503	4,897	5,140	5,468
Road	83.3%	83.5%	82.5%	82.4%	82.8%	82.4%	81.7%	81.1%
Rail	8.6%	8.0%	8.5%	8.8%	8.9%	9.3%	10.0%	10.7%
IWT	5.9%	6.2%	6.4%	6.4%	6.3%	6.4%	6.5%	6.5%
Pipeline	2.2%	2.3%	2.6%	2.4%	2.0%	1.9%	1.8%	1.7%

Source: Ickert et al. (2007, p.102 and p.104).

Table 3-2: Total Transport Performance reported by the German Transport Study

Performance (billion tkm)	1995	2000	2005	2010	2020	2030	2040	2050
Domestic	261	282	298	333	394	439	462	487
Export	58	76	87	106	128	151	173	204
Import	79	99	112	133	163	196	226	267
Transit	41	63	83	113	158	196	231	260
Total	439	520	580	685	843	982	1,092	1,218
Road	64.9%	68.4%	69.7%	70.6%	71.8%	72.0%	71.8%	71.6%
Rail	17.1%	15.9%	16.4%	16.7%	16.9%	17.3%	18.0%	18.7%
IWT	14.6%	12.8%	11.0%	10.2%	9.3%	8.9%	8.6%	8.2%
Pipeline	3.4%	2.9%	2.9%	2.5%	2.0%	1.8%	1.6%	1.5%

Source: Ickert et al. (2007, p.118 and p.120).

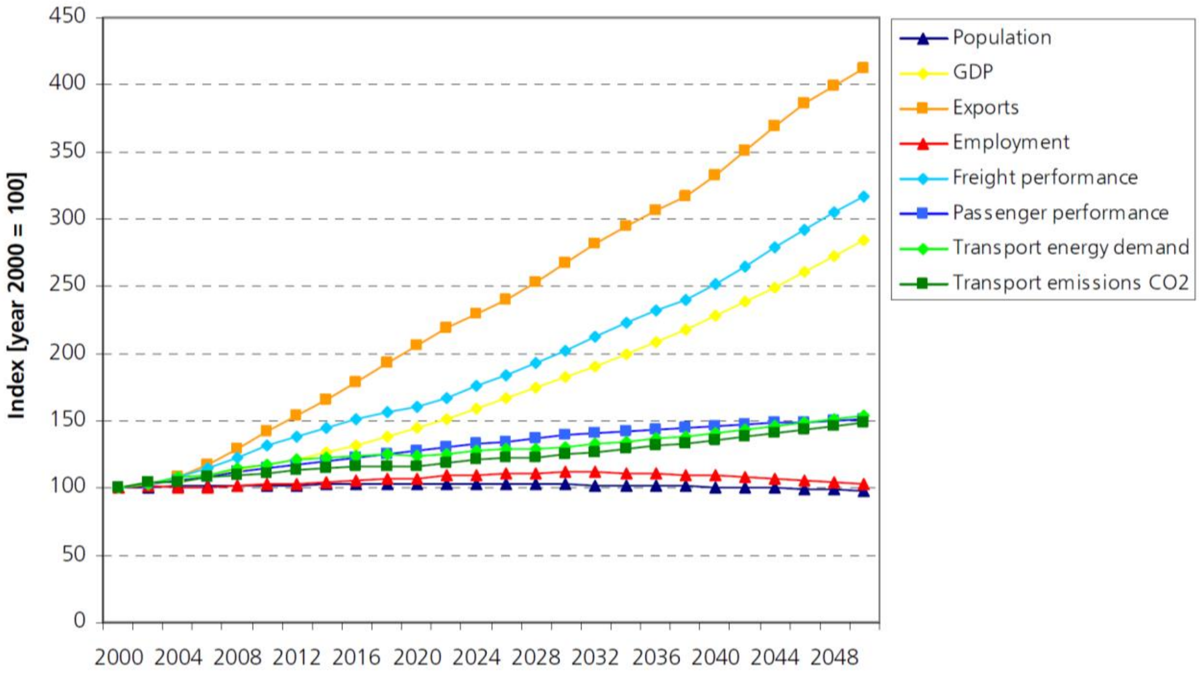
A moderate modal shift is expected. The railway sector is likely to gain most from trends in transport and logistics. Both transport volume and performance are expected to gain 2% point market share in the period from 2005 to 2050. Measured in tonnes the road sector will lose about 1½% point market share due to a decrease in domestic transport. This effect is however countered by an increase in the average transport distance. The overall market share measured in tonne kilometre therefore increases by 2% points. The market share of IWT measured in tonnes remains quite stable throughout the scenario, but IWT is expected to lose market share in tonne kilometres as it hardly benefits from the increased transport distances.

3.4 European TRIAS Scenario up to the year 2050

The TRIAS study was undertaken to develop a methodology for evaluating strategies to reduce greenhouse gas and noxious emissions from transport based on the trilogy (TRIAS) of transport, technology, and energy developments. It applies an integrated model approach for assessing environmental-, economic-, and social impacts of proposed policies. The project was executed by four commercial partners and co-funded by the European Commission DG Research (Schade et al., 2008).

3.4.1 Identified scenarios

The TRIAS study consist of a baseline scenario and eight policy scenarios. The baseline scenario assumes a business-as-usual situation in which transport technology remains focused on the use of conventional fuels and in which biofuels are slowly introduced into the transport market. The main drivers and outcomes of interest for the baseline scenario are reported as indices of the base year 2000 (see Figure 3-6).



Source: Schade et al. (2008, p.31).

Figure 3-6: Overview of Baseline Scenario for EU27 in the TRAIS Study

The eight different policy scenarios either foster accelerated market penetration of biofuels, hydrogen, or both biofuels and hydrogen. The scenarios include subsidies on biofuels and hydrogen, carbon taxes, and additional measures such as biofuel quotas, CO_2 emission limits for cars, and policies enhancing the EU to become a first mover for hydrogen in the transport sector. The output of the policy scenarios is reported as a variation to the baseline scenario.

The structure of the TRIAS project differs from that of a standard scenario study as it does not provide a comprehensive forward view on the basis of a range of exogenous scenarios (such as for population[40] and economic output), but explicitly aims to investigate the effect of specific emission policies on the overall economic output, transport volumes, energy demand, and emission levels. To define the effects of a proposed policy on the economy, the baseline population and GDP scenarios were internalised as endogenous variables (i.e. defined by the model while taking into account the necessary feedback loops) and calibrated against the outcome of a single projection, that was obtained from an external source. The baseline population scenario was calibrated against the EUROSTAT population projection. The baseline economic scenario was calibrated against the baseline scenario of the European ADAM project (Krail et al., 2007, p.32 and p.156).

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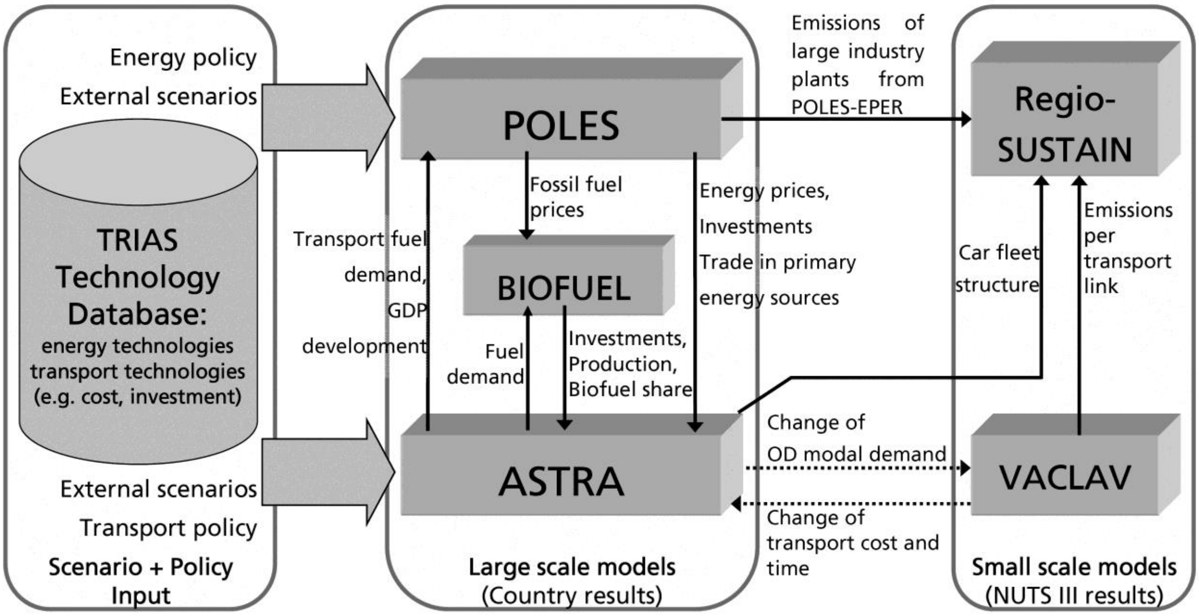
[40] Though one would expect population to be treated as an exogenous variable it was reported to be treated as an endogenous variable. This implies that, for instance, the effects of the proposed policies on the per capita income are assumed to have an effect on the birth rates and thereby on the overall population. The report does however not state how the effects of specific emission policies on the size and composition of the population were taken into account – and Figure 3-8 does also not show any feedback loops that affect the population. It is therefore unclear what relations have been taken into account.

3.4.2 Applied Methodology

The applied methodology is based on a new technology database and an integrated set of established models[41]. The applied model structure is indicated in Figure 3-7.



Source: Schade et al. (2008, p.12).

Figure 3-7: Model Structure applied in the TRIAS Study

The left side of the figure concerns exogenous data on: evolutionary paths of new future technologies; expected socio-economic developments; policies; and potential mega-trends shaping the next 30 to 45 years. The middle section contains the mathematical hart of the model in which the effects of exogenous developments and proposed policies on the energy and transport sector as well as on the economy are defined. The two models on the right side are necessary to define the environmental impact of transport on a small regional scale. The energy sector is jointly covered by the POLES and BIOFUEL model and the transport sector is covered by the ASTRA (Assessment of Transport Strategies) model. The models are highly interrelated. The output of the ASTRA model (e.g. fuel demand) is for instance required by the energy models, while the output of the energy models (e.g. fuel prices) is required by the ASTRA model. The calculation therefore requires many iterations.

The ASTRA model is based on a system dynamics approach (see Figure 3-8). This approach offers sufficient flexibility to incorporate elements of different modelling techniques into a single framework[42]. For that reason it was used as the backbone of the integrated model. The other models (POLES, Regio-SUSTAIN, and VACLAV) were converted into system

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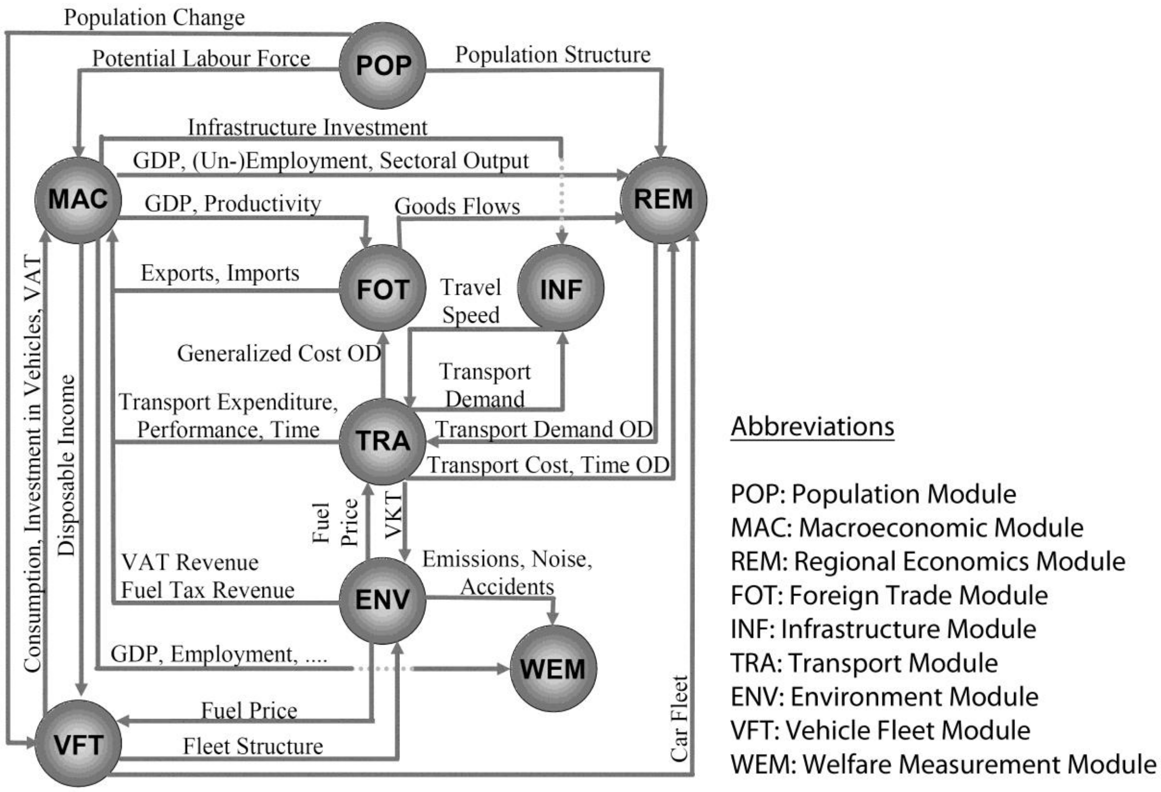
[41] Except for the BIOFUEL model which has been newly developed for the purpose of the TRIAS study.

[42] Krail et al. (2007, p.29): *"various techniques from other modelling approaches outside the system dynamics are borrowed. This includes econometrics to estimate functional relationships between variables for which all relevant data is available. It incorporates input-output analysis to reflect sectoral relationships of economies. It even covers equilibrium approaches as these are frequently used in transport modelling".*

dynamics models in order to deal with the many inter-model feedback loops. In addition a new interface (referred to as the ASTRA-Merger) was developed as an overall layer to manage the complexity of the framework and handle the vast amount of iterations.



Source: Krail et al. (2007, p.31), adjusted layout.

Figure 3-8: Structure of the nine Modules applied in the ASTRA Model

It was indicated by Krail et al. (2007, p.29) that *"The ASTRA model consists of nine modules that are all implemented within one Vensim system dynamics software file. One scenario simulation between 1990 and 2050 with 2-yearly saving intervals of the selected result indicators generates about 800 Mega-Byte of output data for the EU29 countries. The model comprises close to 30 million objects in Vensim. Objects could be variables, which equal to equations, constant data or input. More than 1 million objects are level variables and hence are dynamic variables. Two major types of level variables can be distinguished: delay variables and accumulating variables of which the former stands for the greater share of level variables in the model. About 12.000 time series are used to calibrate ASTRA for the period 1990 until 2000"*.

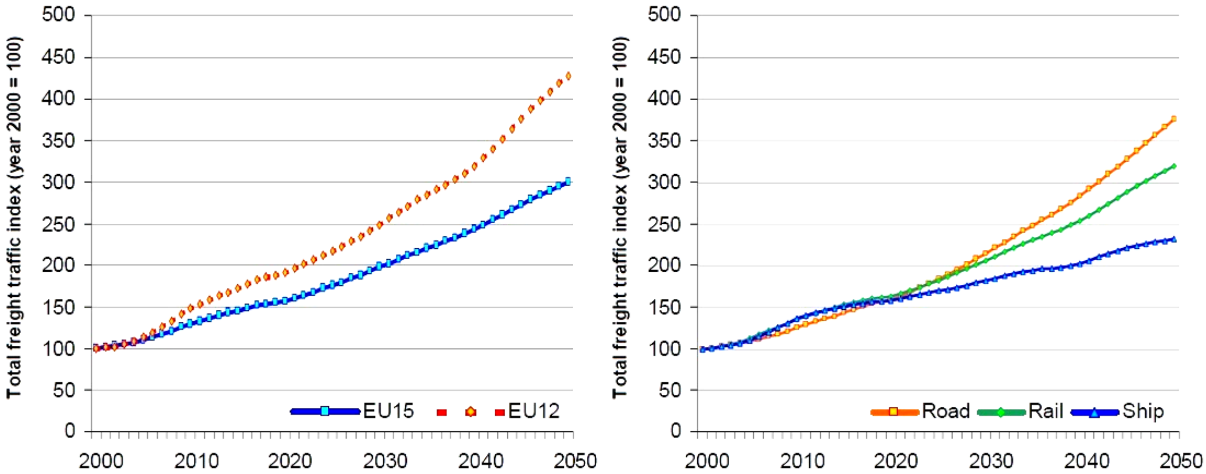
The large size and complex structure of the applied system dynamics modelling approach also has a number of drawbacks that need to be addressed. First of all the high level of detail implies that the model may provide a false sense of accuracy. In addition it is also not transparent which makes it impossible to review the many assumptions made. It is therefore almost impossible to judge the quality of the output of the integrated model system. I consider this a major drawback for the use of such large models.

3.4.3 Scenario drivers

The TRIAS study combines five large models containing many parameters that feed into each other. Due to the applied structure it is not easy to distil the main scenario drivers, but if one places a boundary around the entire set of applied models (and regard the scenario data that were used for the calibration of the models as exogenous input) the main model drivers would probably include: population, GDP, foreign trade, fossil reserves and production techniques, technological development, infrastructure, and policy measures.

3.4.4 Scenario output

The TRIAS modelling framework provides a broad range of output data including socio-economic data (i.e. population, GDP, and trade volumes)[43], traffic and transport volumes by mode of transport, energy demand, and fuel consumption per type of fuel. With respect to freight transport the baseline scenario reports on the total transport performance measured in tonne kilometres. Figure 3-9 presents a breakdown of the results for the EU15 and EU12 (left) as well as for the entire EU27 by mode of transport (right).



Source: Krail et al. (2007, p.164 and p.167), adjusted size and scale.

Figure 3-9: Development of Transport Performance in the TRIAS Baseline Scenario

The baseline scenario assumes a considerable growth of freight transport up to the year 2050. The majority of this growth is related to road and rail transport. For shipping a lower growth rate is expected. The label 'Ship' refers to short sea shipping, it is not clear if IWT is included.

3.4.5 Sensitivity analysis

The TRIAS study includes a sensitivity analysis that addresses the sensitivity of the baseline scenario to major changes of important exogenous variables. The selected variables for which a sensitivity analysis was undertaken are: *the amount of fossil fuel reserves*, *the amount of fossil fuel trade*, *the expected fossil fuel prices*, and *the expected GDP growth of China and India*. For each of these variables a range (or envelope) of possible developments was defined and for each combination of possible developments the outcome of the model was calculated. The structure of the sensitivity analysis is indicated in Figure 3-10.

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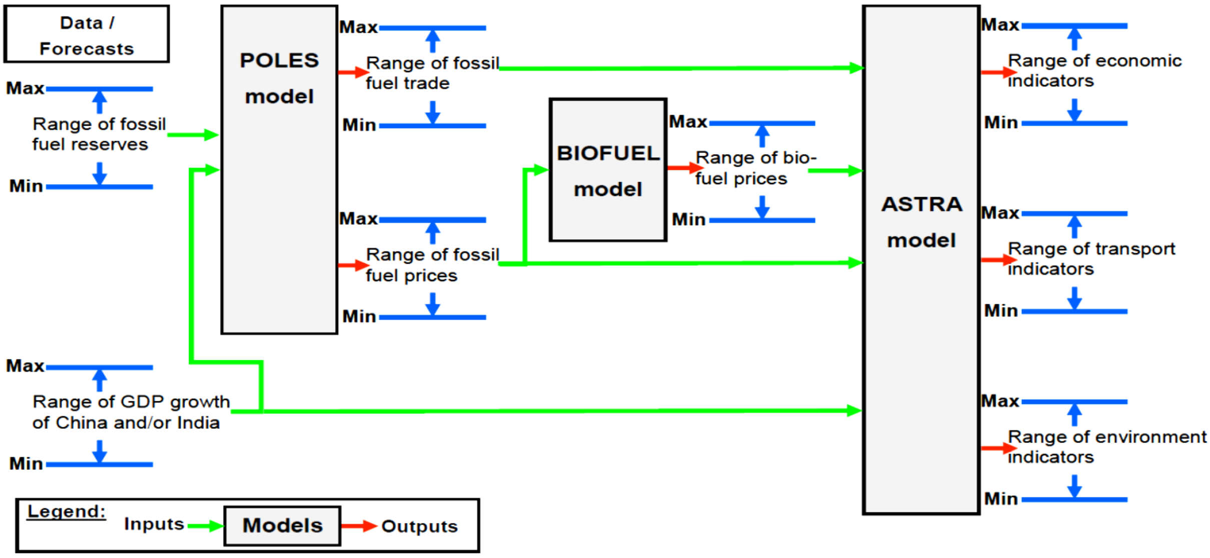
[43] In most transport models the socio-economic data is regarded as exogenous input for the model. The TRIAS study however defined the socio-economic data inside the model as endogenous output.



Source: Schade et al. (2008, p.52).

Figure 3-10: Structure of applied POLES-BIOFUEL-ASTRA Sensitivity Analysis

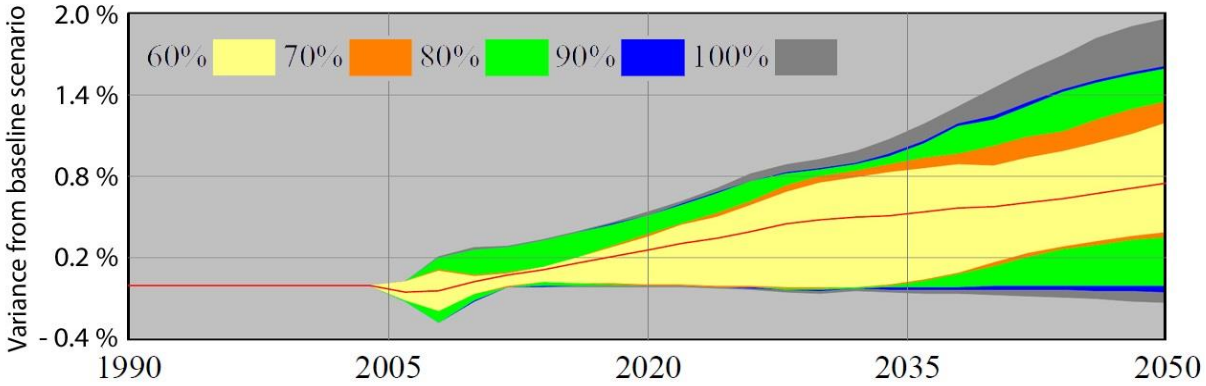
The selected parameters in the sensitivity analysis were varied by a number of discrete steps. Table 3-3 indicates the multiplication factors that were applied to the baseline values of the selected variables. A value of 0.2 for instance refers to 20% of the baseline scenario value.

Table 3-3: Applied variance on the selected Model Assumptions

Parameter	Source	Min	Max	Step	Iterations
GDP growth of China and India	Assumption	0.2	2.2	0.4	6
Import fossil fuels	POLES	0.5	3.5	0.5	7
Fossil fuel prices	POLES	0.5	2.0	0.25	7
Biofuels prices	BIOFUEL	0.8	1.4	0.2	4
Total iterations					1176

Source: Schade et al. (2008, p.55).

The output of the sensitivity analysis is reported as a deviation from the baseline scenario (see Figure 3-11). The coloured lines indicate the probability intervals of the applied sensitivity analysis for the calculated envelope of 1176 discrete futures.



Source: Schade et al. (2008, p.56), adjusted size and layout.

Figure 3-11: Effect of Sensitivity Analysis on overall GDP of the EU27 Countries

It can be concluded that the systematic variation of the selected variables has very little effect (less than 2%) on the overall development of the European GDP. This supports the assumption made in the previous scenarios that the effect of high fuel prices on the level of economic output is rather limited. In fact, the results indicate a small growth of GDP for virtually all possible combinations of variables. Schade et al. (2008, p.56) explains the increased economic output by the fact *"…that higher fossil fuel prices foster investments into energy efficient and/or alternative energy vehicles with higher prices. This also causes second round effects as the vehicle sector then demands also more investments from other sectors"*. The results further indicate that changes to the level of economic growth in China and India are also likely to have a rather small effect on the overall development of the European GDP.

3.5 European TRANSvisions Scenarios up to the year 2050

The report on the European TRANSvisions scenario was prepared for and is issued by the European Commission DG TREN (Petersen et al., 2009). The report is intended to provide technical support in the debate on transport scenarios with a 20 to 40 year time horizon.

3.5.1 Identified scenarios

The TRANSvisions study distinguishes between *forecasting* and *foresight* methods. For the period up to the year 2030 three forecasts were developed with TRANS-TOOLS, a classic four stage transport model that is owned by the European Commission[44]. These forecasts were presented as a *'baseline'*, *'low growth'* and *'high growth'* scenario. It was noticed that forecast models aim to provide a *'scientific view'* of the future by extrapolation of existing trends. The advantage of this approach is that *"The methodology restricts as much as possible the role of subjectivity in the modelling process. Once it has been decided which input data should be used for a modelling exercise, the (transparent) assumptions and algorithms within the model should (in theory at least) provide the same results, independently of whoever is running the model"* (p.73). The disadvantage of this approach is that it *"only considers certain driving forces with respect to future change (the most common being GDP growth and demographic changes such as population growth)"* and that the *"use of a forecasting model implicitly assumes that driving forces not represented in the model have no substantial effect upon the evolution of the future"* (p.74). This implies that detailed forecast models are not intended to take uncertain very long term developments into account.

The TRANSvisions study therefore applies a different approach for the development of a very long term view up to the year 2050. This approach, that is referred to as the foresight approach, deals with the profound lack of information on the state of the future by developing a plausible set of narrative *'storytelling'* scenarios. These scenarios *"deal with so many uncertainties that they can never be true in the strict classical sense as there is no factual evidence to refer to"* (p.93). Therefore *'storyline scenarios'* cannot be judged as right or wrong, they can only be checked on internal consistency. The primary aim of the foresight approach is to *"provide a set of images of the future for the purpose of discussion"* (p.75).

The TRANSvisions study aimed to support the development of effective emission policies. For this reason four policy guiding and four exploratory scenarios were developed in addition

[44] The principles of the classic four stage transport model are discussed in Chapter 11. A further discussion of the TRANS-TOOLS model is provided in Chapter 12.

to a global reference scenario. Two of these policy guiding scenarios were based on forecasting techniques. The other two scenarios were developed by applying backcasting. Backcasting is a technique in which one first defines the final goal and then uses backward reasoning to define the actions that need to be taken in order to reach this goal.

The exploratory scenarios were developed along the axis of: (1) an *'economy-technology-market'* dimension that deals with economic growth, and (2) an *'society-environmental'* dimension that relates to a change of human wellbeing. The very long term scenarios were quantified by means of a high level Meta-Model that was developed in Microsoft EXCEL and Microsoft ACCESS. This so called Meta-Model was calibrated against the aggregated output of the detailed TRANS-TOOLS model. Table 3-4 provides a list of: (1) the scenarios requested by the terms of reference of the TRANSvisions study; (2) the scenarios provided in the report; and (3) the applied quantitative modelling approach.

Table 3-4: Requested and Applied Scenarios in the TRANSvisions Study

Terms of reference request	Scenarios provided in final report	Quantitative analysis means
Business as usual	Global reference scenario	Trans-Tools and Meta-Models
+ Four policy guiding scenarios		
Backcasting climate change 1 -10% CO2 in 2020 and -50% in 2050	Competitive linking to "Induced mobility" (Technological development)	Trans-Tools and Meta-Models
Backcasting climate change 2 -10% CO2 in 2020 and -50% in 2050	Cohesion linking to "Decoupled mobility" (Mobility reduction based on road pricing)	Trans-Tools and Meta-Models
Policy scenario 1 High Growth, more infrastructure	Sustainable Economic development (High economic growth) linking to "Decoupled mobility"	Trans-Tools up to 2030
Policy scenario 2 Low Growth, charges and pricing	Slow economic growth linking to "Reduced mobility"	Trans-Tools up to 2030
+ Four exploratory scenarios		
Exploratory scenario 1 Competitiveness	"Induced mobility" or "Move Alone"	Meta-Models
Exploratory scenario 2 Regulation and behavioural change	"Decoupled mobility" or "Move Together"	Meta-Models
Exploratory scenario 3 Pricing, planning and cohesion	"Reduced mobility" or "Move Less"	Meta-Models
Exploratory scenario 4 Technology failure	"Constrained mobility" or "Stop Moving"	Meta-Models

Source: Petersen et al. (2009, p.24).

3.5.2 Applied methodology

The TRANSvisions study applied a different approach for the 20 year period up to the year 2030 and the 40 year period up to the year 2050. The long term scenarios up to the year 2030 were quantified with the rather detailed TRANS-TOOLS model, that provides a forecast of the transport volumes at the network level. For the 40 year period up to the year 2050 a Meta-Model was developed, that is much simpler to use and does not require complex equilibrium algorithms and sophisticated statistical calibrations. With respect to the applied Meta-Model it was indicated that: *"The model system consists of approximately 300 variables, linked together by growth factors and elasticity functions (based on TRANS-TOOLS as well as other official sources), and feed-backs and constraints"* (p.130). Running a Meta-Model is much faster than running a large transport model. The applied Meta-Model therefore allowed for the simulation of many alternative policy options and many different scenarios for external developments at an aggregated level. It was used for the identification of successful emission policies in the backcasting scenarios as well as for the quantification of the outputs of interest in the exploratory scenarios.

3.5.3 Scenario drivers

Petersen et al. (2009) distinguish between *external*-, *internal*-, and *policy* drivers. This approach differs from the approach applied in the Dutch WLO scenarios.

External drivers relate to developments outside the transport sector, such as: *demographic change*, *economic development*, *energy supply*, *technology development*, and *social change*. From a demographic point of view Europe is aging. This puts pressure on the labour force. To substitute the missing work force the age of retirement is expected to increase. In addition immigration from outside Europe can be expected. Demographic changes affect the economy as *“economic development is linked to factors such as population development (particularly development of working age population), world trade, labour productivity and capital formation”* (p.29). Economic output (i.e. GDP), trade, and globalisation can be regarded as the main drivers for the level of freight transport. In addition it was argued that decoupling of freight transport and economic output can be expected. For this reason decreasing GDP elasticities for freight transport were applied. High energy price levels are expected to have little effect on the overall transport performance, but they do enhance the development fuel efficient technologies and foster economies of scale.

Internal drivers relate to the development of the transport sector itself. They include: *available infrastructure*, *new vehicles and fuel types*, *congestion*, and *transport impact on environment and society*. Most of the EU’s future transport infrastructure is already in place – or at least in the planning stage. Road networks, rail networks, airports, and ports have been constructed over a long period of time. Existing (and planned) infrastructure will remain the backbone for transport services in the future. Road transport remains the most flexible mode of transport for both domestic as well as international transport. In rail transport there are problems with interoperability. However the European rail policy aims at sending a train across Europe with the same locomotive, the same driver, and without unnecessary stops at the borders. The introduction of the container has already revolutionized freight transport, but still a further increase in economies of scale and density can be expected. This results in larger shipments at lower costs. The impacts of transport on the environment and the European society are referred to as externalities. Externalities include noise pollution, congestion, emissions, accidents, visual impact, and inability to use land for other purposes. Congestion occurs where vehicles compete for scarce capacity. Adding additional infrastructure is not always a good solution, because release of suppressed demand may counter the measures taken. In that case pricing can be considered as an alternative option. Once pricing mechanisms are in place it is not unlikely that they will also be used to price for externalities.

Policy drivers take into account the present and anticipated future development of global and EU policies on transport. They include issues like: *the enlargement of the EU*, *EU transport policies*, and *international policies with respect to climate change and security issues*. Future policies are likely to aim for sustainable economic-, environmental-, and social developments. The further enlargement of the EU has a direct effect on the level of transport. EU transport policies aim at cohesion and integration of the European infrastructure. Climate policies may impose far reaching restrictions on greenhouse gas emissions and mobility (possibly even by imposing quotas). Security issues may erect new barriers to transport.

Petersen et al. (2009) identified the main drivers and their impact on the transport system. The identified drivers for freight transport are listed in Table 3-5.

Table 3-5: Main Drivers for Freight Transport

Driver	Sub driver	Impact on freight transport
Population	Size	Level of transport by sector
Economy	Macro-economic development	Level of transport
	Productivity by sector	Level of transport by sector, mode choice
	Logistics	Mode choice, trip distance
	Trade	Level of transport by sector, distribution by country, mode choice
	Globalisation	Level of transport by sector, mode choice, trip distance
Social change	Sustainable consumption	Change in transport by sector
Energy	Energy price	Level of transport, mode choice, trip distance
	Availability of fuel	Level of transport
Technology	New and improved transport modes	Mode choice
	ICT	Trip distance
Infrastructure	Improved accessibility	Mode choice, transport distance
	Congestion	Mode choice, route choice, transport distance
	Interoperability	Mode choice, route choice
Environment	Internalisation of external costs	Mode choice, route choice, transport distance, change to more clean transport modes.
Policy	Enlargement (of the EU)	Level of transport, trip frequency, transport distance, mode choice.
	Security	Mode choice

Source: Petersen et al. (2009, p.67-68).

The impacts for the various drivers were defined as:

- Level of transport: indicates that the total transport level in tonnes in the European Union is affected by the driver;
- Level of transport by sector: indicates that the total transport level of a certain economic sector in tonnes in the European Union is affected by the driver;
- Trip frequency: indicates that the number of tonnes carried per trip (i.e. the average parcel size of the shipments) is affected by the driver;
- Mode choice: indicates that the choice of the transport mode is affected by the driver;
- Route choice: indicates that the choice of route is affected by the driver;
- Trip/transport distance: indicates that the transport distance is affected by the driver.

3.5.4 Scenario output

The applied transport indicators were reported to be consistent with the data in the document *'EU Energy and Transport in Figures: Pocketbook 2007/2008'*. The main indicators for the level of transport are the annual *freight tonne-kilometres* and the annual *passenger-kilometres*. The main indicators for the economic-, environmental-, and social development of the scenarios are: (1) the increase in GDP measured as a percentage increase over a longer period; (2) the emission of carbon dioxide (CO_2) measured in tonnes per year; and (3) the number of road accident fatalities measured in deaths per year.

Table 3-6 shows the main input and output of the TRANS-TOOLS model. Freight transport (measured in tonne kilometre excluding short sea shipping) is expected to increase by 32% up to the year 2020 and by 50% up to the year 2030 compared to the base year 2005. The low and high scenarios show an increase by respectively 15% and 62% up to the year 2030.

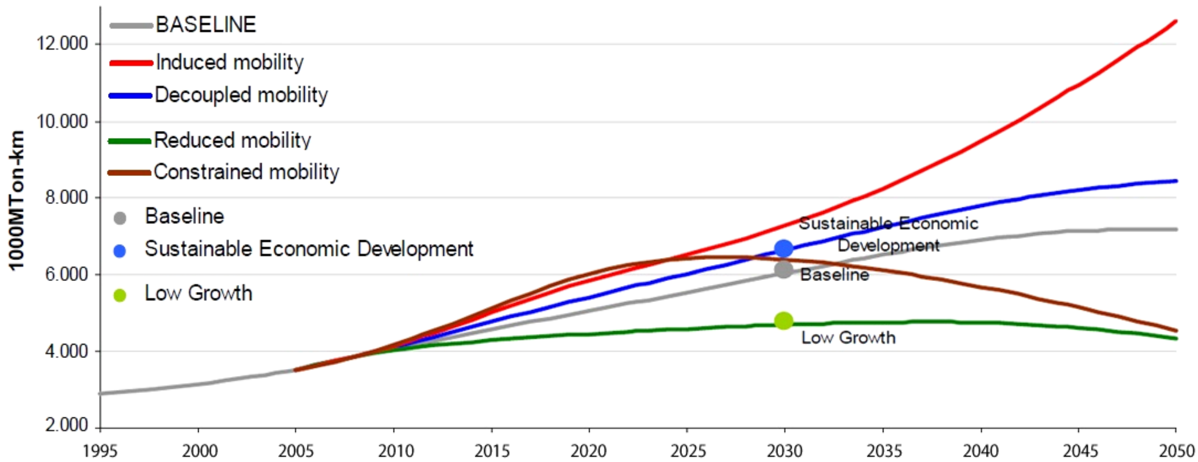
Table 3-6: Main Input to and Output from the TRANS-TOOLS Model

Main scenario indicators for EU27	Real 2005	Base 2020	Low 2030	Base 2030	High 2030
GDP increase compared to year 2005 output*	N/A	38.6%	20.1%	61.4%	77.4%
Freight inside EU27 in billion tkm excluding short sea; year 2005 index.	2288 100	3020 132	2624 115	3429 150	3709 162
Passenger inside EU27 in billion km for car and intercity rail; year 2005 index.	4889 100	5956 122	5344 109	6746 138	7565 155
CO_2 from land transport in million tonnes; year 2005 index.	560 100	634 113	534 95	705 126	774 138
Road accidents in thousands of fatalities; 2005 index.	41.6 100	29.4 129	10.6 175	12.7 169	13.7 167

Note: *Input to TRANS-TOOLS model.

Source: Petersen et al. (2009, p.113), reduced content.

The Meta-Models were developed for the extension of the time horizon up to the year 2050. Since the applied methodology differs from the TRANS-TOOLS model, the scenarios follow a different path. In addition the values reported for the TRANS-TOOLS model exclude short sea shipping while the reported values for the Meta-Models include short sea shipping. Figure 3-12 shows the freight volumes for all modes of transport inside the EU27 in tonne kilometres (i.e. for transport with an origin and/or destination that is located within the EU27).



Source: Petersen et al. (2009, p.134), adjusted size and layout.

Figure 3-12: Total Freight Transport (including Short Sea Shipping) inside the EU27

The three marked dots refer to the low-, medium-, and high estimates of TRANS-TOOLS model. These dots were used to calibrate the Meta-Model. They were linked to the baseline-, decoupled-, and reduced mobility scenarios. For the baseline scenario a 90% increase is expected over the period from the year 2005 to the year 2050. The anticipated growth in the reduced- and induced mobility scenarios is respectively 12% and 262%. It can therefore be observed that the transport performance differs considerably among the various scenarios.

3.6 Lessons learned from the analysed Scenario Studies

This section combines the lessons learned from the four scenario studies that were analysed in this chapter. In line with the previous sections it will address the: *identified scenarios*, *applied methodology*, *main scenario driv*ers, and *relevant output parameters*.

3.6.1 Identified scenarios

The analysed scenario studies dealt with scenarios in a different way. The Dutch WLO study contains four different scenarios that are shaped around two key drivers being: (1) the extent to which nations and international trade blocks cooperate, and (2) the way governments will balance between market forces and a strong public sector. The German study concerned a single forecast towards the year 2050, that was presented as *'a possible scenario'* in order to emphasise the uncertain nature of the forecast. The European TRIAS study aimed to develop a tool to evaluate the effects of proposed emission policies on the economy, the transport system, and the environment compared to a baseline scenario. The TRANSvisions study distinguished between forecasting and foresight methods. For the period up to the year 2030 three forecasts were developed. These forecasts were presented as a *'baseline'*, *'low growth'* and *'high growth'* scenario. For the period up to the year 2050 a number of plausible scenarios was developed by applying foresight methods. The approach of the Dutch WLO scenarios, in which different scenarios are shaped around a number of key drivers, will also be used for the development of the Shipping Scenarios in Chapter 13.

3.6.2 Applied methodology

The Dutch WLO scenarios were quantified by a chain of linked models in which the output of the high level models was used as input to the more specific models. Unnecessary complexity was omitted by avoiding feedback loops between these models. The German study applied different scenario drivers for the period up the year 2030 and the period thereafter up to the year 2050. The TRIAS study applied a comprehensive system dynamics modelling approach that contains nine modules in which millions of variables are linked together to define the effects of proposed emission policies on the output of the system up to the year 2050. The TRANSvisions study made a clear distinction between, what they refer to as, the *'forecasting'* and *'foresight'* approach. The scenarios up to the year 2030 were quantified by means of a classic four stage transport forecast model named TRANS-TOOLS. The plausible storyline scenarios up to the year 2050 were quantified by means of a so called Meta-Model, that contains only a relatively small number of variables and is much easier to run than the far more detailed TRANS-TOOLS model. In line with the TRANSvisions study I would argue that a different modelling approach is required for the development of long term and very long term projections. In general, the farther one looks ahead, the less detail one can take into account in the analysis. This implies that very long term transport models need to be developed at a higher level of aggregation than their long term counterparts.

With respect to the methodology applied in the TRANSvisions study it should be noted that the shift from forecasting to foresight also implies a shift from a bottom-up towards a top-down approach. The forecasting approach provides a detailed view of the developments at the network level, while the foresight approach concerns the development of the general trend at a much higher level of aggregation. Meta-Models are not intended to develop detailed long term projections at the network level. However, in case detailed projections are required one can still obtain an order of magnitude estimate by imposing the general trend onto the local situation (e.g. by taking a certain base year and applying a growth factor). This approach was for instance applied in the TRIAS study where the transport performance was first defined on a country level and thereafter imposed onto the local NUTS 3 level[45]. A similar approach will be suggested in the outline of the proposed very long term transport model in Chapter 11.

3.6.3 Scenario drivers

The Dutch WLO study distinguishes between external- and internal (or policy) drivers. According to this definition external drivers lie outside the political sphere of influence, while internal drivers can be affected by the policy maker. The TRANSvisions study applied a different definition. It distinguishes between external-, internal- and policy drivers. According to this definition external drivers are related to developments outside the transport sector such as: demographic change, economic development, energy supply, technology development and social change; internal drivers are related to developments of the transport sector itself such as: available infrastructure, new vehicles and fuel types, congestion, and transport impact on environment and society; and policy drivers take into account the present and anticipated effects of global and EU policies on transport such as: enlargement of the EU, EU transport policy, and policies related to climate change and security. One should therefore be aware that different definitions are applied in transport scenario studies. For the development of the proposed policy framework in Chapter 6, use will be made of the definition as applied in the Dutch WLO study, that distinguishes between external drivers and (internal) policy drivers.

The level of transport is driven by: the size of the population, the economic-output (i.e. GDP) of the region, trade volumes, globalisation, European integration, energy price levels and availability of fuel. Economic output, but also trade volumes, appear to be the most important drivers for the level of transport, though decoupling of economic output and freight transport can be expected. Some variables such as the size of the labour population and the overall trade volumes are closely related to economic output. Trade volumes depend on the size and openness of the economy under consideration. The latter is amongst others a function of globalisation and European integration. High fuel and energy prices are not likely to have much effect on the overall level of economic output and consequently also not on the overall level of transport, but they do affect the relative cost levels and the competitiveness of the inland transport modes and thereby the modal split. In a similar way environmental policies can be expected to enhance a shift towards cleaner modes and means of transport. In line with these insights the overall transport projections of Chapter 7 will only take the socio-economic scenarios, trade scenarios, and effects of decoupling into account. The more specific aspects, such as the development of fuel and energy prices, the specific fuel consumption of the transport means, and the effects of environmental transport policies, will only be taken into account to define the possible effects on the competitiveness of the various transport modes (in Chapter 10) and the modal split (in Chapter 11).

3.6.4 Scenario output

The output of the transport scenarios is generally related to the overall transport performance measured in tonnes and tonne kilometres. In addition the external effects of transport on the living environment are often also reported. Details regarding the transport performance are generally provided by type of trade (i.e. transit, international import/export, and domestic),

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[45] The NUTS classification (Nomenclature of territorial units for statistics) is a hierarchical system that divides the territory of the European Union into the following three levels: NUTS 1: major socio-economic regions; NUTS 2: basic regions for the application of regional policies; and NUTS 3: small regions for specific diagnoses (See also http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction).

mode of transport (i.e. road, rail, IWT, short sea, and pipeline), transport characteristics (e.g. containerised, non-containerised), and type of cargo (e.g. by NSTR category).

The Dutch WLO scenarios assume the overall transport performance (measured in tonne kilometres) to increase by a factor 1.1 to 2.4 over the period 2002 to 2040; the transport performance in the German transport scenario is assumed to increase by a factor 2.3 over the period 2000 to 2050; the overall transport performance in the TRIAS baseline scenario is expected to grow even faster with a factor 3.2 over the period 2000 to 2050; and finally the Meta-Models applied in the TRANSvisions study assume a growth by a factor 1.1 to 2.6 over the period 2005-2050. On the basis of these numbers it can be concluded that the analysed transport scenarios roughly assume the transport performance (measured in tonne kilometres) to grow by a factor 1 to 3 over the first half of the 21st century.

3.7 Reflection on the Applied Methodology and Scenario Input

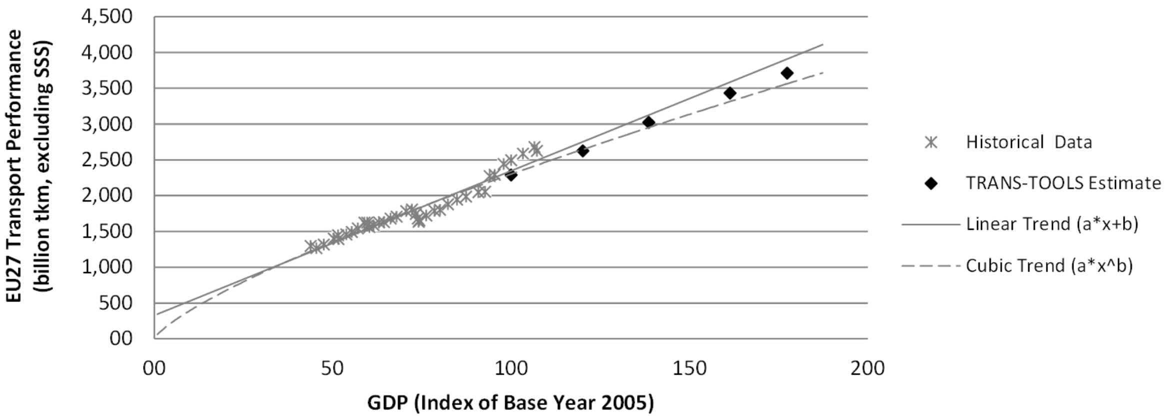
The nature of forward looking projections is such that ex-ante validation of the output by means of obtaining additional sample data is not possible. One can only judge the quality of a scenario quantification by analysing the applied methodology and input data. This section addresses my concerns with the methodology applied for the modelling of (very) long term effects as well as with the applied scenario input.

3.7.1 Concerning the level of detail applied in the transport models

To be confident about the output of an applied transport model one should be confident about applied methodology. In this respect it should be noted that I am concerned about the large amount of detail taken into consideration in some of the models. I think that there is a trade-off between the anticipated time horizon and the amount of detail that can be taken into account. For highly aggregated issues, such as the overall size of the population or the total economic output in a large region (e.g. Western Europe) it may still be possible to develop a very long term forecast with a time horizon over 30 or even 50 years ahead, but this does not hold in general. The more detailed the aspect under consideration the less far one can look ahead. Detailed aspects, such as the development of fuel prices, are for instance very hard (if not impossible) to forecast more than a few years ahead.

Despite the fact that details on, for instance, fuel prices are very hard to forecast they are still used as input in some of the applied transport models. *The TRIAS model for instance defined the investments in biofuel production on the basis of fuel demand and fossil fuel price levels. In the next step the investments in biofuels were used to estimate the production of biofuels. The biofuel production reduces the demand for fossil fuels. This once again affects the fossil fuel price (hence the circle is closed, next iteration).* I question the validity of using detailed models for long- and very long term projections. Modelling variables that are too detailed to be forecasted will, in my opinion, only provide a false impression of accuracy.

The analysed scenarios were generally quantified by large and complex models that require many causal relations and huge amounts of data. I question if the vast amount of detail in these models will lead to more accurate estimates. Adding some additional variables may initially improve the model results, but at a certain point the models reach a stage in which they become more detailed, but not necessarily more accurate. In addition it is also a waste of effort to develop models that are much more complicated than would be necessary for the purpose under consideration. The estimate of the total transport performance derived by the TRANS-TOOLS model in the TRANSvisions study could have, for instance, also been obtained from a simple one variable relation to the GDP (see Figure 3-13).



Source: Historical Data: Database of Appendix A; TRANS-TOOLS Estimates: Table 3-6.

Figure 3-13 Comparison of Historical Trend and TRANS-TOOLS Estimate

According to Lee (1973, p.175) *"Probably the most important attribute any model should have is transparency. It should be readily understandable to any potential user with a reasonable investment of efforts. "Black Box" models will never have an impact on policy other than possibly through mystique, and this will be short lived and self-defeating. A transparent model is still about as likely to be wrong, but at least concerned persons can investigate the points which they disagree".* Some of the applied transport models have become so large and complex that it is no longer possible to provide an understandable description of the model. In this respect these models have become real 'Black Boxes'.

A possible way to validate the quality of a Black Box model is to compare the aggregated results of the model with the results of a much simpler model that is still understandable. Simple high level comparisons were however not reported and therefore it appears that they are uncommon in practice. In fact, the preparation of the TRANSvisions Meta-Models worked out the other way around as the detailed TRANS-TOOLS model was assumed to be correct and the less detailed Meta-Models were calibrated against the output of the TRANS-TOOLS model. I think this is the wrong way around. Aggregated models should be developed first to serve as an order of magnitude check for larger more detailed models.

The TRANSvisions study indicates that detailed transport models are not suitable for the preparation of very long term transport projections. It was therefore suggested to quantify the very long term scenarios by means of an aggregated Meta-Model, that no longer attempts to provide a detailed forecast at the network level. I fully support this view as I consider it impossible to produce sensible forecasts of detailed issues at a very long time horizon. In this respect the Meta-Model provides an interesting attempt to develop an aggregated long term transport model up to the year 2050. For the quantification of very long term transport scenarios up the year 2100 I think even simpler far more basic models should be applied, that contain only the bare minimum of variables necessary to model the subject. For this reason I will propose a fairly basic forecast approach in Chapter 7.

3.7.2 Concerning the quality of the applied scenario input

To be confident about the quantitative output of the analysed transport scenarios one should also be confident about the applied scenario input for the main drivers of the transport system (i.e. GDP and trade volumes as well as the effects of decoupling). Despite being important, it was not possible to reflect on the applied assumptions concerning the decoupling of transport and economic growth, because almost nothing has been reported on the applied mathematical model relations that were used for the quantification of the scenarios, nor on the underlying assumptions regarding the effects of decoupling. It was nevertheless possible to analyse the socio-economic scenarios that were used as input for the transport projections. Appendix B provides an in depth analysis and reflection on the applied scenario input for the population and working age population, labour participation rate, labour productivity rate, economic output, and trade volumes. This section provides a summary of the main findings.

For the reflection on the applied demographic scenarios I relied on a comparison with other demographic studies. I concluded that the assumptions on the size of the overall population and working age population are in line with other projections, and therefore I consider them quite reasonable. With respect to the size of the labour force I think that the applied assumptions on labour participation may be slightly optimistic in the Dutch and German studies, but I consider this is a minor issue that does not need to be further addressed.

I reflected on the applied labour productivity assumptions by putting them into an historical perspective. I fitted an exponential-, a linear-, and a diminishing trend through 60 years of historical data (for the period from 1950 to 2010). The regression statistics indicate that labour productivity is not likely to remain growing at an exponential rate (i.e. a fixed annual growth percentage). The unexplained variance of the exponential function turned out to be 2½ to 12 times higher than for the linear and diminishing trends (see Appendix B for further details on the applied regression statistics). However, despite the inferior fit of the exponential function, all four analysed scenarios seemed to be developed in line with an exponential trend. This contradicts my empirical findings. I consider it far more likely that labour productivity growth will follow a linear or even a diminishing trend over the next 40 years. As a result I expect the economic projections in all four analysed transport studies to be too optimistic. If I am right, the long term GDP projections of the baseline scenarios for the year 2050 could be typically a factor 1.3 to 1.8 too high.

Trade volumes can be regarded as the mathematical product of the level of economic output (GDP) and the openness of the economy (that is reflected by the trade to GDP factor: trade volume/GDP). Given a stable international geopolitical setting the trade to GDP factor can be expected to remain constant over time. Over the past half century the integration of countries into the European Union and the effects of globalisation resulted in an increased openness of the economy. For this reason the trade volumes have been growing much faster than the GDP. However, the European Union cannot expand much further and the world has now already become a global village. The trade to GDP factor is therefore likely to reach its saturation level (at least for Western Europe), which implies that it will not continue to growth at a much faster rate than the economy. This is realised by the TRIAS study, that assumes the trade to GDP factor to stabilize from about 2020 onwards, but it is not realised in the Dutch and German scenario studies, that still foresee a strong growth of the trade to GDP factor. Assuming that I am right, the long term trade projections of the baseline scenarios for the year 2050 could be typically a factor 1.7 to 2.5 too high.

I am therefore concerned about the economic growth projections that are applied in the four analysed transport studies, because they are apparently based on the assumption of ongoing exponential growth of labour productivity, while my empirical findings show that labour productivity is more likely to follow a linear or even a diminishing trend. The differences between these views are already quite severe for the year 2050, but they will become even larger when looking farther ahead. Given the close relation between the level of economic output (but also trade) and the level of transport (see Figure 3.13 and Chapter 7) one can expect the obtained scenarios to be considerably overestimated. Chapter 4 therefore continues with a discussion on the very long term economic perspective, that addresses the reasons why a different paradigm on economic growth should be adopted.

3.8 Concluding Summary

This chapter addresses the second general sub question (GSQ 2): *"What can be learned from other regional long term transport scenario studies concerning: the use of scenarios, the applied methodology for quantifying scenarios, the main drivers of the transport system, the presented output parameters, and the obtained long term scenario projections?"*. The primary aim of this chapter is to answer the above question by analysing four recent transport scenario studies (i.e. the Dutch WLO scenarios, a German scenario, the European TRIAS scenarios, and the European TRANSvisions scenarios), but in addition it also reflects on two important issues that were encountered with the applied methodology and the applied scenario input.

3.8.1 Conclusions with respect to the general sub question

In response to GSQ 2 I conclude that the analysed scenario studies were generally intended to explore the future and to ex-ante evaluate the effects of proposed policies on the performance of the transport system. Long term transport scenarios with a time horizon of 20 to 30 years can be quantified by detailed transport models that apply forecasting techniques in combination with expert judgement. These models are still able to address the specific development of the transport flows at the network level. For the quantification of scenarios with a longer time horizon up to the year 2050 the use of more aggregated so-called Meta-Models was suggested by the TRANSvisions study. Meta-Models use foresight to address the general trend at a much higher level of aggregation. They no longer indicate the developments at the network level. However, in case a detailed very long term view (or scenario) is required one can still obtain an order of magnitude estimate by imposing the general trend onto the local situation, for instance by taking a certain base year and applying a growth factor to the base year values.

It is common to distinguish between external drivers and policy drivers. External drivers lie outside the range of influence of the policy maker, while policy drivers can be influenced by the policy maker. The level of transport is mainly driven by socio-economic drivers of which economic output (i.e. GDP), but also trade volumes, are considered the most important ones. However, on the long- and very long term decoupling of economic output and transport can be expected. Fuel prices are not expected to have much effect on the overall level of transport, but they do affect the cost structure of transport and thereby the choice for the applied mode of transport (i.e. the modal split). The same holds for technological developments that affect the performance of the transport system. The main policy drivers are related to the level of infrastructure provided, the charges applied for the use of infrastructure, and the charges applied for internalisation of external costs. The drivers that act on the transport system may change over time. A different set of scenario drivers may therefore be applied for the long term period up to the year 2030 and the subsequent period up to the year 2050.

The output of the transport scenarios is generally related to the transport volume in tonnes and the transport performance in tonne kilometres. In addition it is also common to report on the external effects of the transport system such as: noise pollution, congestion, emissions, accidents, visual impact, and inability to use land for other purposes. The analysed scenario studies indicate that the transport performance (measured in tonne kilometres) is expected to grow by roughly a factor 1 to 3 throughout the first half of the 21st century.

3.8.2 Reflection on the applied methodology and scenario input

The nature of forward looking projections is such that ex-ante validation of the output by means of obtaining additional sample data is not possible. The only option to verify the quality of scenario quantifications is to analyse the quality of the applied methodology and the applied input data (e.g. the scenario input). For this reason this chapter concludes with a reflection section on the applied methodology and the applied scenario input.

Concerning the applied methodology

The level of detail in the applied transport models is sometimes very high. Some models contain millions of variables. This makes it impossible to validate the outcome of the models. In this respect some models have become real 'Black Boxes'. A possible way to validate the quality of a Black Box model is to compare the aggregated results of the model with the results of a much simpler model that is still understandable. The estimate of the total transport performance as derived by the TRANS-TOOLS model could have, for instance, also been obtained from a simple one variable relation to the GDP (see Figure 3-13). Simple high level comparisons were however not reported and it therefore appears that they are uncommon in practice. In fact the preparation of the Meta-Model in the TRANSvisions study worked out the other way around, as the detailed TRANS-TOOLS model was assumed to be correct, and the aggregated Meta-Model was calibrated against the output of the TRANS-TOOLS model. I think this is the wrong way around. Aggregated models should be developed first to serve as an order of magnitude check for larger more detailed models.

I consider the level of detail, that is applied in the analysed transport studies, too high for the development of an aggregated very long term view up to the year 2100. The evaluation of very long term policies and external developments up to the year 2100 will require much simpler and far more aggregated models, that only contain a few very important drivers to define the general trend. It appears that these models still need to be developed.

Concerning the applied scenario input data

I aimed to reflect on the scenario input data that was applied for the main transport drivers (i.e. GDP and trade volumes as well as the effects of decoupling). It was however not possible to reflect on the applied assumptions concerning the decoupling of transport and economic growth, because almost nothing has been reported on the underlying assumptions. For this reason I could only reflect on the population and working age population, labour participation, labour productivity, economic output, and trade volumes. With respect to the socio-economic and trade assumptions I concluded that the population- and working age population projections are quite reasonable; that there may be some minor issues with the assumptions on labour participation (that are of minor importance and not worth further discussion); and that there are some major issues with the assumptions on labour productivity, economic output, and trade volumes.

My primary concern is related to the assumed growth of labour productivity. I fitted an exponential-, a linear-, and a diminishing trend through 60 years of historical data and found that labour productivity is not likely to continue its growth at an exponential rate, because the unexplained variance of the exponential trend is generally 2½ to 12 times higher than for the linear and diminishing trends. However, despite the inferior fit of the exponential function all the analysed scenario studies turned out to be developed in line with an exponential trend. I consider it far more likely that the growth of labour productivity will follow a linear or even a diminishing trend. As a result the economic projections in all four analysed scenarios may be too optimistic. Assuming that I am right, the long term GDP projections of the baseline scenarios for the year 2050 could be typically a factor 1.3 to 1.8 too high.

In addition I found that some studies ignore the limits that apply to the relative openness of their economies. Trade volumes cannot simply be assumed to continue to grow at a much faster rate than the economy. This is realised by the TRIAS study, that assumes the trade to GDP factor to stabilize from about 2020 onwards, but it is not realised by the Dutch and German scenario studies, that still foresee a strong growth of the trade to GDP factor. Assuming that I am right, the long term trade projections of the baseline scenarios for the year 2050 could be typically a factor 1.7 to 2.5 too high.

Given the close relation between the levels of economic output (but also trade) and the level of transport one can expect the corresponding scenarios to be considerably overestimated.

3.8.3 Answer to General Sub Question 2

In answer to GSQ 2, I conclude that transport scenarios are generally applied to explore the future and to ex-ante evaluate the effects of proposed policies on the performance of the transport system. Long term transport scenarios up to about 30 years ahead can still be evaluated by rather detailed transport forecast models, while scenarios with a longer time horizon need to be quantified by more aggregated models that consider the trends at a higher level of aggregation. The level of transport can be estimated on the basis of socio-economic drivers, of which economic output (i.e. GDP) and trade volumes are considered the most important ones, but one should be aware that decoupling of economic activities and freight transport is expected to take place on the long term. Fuel prices, technological developments, and environmental policies are not expected to have much effect on the overall level of transport, but they do affect the cost structure of transport and thereby the applied mode of transport (i.e. the modal split). Transport studies generally report on the transport volume in tonnes and the transport performance in tonne kilometres as well as on the external effects of transport. The analysed scenario studies reported a growth of the transport performance (measured in tonne kilometres) by a factor 1 to 3 throughout the first half of the 21st century.

In addition to answering GSQ 2, I also raised two important issues concerning the quality of the applied methodology and the scenario input. First of all I argued that the level of detail in some of the applied models has become so large that the models have become real ‘Black Boxes’, that cannot be verified other than by comparison with simpler models that are still understandable. But such simple models do not yet seem to exist. Secondly, I analysed and reflected on the socio-economic data that was used for the quantification of the transport scenarios. For the year 2050 I concluded that, if I am right, the long term GDP estimates could be typically a factor 1.3 to 1.8 too high, and that the trade volumes could be typically a factor 1.7 to 2.5 too high. Given the close relation between the levels of economic output (but also trade) and the level of transport this implies that the quantifications in the analysed transport studies are also likely to be overestimated.

Literature:

Barrell, R., and O. Pomerantz (2004) *Oil prices and the world economy*. NIESR, discussion paper 242, London.

Bollen, J., T. Manders, M. Mulder (2004) *Four Futures for Energy Markets and Climate Change*, CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands.

Huizinga, F. and B. Smid (2004) *Vier vergezichten op Nederland, Productie, arbeid en sectorstructuur in vier scenario's tot 2040*. Centraal Planbureau, Den Haag.

Ickert, L., U. Matthes, S. Rommerskirchen, E. Weyand, M. Schlesinger, J. Limbers (2007) *Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050*, ProgTrans AG.

Janssen, L.H.J.M., V.R. Okker, and J. Schuur (2006a) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040*, Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau, www.welvaartenleefomgeving.nl/pdf_files/WLO_hoofddocument.pdf

Janssen, L.H.J.M., V.R. Okker, and J. Schuur (2006b) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040; Achtergronddocument*, Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau, www.welvaartenleefomgeving.nl/pdf_files/ WLO_achtergronddocument.pdf

Jiminez-Roderiguez, R., and M. Sanchez (2004) *Oil price shoks and real GDP growth, empirical evidence for some OECD countries*. Working Paper Series, no. 362, European Central Bank, Frankfurt.

Krail M., W. Schade, D. Fiorello, F. Fermi, A. Martino, P. Christidis, B. Schade, J. Purwanto, N. Helfrich, A. Scholz, M. Kraft (2007) *Outlook for Global Transport and Energy Demand.* Deliverable 3 of TRIAS (Sustainable Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Lee, D.B. (1973) *Requim for Large-Scale Models*, Journal of the American Institute of Planners, vol. 30, no. 3, pp. 163-178.

Lejour, A. (2003) *Quantifying Four Scenarios for Europe*, CBP Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands.

MCRIT (2009) *Mobility scenarios towards a postcarbon society – TRANSvisions Task 2 Quantitative Scenarios.* Barcelona, Spain.

Meijermans, E. en P. van Brusselen (2005) *The macroeconomic effects of an oil price shock on the world economy; a simulation with the NIME Model*. Working Paper 6_05, Federal Planning Bureau, Brussels.

Mooij, R. de, and P. Tang (2003) *Four Futures of Europe*, CPB Netherlands Bureau for Economic Policy Analysis, The Hague, The Netherlands.

Petersen, M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, A. Ulied (2009) *TRANSvisions: Report on Transport Scenarios with a 20 and 40 year Horizon, Final Report*, Funded by DG TREN, Copenhagen, Denmark.

Port of Rotterdam Authority (2014) *Port Vision 2030, Port Compass: Direct the future. Start Today*, www.portofrotterdam.com/portcompass.

Schade W, D. Fiorello, J. Köhler, M. Krail, A. Martino, B. Schade, T. Wiesenthal (2008) *Final Report of the TRIAS Project: SIA of Strategies Integrating Transport, Technology and Energy Scenarios.* Deliverable 5of TRIAS (Sustainable Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Schwartz, P. (1991) *The Art of the Long View, Planning for the Future in an Uncertain World*, Doubleday, a division of Bantam Doubleday Dell Publishing Group, Inc., New York.

Van den Akker, J., M. Betsema, T. Oegema, G. Wurpel (2013) *Updating the future: The next steps in becoming the sustainable global port, using scenarios from Limits to Growth*, IMSA Amsterdam, The Netherlands.

Websites:

CPB (accessed: 2011) *Use of even set of scenarios*, [www.cpb.nl/nl/prognoses_algemeen.html]

EU (accessed: 2014) *Explanation of NUTS nomenclature*, [http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction]

Port of Rotterdam (accessed: 2011) *Degree of Containerisation*, [www.portofrotterdam.com]

WLO (accessed: 2011) *Dutch WLO Scenarios*, [www.welvaartenleefomgeving.nl/]

4 The Very Long Term Economic Perspective

"We are moving towards a condition in which economic growth is no longer evident. For us this is something new, but for previous generations – those living in the fifties of the twentieth century and all centuries before – economic growth has never been self-evident. In this respect we are returning to historically more normal times. The age of growth of the second half of the twentieth century was the exception, not the rule."
- Jaap van Duijn (Beyond Growth, 2007, p.198, translated citation and title)

4.1 Introduction

The previous chapter identified economic output (i.e. GDP) as the most important driver for the development of the overall level of transport demand – and raised some concerns with the high economic growth assumptions that are presently applied in transport scenarios. This chapter addresses the third general sub question (GSQ 3): *'What are the main trends and drivers for the very long term development of the world economy (i.e. the main driver of the transport system)?'*. It aims to identify the main trends and drivers of the world economy throughout the 21st century and explains why I think a different paradigm on economic growth should be applied.

Section 4.2 starts with the definition of what I consider the very long term. This is necessary because the definition of *'the very long term'* depends on the inertia of the process under consideration. Section 4.3 introduces the concept of Megatrends, that can be related to fundamental long term processes of transformation with a broad scope and a dramatic impact that take place over a timespan of at least a decade. However, for dealing with very long term developments even longer more fundamental trends and cycles should be considered. Section 4.4 therefore continues with a discussion of the various economic cycles that can be observed in the world economy, of which the about 50 years lasting '*Kondratieff*' cycle is the most relevant for this thesis. Section 4.5 proceeds with a discussion of two very long term trends that are referred to as the *'Secular trend'* and the *'Great Transition'*. The so called *'Secular trend'* refers to the development of the world economy since the Middle Ages and the *'Great Transition'* places the very long term development of the world economy into the broader perspective of an about 400 year lasting transition process that started at the beginning of the Industrial Revolution. I endorse the latter view that takes physical limits to economic growth into account, but it should be noted that this view is not in line with today's mainstream views of ongoing exponential economic growth as adopted in virtually all official long term and very long term scenario studies. Section 4.6 therefore continues with a reflection on the mainstream- and alternative views on economic growth in order to redefine the economic growth paradigm in such a way that it can be applied to the GDP projections of Chapter 7. Section 4.7 contains a concluding summary that provides an answer to GSQ3.

4.2 Definition of the Very Long Term

It is not easy to obtain a clear definition of *'the long term'*. Armstrong (1985, p.5) mentions a few definitions that are applied in forecasting literature: *"long range is the length of time required for all parts of the system to react to a given stimuli [...]; it is anything over 2 years in the future; it's the length of time over which large changes in the environment can be expected"*. DeLurgio (1998, p.749) indicates that there does not exists a universal convention on the length of short-, medium-, and long term developments.

The reason that a universal convention on the length of time does not exist relates to the fact that the perception of time depends on the inertia of the processes under consideration. For infrastructure planning the suggested minimum length of two years makes little sense as the planning horizon can be in the order of 100 years. Longer planning horizons may also be required for other issues such as the effects of climate change. Bruce (2004) even suggests an *"Integrated 1000-year planning"* that forces us to take action in order to be in time to face ultimate threats to survival of humanity and other life on earth. To avoid confusion I will now propose my own unambiguous convention on the length of time that will be further applied throughout this thesis. This convention is indicated in Table 4-1.

Table 4-1: Proposed Convention on the Length of Time

Perspective	Planning Horizon	Planning Issues
Short Term	0-1 year	Day to day operational and business decisions.
Medium Term	1-5 years	Product development, maintenance and replacement.
Long Term	5-30 years	New technology introductions, business concessions.
Very Long Term	30-200 years	Public infrastructure, new generations, shifting. global power, renewable energy, climate change.
Ultra Long Term	200-1.000.000 years	Nuclear waste, human survival.
Ultimate	$1.000.000^{++}$ years	Existence of the solar system, big bang.

The proposed convention considers short term-, medium term-, long term-, very long term-, ultra long term-, and ultimate developments. This thesis will mainly deal with very long term issues of which the planning horizon is defined as 30 to 200 years ahead.

4.3 Megatrends

When considering long term developments it is obvious to look at long term trends. Long term trends are almost invisible in everyday life, but contain a lot of information regarding the direction of our future world. Long term trends are often referred to as *'Megatrends'*. An example of twenty present Megatrends is indicated in Table 4-2.

The term *'Megatrends'* was introduced by Naisbitt (1982, 1990) who wrote two equally named books on this subject. Each book presented ten fundamental driving forces of modern society. In his second book Naisbitt (1990, p.12) indicates that: *"Megatrends do not come and go readily. These large social, economic, political, and technological changes are slow to form, and once in place, they influence us for some time – between seven and ten years, or longer. They have the scope and feel of a decade's worth of change"*. The Oxford English Dictionary defines a Megatrend as *"An important shift in the progress of a society or of any other particular field or activity"*. A more profound discussion on Megatrends is provided by Z-punkt (2008) who describes Megatrends as *"[...] long-term processes of transformation with a broad scope and a dramatic impact"*. Megatrends contain the basic driving forces in our society, which are often so common that one can hardly observe them.

Table 4-2: Twenty most important Megatrend according to Z-punkt

1. **DEMOGRAPHIC CHANGE:** In the West, ageing and shrinking populations; In the developing countries, a baby boom; Increasing migration streams; Demographic shifts.
2. **INDIVIDUALISATION REACHES A NEW STAGE:** Individualism, a global phenomenon; Changing relationship patterns: Few strong, many loose relationships; From mass markets to micro markets; Self-sufficiency and DIY-economics.
3. **HEALTH THRIVES:** Increasing health awareness and higher personal responsibility; Health tech – health style; New foodstuffs (functional food, genetically modified food, novel food); New converging markets (food, pharmaceuticals, drugs, cosmetics).
4. **WOMEN ON THE RISE:** Women are integrated into the working world "Female" soft skills become more important; Participation as market actors: Defining influence on product and service standards Work-life balance.
5. **CULTURAL DIVERSITY:** Plural ways of life between tradition and today; Value systems compete globally; Emergence of hybrid culture.
6. **NEW PATTERNS OF MOBILITY:** Globally, mobility increases; Barriers to mobility increase; Transport infrastructures are upgraded/extended; New vehicle concepts – new drive technologies.
7. **DIGITAL LIFESTYLE:** Web 2.0: New media find their way into our everyday lives; Digital lifestyle: Virtual reality becomes real; Virtual business worlds.
8. **BIOMIMICRY, OR, LEARNING FROM NATURE:** Biology becomes the leading science; Renaissance of bionics; Swarm intelligence: New forms of social organization.
9. **UBIQUITOUS INTELLIGENCE:** IT-revolution continues; Ambient Intelligence: New interfaces, new surfaces; Neuro sciences, artificial intelligence, and robotics; Transparent society: Surveillance and control.
10. **TECHNOLOGY CONVERGENCE:** Information and nanotechnology to be key drivers of convergence; Stimuli in many areas of application (medical science, energy, materials); NBIC-convergence.
11. **GLOBALISATION 2.0:** Shift to Asia and a new role for the West Global strategies, customised to places and regions ; Emergence of a global middle class Globalised Flow of Capital.
12. **KNOWLEDGE-BASED ECONOMY:** Education and learning as a basis; Innovation as a key driver and competition factor; New global knowledge elite – the creative class.
13. **BUSINESS ECOSYSTEMS:** Open systems and networks: Limits of industries, markets, and businesses dissolve; New value-adding chains (customer integration, coopetition); Business Mashups: Interfaces give rise to new markets.
14. **CHANGES IN THE WORK WORLD:** Advances in automation (from the sector of production to the sectors of service and knowledge); Highly flexible working practices (anytime, anywhere); Flexible, interactive work structures.
15. **NEW CONSUMPTION PATTERNS:** The Third World participates in economic wealth (Bottom of the Pyramid); Catch-up luxury in China, India, and Russia; Sustainable consumption in the West (Lifestyle of Health and Sustainability, Eco Chic, Moral Commerce).
16. **ENERGY AND RESOURCE REVERSAL:** Strategic resource scarcities (fossil fuels, freshwater, minerals, metals); Use of alternative sources of energy and renewable resources; Revolution in energy efficiency; Decentralised energy supply.
17. **CLIMATE CHANGE AND ENVIRONMENTAL IMPACTS:** CO_2-discharges and global rise of temperatures; Increase of environmental problems in emerging and developing countries; Clean technologies; Corporate responsibility increases.
18. **URBANISATION:** Megacities grow strongly; Development of adapted infrastructure solutions; New forms of residence, living, and participation.
19. **NEW POLITICAL WORLD ORDER:** China and India join the ranks of world powers; Crisis of Western democracies; Russia's renaissance Africa awakes.
20. **GROWING THREATS TO INTERNATIONAL SECURITY:** Global risk society; Festering cultural conflicts and failed states; Global terrorism; Proliferation of weapons of mass destruction.

Source: Z-punkt (2008, translated).

Z-punkt (2008) noticed that Megatrends differ from normal trends with respect to the:

- Time horizon: Megatrends can be observed over decades. Quantitative, empirically unambiguous indicators are available for the present. They can be projected – with high probabilities – at least 15 years into the future.
- Reach: Megatrends impact comprehensively on all regions, and result in multi-dimensional transformations of all societal subsystems, whether in politics, society, or economy. Their precise features vary according to the region in question.
- Intensity of impact: Megatrends impact powerfully and extensively on all actors, whether it is governments, individuals and their consumption patterns, or corporations and their strategies.

The definitions of Naisbitt and Z-punkt refer to a time span of at least 7-10 and 15 years respectively, but for the evaluation of very long term developments much longer trends need to be considered. Spies (1998) looked at Megatrends that can be related to 50 and 200 year periods. The 50 year periods are linked to the very long term economic cycles of Nikolai Kondratieff. The longer 200 year periods are placed in the perspective of the secular trend over the ages. Both trends will be discussed in the next two sections.

4.4 Economic Cycles

The previous section referred to the existence of long term Kondratieff cycles of which the driving forces can be described by Megatrends. Economic literature addresses various cycles. On the short term these cycles can be daily, weekly, monthly or annual/seasonal. On the medium to long term these cycles are often referred to as business cycles or economic cycles. This section addresses the various medium to very long term cycles in economic literature.

4.4.1 The fixed investment cycle of Clement Juglar (7-11 years)

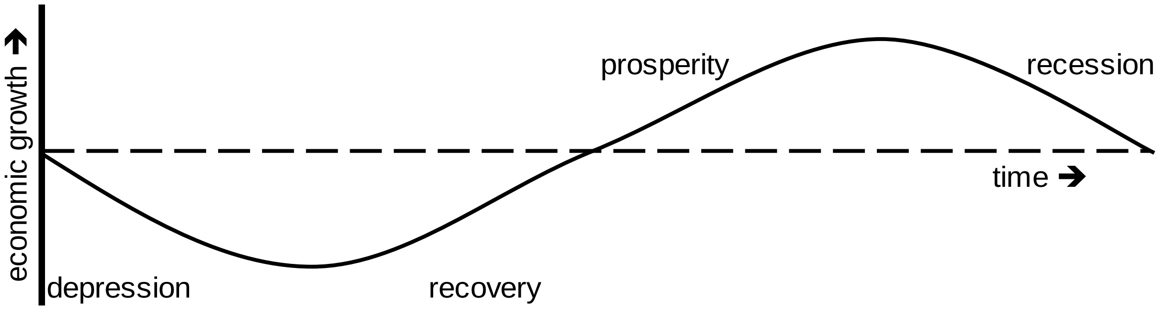
Substantial research has been devoted to economic cycles ever since the Industrial Revolution caused crises. The first breakthrough came from Clement Juglar (1862), who no longer looked at the isolated problem of the crises, but described business cycles as wave motions in which crises followed periods of unsustainable growth and over-speculation. Schumpeter[46] (1954, p.1124) regarded Juglar as the founder of modern business-cycle analysis because (1): *"he was the first to use time-series material (mainly prices, interest rates, and central bank balances) systematically"*, (2): *"having discovered the cycle of roughly 10 years' duration that was most obvious in his material […] he preceded to develop a morphology of it in terms of 'phases' (upgrade, 'explosion,' liquidation)"*, and (3): *"he went on and tried his hand at explanation […] all-important was his diagnosis of the nature of depression […] 'the only cause of depression is prosperity'"*. Schumpeter (1931) argued that Juglar shifted the paradigm towards a new generation: *"The former generations asked: Why do we have a breakdown from time to time? The next ones asked: Why does not economic progress go on smoothly like the growth of a tree, but 'wave-like' in the form of phases of recurring prosperity and depression?"*. Besomi (2005, p.8) provided a profound discussion of Juglar's business cycle mechanism: *"Juglar identified three phases: prosperity, crisis, and liquidation (1862, p. 164), and discussed how they succeed each other. […] during prosperity people become unduly optimistic (1862, pp. 202, 205–6) and start overspeculating. […] Some of these exaggerations and excesses refer to the credit market and the stock exchange, others*

[46] Schumpeter contributed much to the development of the theory of business cycles (see also Section 4.4.2).

affect production and goods markets. In particular, expenditure exceeds receipts, and investment runs ahead of saving". With respect to the length of the cycle Juglar (1862, p.202, translated) indicated that: *"While the commercial downturns are quite short, a year or two at most, prosperous periods have a longer duration of several years, six to seven on average"*. The average length of the cycle as indicated by Juglar was therefore about 7 to 9 years. Nowadays most writers agree on a period of about 7 to 11 years (Besomi, 2005, p.18), but different lengths are still reported in literature[47]. I will further assume an average length of about 9 years for an average Juglar cycle in this thesis.

4.4.2 Schumpeter's contribution to the theory of business cycles

Schumpeter devoted much of his professional life to the research of business cycles. In 1939 he published the book *"Business Cycles"* of which he chose the title deliberately *"to emphasize the economic ebb and flow that defines capitalism"* (McCraw, 2006, p.234). Schumpeter developed the asymmetric three-phase model of Clement Juglar into a sinusoidal four-phase model that consists of the phases prosperity, recession, depression and recovery. The depression phase is however not necessarily included in the cycle (Schumpeter, 1936, Vol. 1, p. 167). The Schumpeterian wave is indicated in Figure 4-1.



Note: The figure represents a conceptual framework that indicates the four phases of a Schumpeterian business cycle. The dotted timeline indicates the average economic growth throughout the cycle.
Source: based on Van Duijn (2007, p.98), adjusted.

Figure 4-1: Four Phases of a Schumpeterian Business Cycle

Both Juglar and Schumpeter shared the idea that the wavelike-movement is an inherent characteristic of capitalistic development, but according to Juglar the fluctuations are caused by *"excessive speculative behaviour that requires a crisis to adjust the system"*, while according to Schumpeter they are *"a consequence of innovation"* (Dal-Pont Legrand and Hagemann, 2007, p.22). Schumpeter incorporated new insights from others such as Kitchin and Kondratieff and concluded that there are multiple cycles acting at the same time. The overall cyclical movement can be obtained by summarizing the individual cycles. The other way around the cyclical movements can be decomposed into a secular trend and various economic cycles with different lengths. Schumpeter adapted a three cycle approach for which he concluded that *"Baring very few cases in which difficulties arise [...] it is possible to count off, historically as well as statistically, six Juglars [eight-to-ten-year cycles] to a Kondratieff [fifty to sixty years] and three Kitchins [forty months] to a Juglar – not as an average but in*

[47] For example: Schumpeter (1954, p.1124) referred to Juglar's 9-10 year cycle, Forrester (1976, p.1) speaks about a 3-7 year business cycle, and Wikipedia (2009) mentions an 8-11 year Juglar Cycle.

every individual case" (Schumpeter, 1939, vol. 1, p.169-174). Following Schumpeter's typology the main economic cycles are nowadays named after their discoverers or proposers, which include the:

- 3-5 year inventory cycle of Joseph Kitchin;
- 7-11 year fixed investment cycle of Clement Juglar;
- 15-25 year infrastructural investment cycle of Simon Kuznets;
- 45-60 year long wave technological cycle of Nikolai Kondratieff.

The Kitchin, Kuznets, and Kondratieff cycles will be discussed in the following sections, but there exist many more cycles. For a comprehensive overview of all known economic cycles reference can be made to the meta-analysis of De Groot and Franses (2009).

4.4.3 The inventory cycle of Joseph Kitchin (3-5 years)

Kitchin (1923) discussed the existence of *"Minor Cycles"* with an average length of about 3⅓ years or 40 months and concluded that *"Though single cycles may vary considerable from this average, an underaverage cycle is often followed by an overaverage cycle, and vice versa, so that the average of two or three consecutive cycles is closer than the single cycle to the general average length"* (Kitchin, 1923, p.10). He further concluded that two or three 'minor cycles' fit within one 'major cycle' (that is nowadays referred to as the Juglar or Business Cycle). *"Major Cycles, or so-called trade cycles, which are merely aggregates usually of two, and less seldom of three, minor cycles, the limit of each being distinguished by a maximum of exceptional height, by a high bank rate, and sometimes by a panic, though panics seem to be disappearing. The facts that they average about 8 years, and that they usually come at 7- or 10-year intervals, are due to the circumstance that they are composed either of two minor cycles (ideally 6⅔ years) or three minor cycles (ideally 10 years)"* (Kitchin, 1923, p.14). According to De Groot and Franses (2009, p.6) Kitchin *"explained these fluctuations by stating that after a recession, firms had too little stock of raw materials, parts, half fabricates and final products. While aiming to get their stock at an acceptable level, firms create a demand that influences the entire economy. Demand increases until the firms find out that their expansion has been too exuberant and their stock has become too large. In order to diminish the excess stock, firms will cut back on their stock orders and will lower their output. This in turn can drag the economy into a recession"*. This explains why the Kitchin cycle is often referred to as an inventory or stocking/destocking cycle[48].

4.4.4 The infrastructural investment cycle of Simon Kuznets (15-25 years)

Kuznets (1930) investigated secondary secular movements and concluded that the second secular movements in prices (estimated at 23 years) are similar to those in production (estimated at 22 year). He further argued that the term 'cycle' was too strict. He therefore preferred to refer to the movements of historic incidences. De Groot and Franses (2009) mentioned that *"[...] the Kuznets cycle is widely accepted by economists as well as it is corroborated by plenty of data material"*. They further indicate that the cycle is related to investments in construction and lasts somewhere between 15 to 25 years. The existence of the Kuznets cycle has however been and still is subject to some discussion. Schumpeter (1936, Vol.1, p. 169) was not convinced of the existence of the cycle as he choose to adapt a three

[48] It should be noted that I read through the original 1923 article and could not found any wording on stock inventory. The only stocks mentioned in the article are fixed-interest stocks; the word inventory has not been used in the document. Kitchens document was written to indicate the existence of *Minor* and *Major* cycles.

cycle scheme in his model (Kitchin, Juglar, Kondratieff). A spectral analysis of the World GDP (Korotayev et al., 2010) confirms that evidence for a Kuznets cycle is still weak as they conclude that *"our analysis suggests that the Kuznets swing should be regarded as the third harmonic of the Kondratieff wave rather than as a separate independent cycle"*. I will not pay any further attention to the Kuznets cycle as it does not seem to provide useful insights in the very long term development of the economy.

4.4.5 The long wave technological cycle of Nikolai Kondratieff (45-60 years)

The existence of very long term waves is widely acknowledged after the 1925 publication of the Soviet economist Nikolai Kondratieff in the *"Voprosy konyunktury"*, on *"Long Economic Cycles"* (Tarascio, 1988, p.1). A German translation of Kondratieff's article was published in the *"Archive fűr Sozialwissenschaft und Sozialpolitik"* (1926) and an English summary of the German article was published by Stolper (1935). Kondratieff's initial publication provided a profound empirical discussion that clearly addressed the existence of a long wave period in the economy[49]. The article was reprinted in a book titled *"Bol'shie tsikly konyunktury"* (Long Economic Cycles) by Kondratieff and Oparin in 1928[50]. This book provided a theoretical explanation on the observed cyclic behaviour, but it was not translated until 1984. It therefore remained unknown in the field for a very long time (Tarascio, 1988, p.1).

<u>Historical overview of past Kondratieff waves</u>

Kondratieff (1926) covered a period of 2½ waves of which the first two are 60 and 48 years. Based on this analysis he indicated an average length of about 50 to 55 years. Many others followed him in his research. In absence of a convincing cyclic theory the Kondratieff cycles are generally referred to as a waves. An overview of the upswing and downswing periods of the Kondratieff waves is amongst others provided by Van Duijn (2007) and Korotayev, et al. (2010). Table 3-3 provides an overview of the various Kondratieff waves that have existed since the beginning of the Industrial Revolution.

Van Duijn (2007, p.98) suggested that Kondratieff waves can be subdivided into five standard Juglar Cycles (with a general length of 7-11 years) of which two succeeding cycles are *'prosperous'* Juglars. I have adopted this view. The suggestion that Kondratieff waves can be subdivided into five instead of six Juglars (as suggested by Schumpeter) is quite interesting as it implies that (in absence of major wars) the length of the Kondratieff waves will be about 45 instead of 50 years. From an evaluation of the length of the cycles (excluding war periods) it appears that this suggestion holds quite well (see Table 4-3). In this respect it can be argued that the length of the Kondratieff waves is becoming shorter. In line with these views I will presume the succeeding 6th and 7th Kondratieff wave to have a length of about 45 years (i.e. consisting of five Juglars with an average length of 9 years).

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[49] At the end of the German translation Kondratieff mentions that he early 1926 noticed the work of the two Dutch economists S. de Wolff and J. van Gelderen. He mentions that de Wolff derives similar conclusions and that he is unknown with the works van Gelderen, who according to Tinbergen (1981, p.285) wrote under the pseudonym J. Fedder and was the first to draw attention to the existence of these long wave-like motions.

[50] This was probably the last contribution of Kondratieff as he was dismissed from his post at the institute in 1928. Two years later he was arrested on charges of leading the Working Peasants' Party, and in 1931 he was condemned and sentenced to eight years in prison. In 1938 his sentence was reviewed and he received the death penalty. The date and place of his death are unknown (Source: Encyclopaedia Britannica).

Table 4-3: Historical Overview of past Kondratieff Waves

Kondratieff	1st wave	2nd wave	3rd wave	4th wave	5th wave
Depression	1764-1773*	1825-1836	1872-1883	1929-1937	1973-1980
Recovery	1773-1882*	1836-1845	1883-1892	1937-1948	1980-1992**
Prosperity	1782-1792	1845-1856	1892-1903	1948-1957	1992**-2000
Prosperity	1792-1802	1856-1866	1903-1913	1957-1966	2000-2009*
(War)	(1802-1815)		(1913-1920)		
Recession	1815-1825	1866-1872	1920-1929	1966-1973	2009-2018*
Length	61 years	47 years	57 years	44 years	45 years
Excl. War	48 years	47 years	50 years	44 years	45 years

Note: *I estimated these dates on the basis of an average 9 year Juglar Cycle.
Note: **Corrected. The original table states 1990 but on page 195 Van Duijn states that the fourth cycle lasted from 1948 to 1992. In addition Van Duijn refers to the Juglar recession of 1991/1992 on page 99.

Source: Van Duijn (2007, p.99 and 195), adjusted sequence of phasing and extended timeframe.

Based on the above historical pattern the next upswing period can roughly be expected to take place from the year 2030 to the year 2055 (uncertainty level probably +/- 5 to 10 years).

<u>Cyclical behaviour of long Kondratieff waves</u>
Kondratieff (Stolper, 1935, p. 111) provided a profound analysis of long wave cycles in the capitalistic western world and observed that:

1. *"During the rise of the long waves, years of prosperity are more numerous than, whereas years of depression predominate during the downswing.*
2. *During the recession of long waves agriculture, as a rule, suffers an especially pronounced and long depression. This was what happened after the Napoleonic Wars; it happened again from the beginning of the 1870's onward; and the same can be observed in the years after the World War.*
3. *During the recession of long waves, an especially large number of important discoveries and inventions in technique of production and communication are made, which, however, are usually applied on a large scale only at the beginning of the next long upswing.*
4. *At the beginning of a long upswing, gold production increases as a rule, and the world market [for goods] is generally enlarged by the assimilation of new and especially colonial countries.*
5. *It is during the period of the rise of the long waves, i.e., during the period of high tension in the expansion of economic forces, that, as a rule, the most disastrous and extensive wars and revolutions occur".*

Kondratieff (1935, p.111) further states that: *"It is to be emphasized that we attribute to these recurring relationships an empirical character only, and that we do not by any means hold that they contain the explanation of the long waves"*.

Most of these observations are still relevant. The first observation is confirmed by Van Duijn (2007, p.98) who indicated that the Kondratieff waves contain two prosperous Juglar Cycles. The second observation can be generalised by stating that during the recession of long waves the older sectors will face a more severe recession than the newer industries as they are less flexible by nature. The third observation was confirmed by Grübler and Nakićenović (1991, p.337) who wrote that *"It is the disruptive crisis of the old that provides the fertile ground for new systems to develop"*. The fourth observation is harder to judge. Following the 2009 recession large amounts of money have been injected into the world economy by central banks. If this triggers a new crisis with high levels of inflation it may well stimulate gold production in the early upswing phase of the next Kondratieff wave. In addition one can argue that enlargement of the world market becomes more difficult in our highly globalised world, but it still remains possible to afloat Africa during the upswing period of the next Kondratieff wave (see also item 19 in Table 4.2). This may look very optimistic, but considering the fact that the population is aging in the Western World and booming in Africa it's not that strange.

Finally the fifth observation also holds remarkably well. The 1802-1815 period of the first wave refers to the Napoleonic Wars that followed the French revolution (1789–1799). The American civil war took place from 1861-1865 which is at the end of the prosperous period of the second wave. World War I (1914-1918) involved many of the world's great powers and took place at the end of the prosperous period of the third cycle. The six-day-war (1966) and Yom Kippur War (1973) took place in the Middle-East at the end of the fourth wave (that was based on oil as a main energy source). Nowadays, at the end of the fifth wave, there is once again much unrest in the world. This time the social unrest is caused by the *"exhaustion of aspects of the Western worldview and the industrial ideology that went with it"* that comprises *"elements such as: the denial of limits, the single-minded pursuit of material (economic) growth, the commodification of human needs, the reduction of natural entities to the status of mere 'resources', exploitive trade practices and future-discounting"* (Slaughter, 2002, p.1). This worldview causes tensions between the Islamic- and Western World (*'9/11 attack'* and *'axes of evil'* declaration by the USA), within the Arab world (Arab spring, ISIS), within the Western World (Occupy movement, Financial crisis, Euro crisis, and USA deficit crisis), as well as on a global scale (Food crisis, Climate crisis, etc…). The only exception to the fifth observation appears to be World War II, that evolved in the slipstream of World War I and the miserable state of the economy after the great depression in the 1930s. This implies that the observed recursive relations are quite firm and can be used to identify the next period of upheaval and the beginning of the 6^{th} Kondratieff wave.

<u>Signposts of a new era</u>

Korotayev, et al. (2010) indicated that the world is likely to have entered the downswing of the 5^{th} Kondratieff wave in the period 2008-2010. Others also regard the 2009 financial crisis as the turning point of the long term wave. A convincing argument that a new era is coming can be provided on the basis of Kondratieff's recurring relationships. Allianz Global Investors (2010, p.6) shows that the recent financial crisis fits the following four main characteristics of change leading to a new Kondratieff wave[51]:

1. Potential for further exploitation of an old basic innovation is exhausted;
2. High level of excess financial capital (versus physical capital);
3. Period of severe recession (period of radical change);
4. Social and institutional transformations.

They further argue that, *"Interestingly, a close examination shows that all four of the criteria marking the process of the reorientation of the economy seem to apply to the current financial and economic crisis:*

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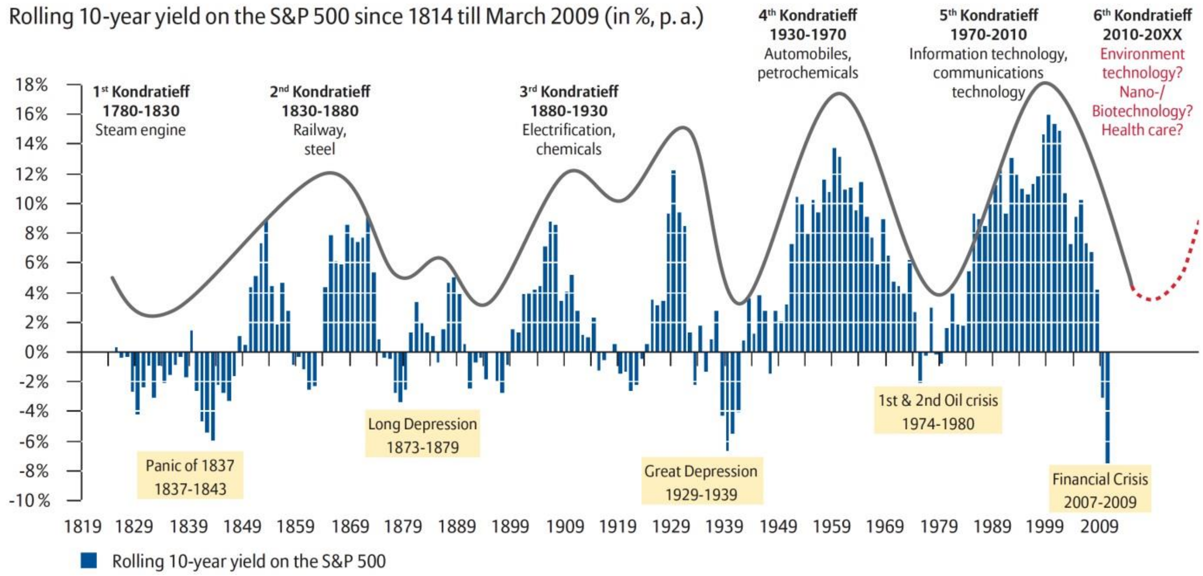
[51] The criteria applied by Allianz Global Investors (2010) are slightly different from the original observations by Kondratieff, but the general tendencies are similar.

- *The surge in productivity that had its origin in the invention of Konrad Zuse's 'Z3' computer in 1941 appears to be slowly coming to an end. Work processes are not made much more productive by an even faster notebook computer. The Internet has already achieved considerable penetration.*
- *Similarly, until 2007, before the outbreak of the financial crisis, there was a substantial surplus of financial capital in the economy. The expansion of the credit (derivatives) economy put too much money into a small segment of the real economy. With the dominance of financial capital over the physical capital (sum of property, plant and equipment) investors sought returns in investment alternatives, which they primarily found in loans on U. S. real estate and in financial derivatives*
- *The result was a financial crisis that became a global economic crisis, the likes of which had not been seen since 1930. The 9th of March 2009 was a historic day for investors – in a negative sense. On that day, U. S. share prices as measured by the S&P 500 not only hit their low point, but the 10-year performance of the U. S. equity index, with an average return of -8 % p. a., also hit its lowest level in 200 years* (see Figure 4-2).
- *Work is now underway on the creation of a new global financial regulatory architecture that is intended to form the basis for a sustainable economic and financial system".*



Source: Allianz Global Investors, Analysis & Trends (January, 2010).

Figure 4-2: Kondratieff Waves and profitability of S&P 500 Stock Index

<u>The relation between Kondratieff waves and diffusion of technology</u>

Grübler and Nakćenović (1991) provide clear empirical evidence that social-, technological-, and economic change plays an important role in the cyclical behaviour of Kondratieff waves. Periods of growth and expansion in economic activities are punctuated with phases of fundamental change in the structure of the economy, the technology base, and many social institutions and relations. At a certain stage the dominating socio-techno-economic paradigm, that has led to the previous upswing phase, reaches its limits of social acceptability and environmental compatibility and begins to saturate. *"In this sense each Kondratieff long wave portrays a barrier to diffusion. Most processes saturate during the end of the inflationary period and the onset of the disinvestment phase in the Kondratieff wave. Very few diffusion processes can tunnel through this barrier. If it is true that this marks the beginning of* *paradigm shifts, it is not surprising that further diffusion of systems associated with the old techno-economic development trajectory is blocked to make way for new. It is the disruptive crisis of the old that provides the fertile ground for new systems to develop. It can be concluded that major innovations are likely to be developed during the downswing of the Kondratieff wave, but that it takes up to the next upswing period until they fully materialise as the main drivers of a new techno-economic paradigm"* (p.337).

Ayres (1990, p.37) provides a comprehensive discussion on the development of the Industrial Revolution in which he relates the first five Kondratieff waves to five major technological transformations: *"The first (1770-1800) was the shift from charcoal to coal for purposes of iron-making, fueling the first steam engines, building the first canals and mechanizing cotton spinning. The second transformation (1830-1850) applied steam power to the textile industry and to transportation (the railway and the steam boat). The third transformation (1860-1900) was complex. It centred on steel-making and the mechanization of manufacturing, on illumination, telephones, electrification and the internal combustion engine. The fourth transformation (1930-1950) centered on synthetic materials and electronics. The fifth, beginning around 1980, centers on the convergence of computers and telecommunications".*

Similar analyses are also provided by others such as Van Duijn (2007, p.97, translated):

1st Kondratieff wave (about 1764* - 1825)[52]

- *Textile: Cotton Gin, Spinning Jenny;*
- *Iron and Steel: Smelter, Puddling Process, Crucible Steel;*
- *Steam Power: Watt's Steam Engine.*

2nd Kondratieff wave (about 1825 – 1872)

- *Railways: Locomotive, Bessemer Steal;*
- *Other: Telegraph, Photography, Sewing Machine, Elevator.*

3rd Kondratieff wave (about 1872 – 1929)

- *Electricity: Edison's Lamp, Power Stations, Transformer;*
- *Automobile: Combustion, Diesel Engine, Pneumatic Tyre, Assembly Line;*
- *Other: Movie, Radio, Safety Razor, Fridge, Airplane, Telephone, Gramophone.*

4th Kondratieff wave (about 1929 - 1973)

- *Plastics: Polystyrene, PVC, Polyethylene, Silicone, Artificial Silk, Nylon;*
- *Other: Television, Helicopter, Jet Plane, Photo Copy, Transistor.*

5th Kondratieff wave (about 1973 – 2018*)

- *Digitalizing: Integrated Circuits, Microprocessor, PC, Software, Internet;*
- *Other: Biotechnology, Mobile Phone, Microwave.*

Based on the above analysis it can be concluded that Kondratieff cycles are closely related to the prevailing socio-techno-economic paradigms of our modern society. In addition Ayres

[52] The timing of the waves presented by Van Duijn is adjusted according to Table 4-3. Dates marked with an (*) refer to estimates based on the assumption of an average 9 year Juglar Cycle.

(1990, p.1) indicates that: *"historical evidence suggests that in many cases the economic impact of an important innovation contributed little to the 'next' upswing but may have contributed significantly to subsequent ones"*. This implies that emerging technologies of the n^{th} wave will not become dominant until the $n+1^{th}$ wave[53]. This important finding makes it possible to anticipate the dominant drivers of the next Kondratieff wave by considering the promising and emerging new technologies of the present wave.

Drivers of the sixth Kondratieff wave

The 5^{th} Kondratieff wave was mainly driven by ongoing unsustainable exploitation of resources and far reaching integration of people (air liners, mobile phone, e-mail); systems (internet, financial systems); and trade (containers, bulk carriers, global trade). The main drivers of this far reaching integration process are amongst others: communication technology (and ICT), efficiency improvement, economies of scale, increased labour productivity, and global outsourcing of production to low-wage countries. I will refer to this broad development as ***'Globalisation'*** (though Globalisation is often also applied in a narrower context).

It is interesting to observe that the end of the 5^{th} Kondratieff also coincides with the end of the Industrial Age and the beginning of the Information Age (see Section 4.5.1). In this respect the beginning of the 6^{th} Kondratieff is more than just another long term wave. The world is now confronted with a number of eminent crises related to the perversities of the Industrial Revolution and the single minded pursuit of materialistic economic growth that came with it.

Along these crises are the environmental and climate change crisis (pollution, acid rain, hole in the ozone layer, extinction of species, dying of coral reefs, loss of biodiversity, rise of sea-levels, melting of poles); raw material and energy crisis (depletion of mineral resources and fossil fuels); food crisis (rise of food prices due to competition with fuel production); financial, deficit, and debt crisis (failure of financial system, bank crisis, real estate crisis, sub-prime mortgages, unsustainable deficits, governances going bankrupt); western lifestyle crisis (unhealthy lifestyle, overweight, high stress levels due to busy lifestyle and extraordinary labour productivity requirements); and social crisis (repressive regimes, unsustainable levels of income and wealth inequality, non-transparency and social-irresponsibility of industrial and government policies – no longer accepted by an increasingly well-educated global population that is connected to internet and organised via social networks). Taking the various crises into account it can be concluded that across the board there is an ever-increasing desire and necessity for a more sustainable society (see also Jackson, 2009). The main driver of the next Kondratieff wave is therefore expected to be related to the broad concept of '***Sustainability'***.

The notion that sustainability can be regarded as the main driver for the development of the next 6^{th} Kondratieff wave is broadly recognised[54]. In this respect the many crises of our modern society may indicate the direction of future Megatrends. I have listed a number of anticipated Megatrends (and related innovative clusters and policies) that directly or indirectly relate to the various crises mentioned above in Table 4-4.

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[53] For this reason Grübler (1990, p.260) listed both emerging technologies and dominating technologies. See also Table 8-1 and Table 8-2 in Chapter 8 of this thesis.

[54] Reference can for instance be made to: Hargroves and Smith (2005), Ayres (2006), Moody and Nogrady (2010), Adams and Mouatt (2010), and Allianz Global Investors (2010).

Table 4-4: Sustainability crises and Megatrends driving the 6th Kondratieff wave

Megatrends	Related Innovative Clusters/ Policies Crisis	Environmental Crisis	Climate Change Crisis	Raw Materials Crisis	Energy Crisis	Food Crisis	Financial Crisis	Deficit Crisis	Debt Crisis	Lifestyle Crisis	Social Crisis
Reuse of materials	Advanced recycling, cradle to cradle, circular economy, waste as resource.	Direct	*Indirect*	Direct	*Indirect*						*Indirect*
Use less materials	Ongoing miniaturisation, nanotechnology, shift from physical to digital products.	Direct	Direct	Direct	Direct						*Indirect*
Use biological products	Biotechnology, genetic engineering, degradable products.	Direct		Direct		Direct					*Indirect*
Use cleaner fuels	Coal with CO_2 storage, shift to gas (including shalegas and biogas), electrification, hydrogen, solar fuels.		Direct		Direct						*Indirect*
Use renewable energy	Wind power, solar power, thermal power, tidal power, hydro power, biofuels.	Direct	Direct		Direct	*Indirect*					*Indirect*
Use less energy	Isolation, green technology, heat pumps, lower speed, new propulsion systems, local production.		Direct		Direct	*Indirect*					*Indirect*
Integrated networks	Smart grids, global knowledge, inter-modal transport, social networks.		Direct		Direct	*Indirect*					Direct
Transparency	Transparent governance, corporate social responsibility, clear financial products.	*Indirect*	*Indirect*			*Indirect*	Direct	*Indirect*	Direct	*Indirect*	*Indirect*
Robustness economics	Balanced equilibrium between failure costs and economies of scale, local solutions.	*Indirect*	*Indirect*			*Indirect*	Direct	*Indirect*	Direct	*Indirect*	*Indirect*
Holistic Healthcare	Physical and psychological health care.								*Indirect*	Direct	*Indirect*
Tax reform	Taxation of ecological footprint (and property) instead of labour.	*Indirect*	*Indirect*	*Indirect*	*Indirect*	*Indirect*	Direct	Direct	Direct	Direct	Direct
Political reform*	Policies aiming at sustainable goals in stead of economic growth and return on investment.	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct	Direct

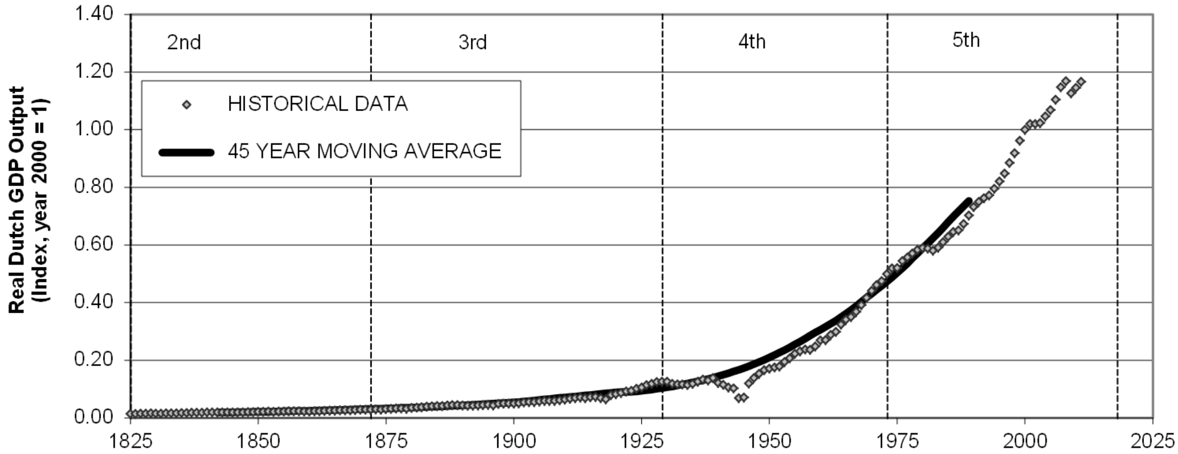
Note: *The signs pointing in the direction of political reforms are still very weak. There is a slight notion that such changes will be necessary, but these trends cannot be observed clearly yet.

I expect the most important drivers of the 6th Kondratieff wave to be related to: using less raw materials, burning less fossil fuels, enhancing transparency and social responsibility, developing robust solutions, and holistic healthcare. Taxes are likely to shift from tax on labour to tax on footprint. Political reforms (aiming for sustainable wealth instead of economic growth) may also be expected in the future, but this trend is less clear today. With respect to transport an ongoing shift towards intermodal transport can be expected.

Apart from the listed trends a few other Megatrends should be mentioned. First of all the population in the developed countries is aging and will be decreasing from 1.2 billion in the year 2000 to 1.1 million in the year 2100 (UN, 2004, p.14). In the same period the population of the developing countries is expected to increase from 4.9 to 7.9 billion persons. In addition economic power is now shifting from Europe and Northern America towards Asia and China in particular. Further in the future a new shift of economic power towards mineral rich regions (such as Africa and South America) could take place, but this is still very uncertain as it for instance depends on the future social and political stability in these regions.

4.4.6 Effect of economic cycles on the overall very long term economic trend

The previous sections discussed the four most important economic cycles reported in economic literature. Most cycles are relatively short and have little effect on the overall very long term trend. The Kondratieff wave is the only cycle with a length that falls into my definition of the very long term (as defined in Table 4-1). It is therefore important to study the effect of this cycle on the development of the aggregated very long term economic trend. I have plotted the development of the Dutch GDP (index of real values at constant price levels) against its 45 year moving average that should no longer be affected by the long Kondratieff waves. The results are indicated in in Figure 4-3[55].



Source: Own calculations based on data from Angus Maddison (update March 2009) and the Total Economy Database (update January 2010).

Figure 4-3: The limited effect of Kondratieff Waves on the Dutch Economy

It can be concluded that, unlike the rolling 10-year yield on the S&P 500 index, the Kondratieff waves have a relatively small effect on the overall level of the very long term GDP trend. This implies that the Kondratieff waves do not have to be taken into account in very long term GDP projections, which is a blessing because the length and amplitude of economic cycles cannot be forecasted accurately. In fact, Armstrong (2001, p.233) warns that forecasting cycles is not at all a good forecasting principle (see also Chapter 5).

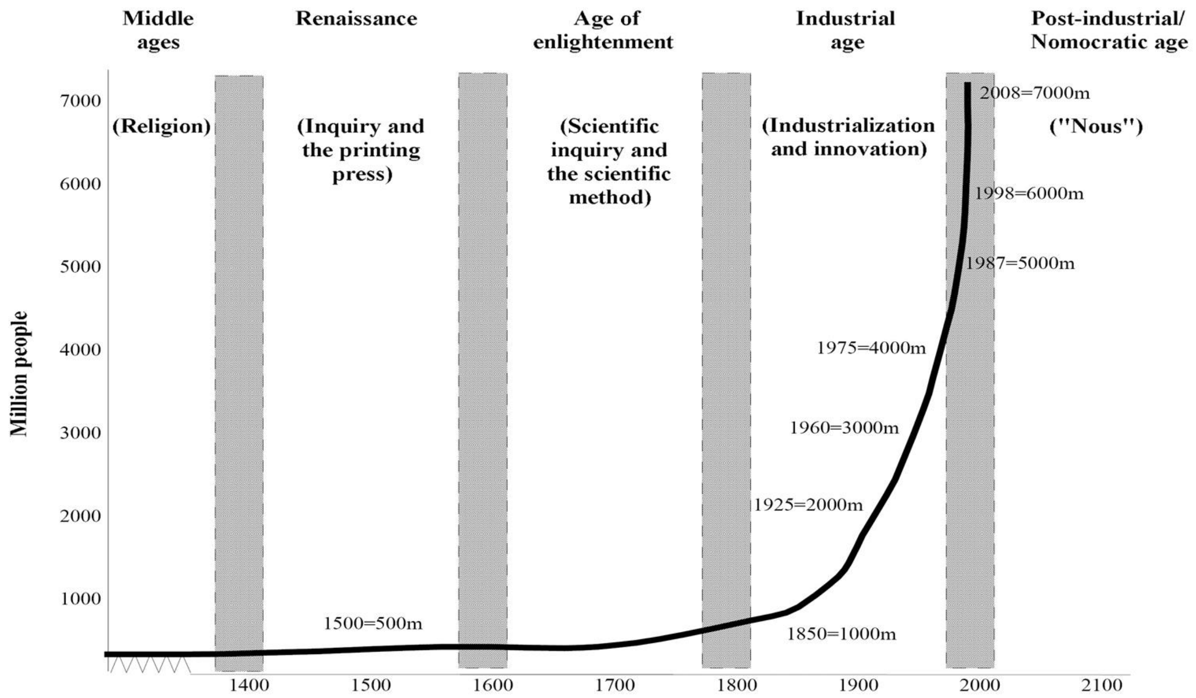
4.5 The Very Long Term Trend

Having discussed the long term Megatrends and very long term Kondratieff waves the next step is to discuss the options to look even farther ahead. The aim of this section is to identify the historical trend over the past millennium as well as the direction of the anticipated trend throughout the next few centuries. In that respect it is worth considering the development of the *'Secular trend over the ages'* and the theory of the *'Great Transition'*. Both subjects will be discussed in this section.

[55] I have presented the Dutch GDP in the Figure 4-3, because much longer times series are available for the Netherlands than for the US or World economy. Similar conclusions can however also be drawn from time series for the US and World economy.

4.5.1 The Secular trend over the ages

The secular trend refers to the very long term trend over the ages. Figure 4-4 shows the basic trend over the past millennium and indicates how in each of the ages the knowledge and skills were developed for the next era to come.



Source: Spies (1998, p.2), adjusted size.

Figure 4-4: Secular Trend over the Ages

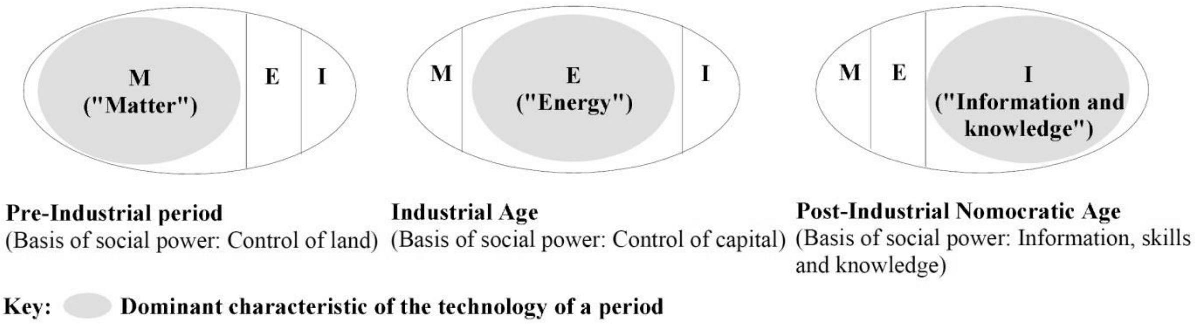
According to Spies (1998) the religion based Middle Ages breaded the information revolution of the Renaissance. The printing press, that was developed during this revolution, enabled the rapid diffusion of new ideas and scientific theories throughout Europe. This resulted in the scientific revolution during the Age of Enlightenment. The scientific revolution triggered the Industrial Revolution, that enabled higher food production yields, increased living standards, and medical healthcare – and fuelled the rapid explosion of the world population during the 19th and 20th century. The world is now about to enter a new Post-Industrial Nomocratic Age, in which Nomocratic stands for knowledge based. Table 4-5 indicates the various modes of production and the various natures of social power that characterise the ages.

Table 4-5: Secular Trend over the past Millennium

Age in History	Mode of Production	Nature of Social Power
Middle Ages (until 15th century)	Agriculture and artisans	Church and landed gentry
Renaissance (until 17th century)	Commerce, agriculture and artisans	Merchants, city states and landed gentry
Age of Enlightenment (until 19th century)	Commerce, agriculture, artisans and small manufacturing	Capital, labour in nation states
Industrial Age (until 21st century)	Manufacturing	Capital, labour in nation states
Post-Industrial Nomocratic Age	Services and networking	Embodied "capital" (knowledge, skills and information in a global society)

Source: Spies (1998, p. 8).

In the pre-industrial ages the control of land was the main basis of power, during the industrial ages power shifted to energy and capital, and nowadays it is moving towards information, skills and knowledge. To illustrate this shift Spies (1998) refers to the MEI-evolution process of Van Wyk (1984, p.107), that is indicated in Figure 4-5.



Source: Spies (1998, p.2), adjusted layout.

Figure 4-5: MEI-Evolution Process of Van Wyk

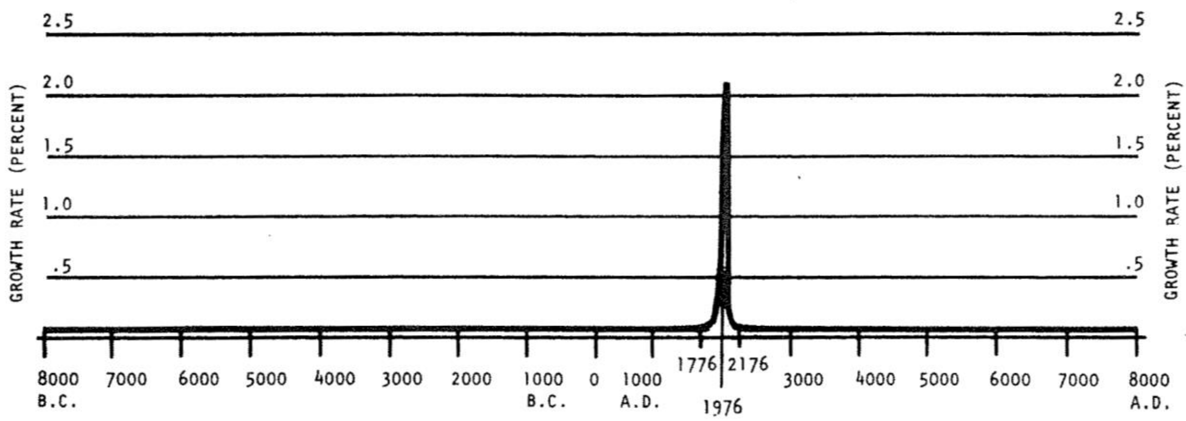
The MEI-evolution process follows a logistic S-shaped pattern of technological diffusion and *"transformed the ages of man – not only in terms of general characteristics of productive activities, but also in terms of the nature of its society, its power relations and mode of operation"* (Spies, 1998, p.7). For the next era a further shift to a much more information intensive and knowledge based society can be expected.

4.5.2 The Great Transition of Herman Kahn

It is possible to look at the secular trend from an even broader time perspective. According to Kahn et al. (1977) there have been two great watersheds in human history which are the agricultural revolution that started in the Middle East's Fertile Crescent period some 10,000 years ago and the Industrial Revolution, that began in Holland and England some 200 years ago. On the impact of the second watershed Kahn et al. (1977, p.1) write: *"that 200 years ago almost everywhere human beings were comparatively few, poor and at mercy of the forces of nature, and that 200 years from now, we expect, almost everywhere they will be numerous, rich and in control of the forces of nature. The 400-year period will thus have been as dramatic and important in the history of mankind as was the 10,000-year period that preceded it"*. They further refer to this period as the *'Great Transition'*.

Kahn et al. (1977, p.1) argue that *"the growth first of population and later of GWP*[56] *will approximate a flattened s-shaped, or logistical, curve, passing from an earlier era of slow growth through the present period of exponential growth to a final levelling-off"*. At the end of the s-shaped curve they foresee a possibility for *"a new s-curve that may start sometime in the 21st century, representing the colonizing of the solar system and eventually generating growth rates that we would not even try to estimate"*. However, regarding the earth-centred perspective there will be only a relatively short (about 400 years lasting) period of growth as indicated in Figure 4-6.

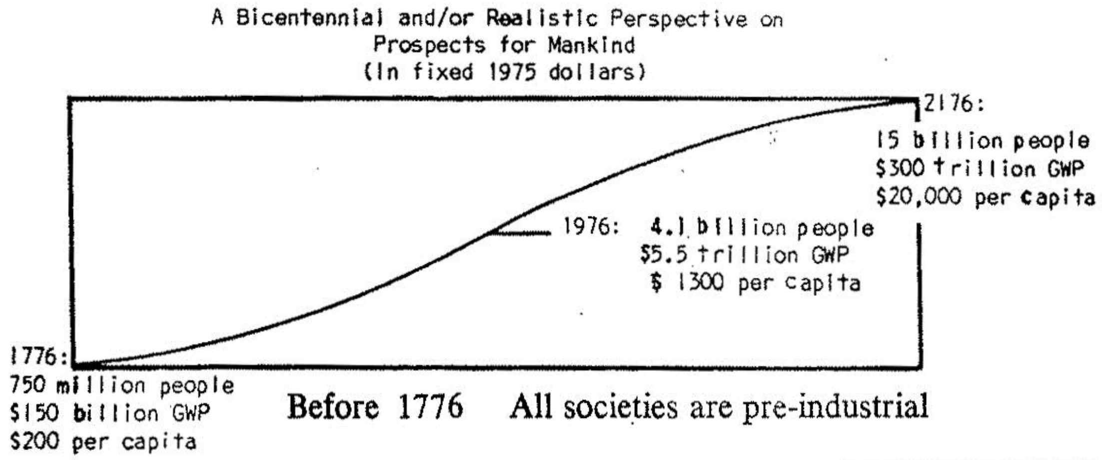
[56] GWP stands for Gross World Product (i.e. the combined GDP of all the countries in the world).



Source: Kahn et al. (1977, p.29) originally adopted from Freeman and Berelson (1974).

Figure 4-6: Population Growth Rate in an Ultra-Long Perspective

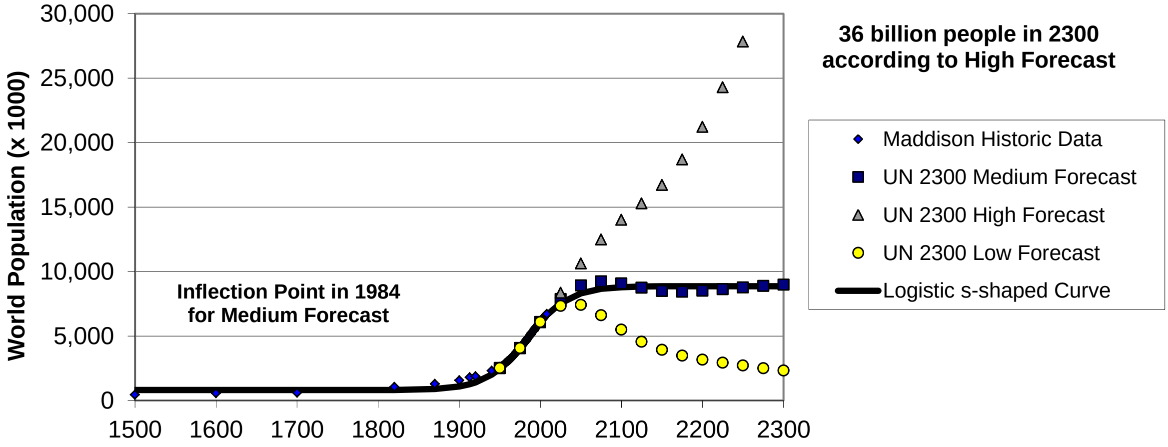
Kahn et al. (1977, p.7) argue that *"The earth-centred perspective assumes that the world population flattens out at least for a while at 15 billion people, give or take a factor two (that is, a range of 7.5 to 30 billion); per capita product at $20,000, give or take a factor three; and GWP at $300 trillion, give or take a factor five"*. To be safe he also states that *"The possible ranges of variability are, of course, larger than those given, but we find the above quite plausible"*. The S-curve of the *'Great Transition'* is indicated in Figure 4-7.



Note: The figure presents a conceptual framework. The time frame indicated on the x-axis ranges from the year 1776 to the year 2176. The y-axis represents World Population, GWP, and GWP per capita.
Source: Kahn at al. (1977, p.6).

Figure 4-7: The Great Transition of Herman Kahn

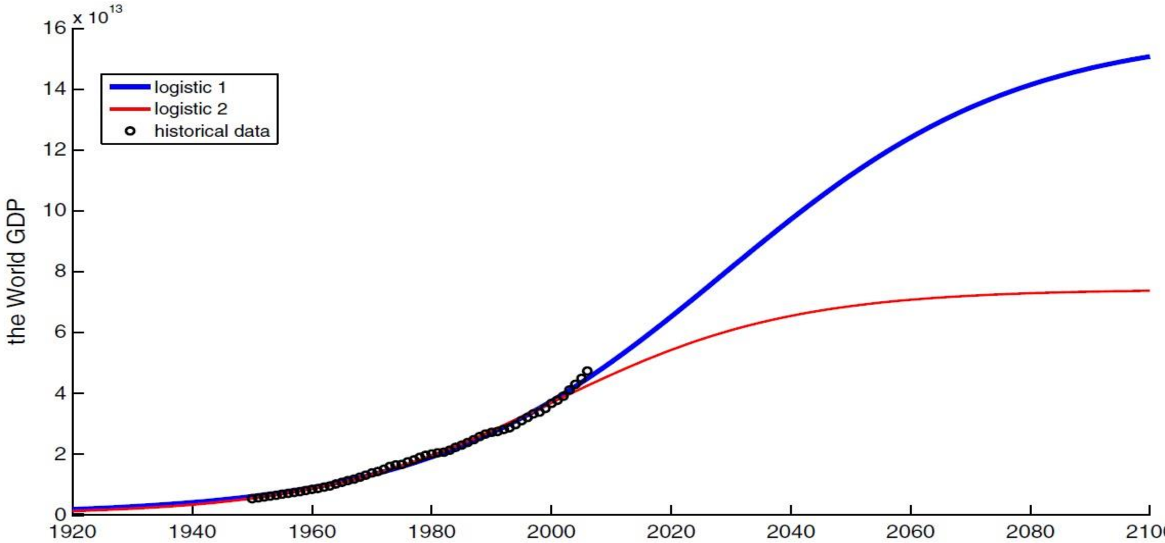
With respect to the inflection point Kahn et al. (1977, p.5) write that: *"The current year (1976) is depicted as the inflection point of the curve, at once both its moment of maximum growth and therefore the beginning of slower growth. In reality, following current UN data and projections, we expect to witness the inflection point in the rate of population growth during the period of 1976 and 1980; [...], we believe that the inflection point in the rate of growth of GWP will lag about a decade behind that of population. While both predictions are far from certain, the second one is much less certain than the first"*.



Source: Own calculations based on data from Maddison (2009) and UN (2004)

Figure 4-8: S-shaped Curve of the World Population

To verify Kahn's view on the timing of the inflection point I updated the shape of the proposed S-curve for the world population on the basis of Maddison's *"Historical Statistics of the World Economy: 1-2006 AD"* and the UN (2004, p.14) projections of the *"World Population to 2300"*. The results of this analysis are indicated in Figure 4-8. When both the historical- and medium forecast data are fitted into a logistic function (i.e. an S-shaped function) the inflection point is likely to have occurred in the year 1984. This is not far off the initially suggested year 1976. Kahn's views therefore still appear to be quite plausible.



Note: Logistic 1 minimised the absolute square errors, Logistic 2 minimised the relative square errors.
Source: Kwasnicki (2013, p.55).

Figure 4-9: S-shaped Pattern for the development of the World GDP

Kwasnicki (2013) also argued the global economy to follow a logistic S-curve (rather than an exponential growth curve) and fitted a logistic function through the year 1950 to 2006 data by minimising the absolute and relative mean square errors. The results of his analysis are indicated in Figure 4-9. Despite the fact that I think it is still too early to make sensible logistic projections on the basis of an S-curve that has not yet well passed its inflection point the results are worth mentioning. Kwasnicki (2013) found the inflection points for the World

GDP to be located in the years 1980 (logistic 1 curve) and 2000 (logistic 2 curve). This is very much in line the presumed development of the World GDP by Kahn et al. (1977) that was expected to lag about a decade behind on the inflection point for the World population.

4.6 Reflection on the Paradigm of Economic Growth

An important implication of the ‘Great Transition’ theory is that the world is moving towards a new reality in which population- and economic growth cannot be sustained forever. This implies that economic output per capita and hence labour productivity are slowly moving towards a maximum attainable very long term output value. It should however be noted that these views are not in line with today’s mainstream neo-classical views on economic growth. This section therefore continues with a reflection on the paradigm of economic growth.

4.6.1 Mainstream neo-classical views on economic growth

The neo-classical views on economic growth are founded on the work of Robert Solow. According to Solow (1956) economic growth can be regarded as a function of labour, capital, and the state of technology, that is referred to as *‘Total Factor Productivity’* (TFP). The output per worker depends on the level of capital relative to each worker (for which there is an optimum referred to as steady state or balanced growth path) and the state of technology[57]. In other words the GDP output per worker increases as a result of technological development and deepening of the capital stock. Once a country has reached its balanced growth path it can only raise its output per worker by raising the state of technology.

Solow (1956) regarded the state of technology (i.e. TFP) as an exogenous variable, but this approach has the disadvantage that developments from inside the economy cannot be taken into account. Economists have therefore developed endogenous growth models, in which the Total Factor Productivity is purely linked to factors inside the economy, such as for instance the level of research investments (Verspagen, 1992). Though these models are only intended to prepare medium to long term projections they have unintentionally contributed to the unfounded belief that the economy of advanced nations is slowly moving towards an equilibrium state with a fixed steady annual technological and economic growth rate on the very long term. This belief is clearly illustrated by the following definition of Investopedia (accessed: 2014): *“Neoclassical growth theory: An economic theory that outlines how a steady economic growth rate will be accomplished with the proper amounts of the three driving forces: labor, capital and technology”*. But this is not what Solow meant by a steady state or balanced growth path (Solow referred to an optimal capital stock to labour ratio, not to an ongoing steady economic growth rate) – nor do economists claim that growth will go on forever, as a fundamental theory that the economy is moving towards an equilibrium state with a fixed steady annual growth rate on the very long term does not exists.

However, today’s economists have been raised in an exceptional time in which ongoing exponential growth stemming from ongoing technological development has been self-evident and could more or less be taken for granted – and as a result these views are now adopted in

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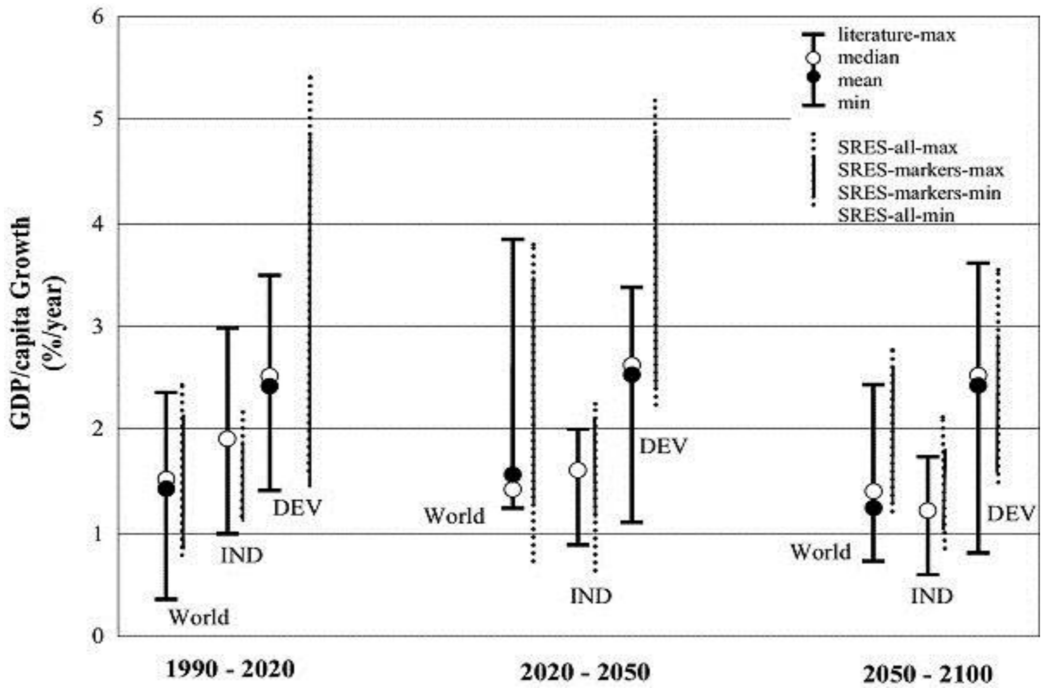
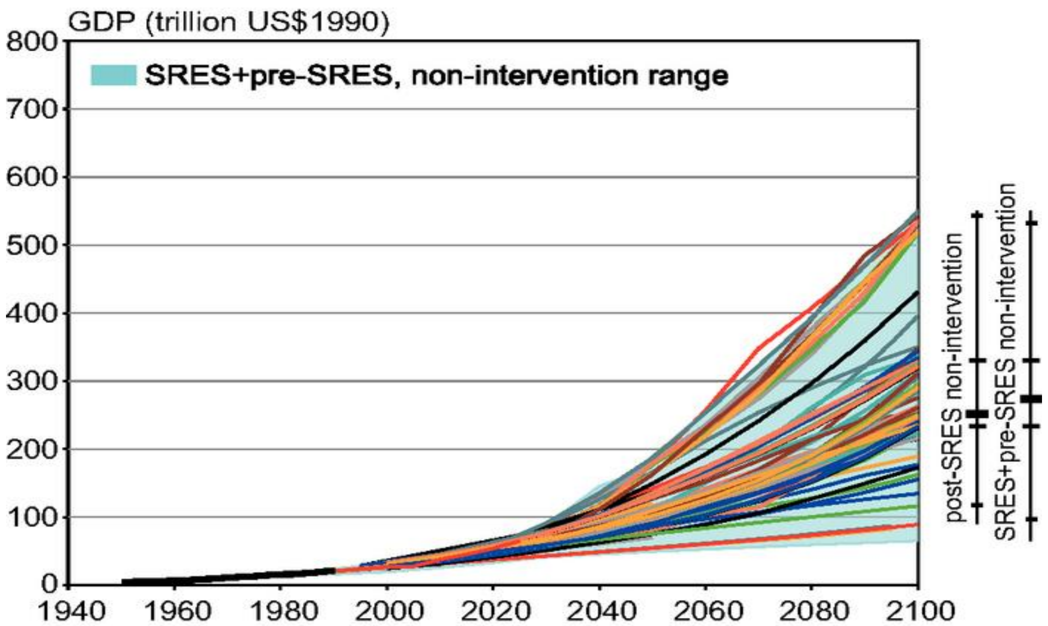
[57] Carone et al. (2006, p.28) explains that *“In the long-run, according to the neo-classical growth model (Solow model), the economy should reach its equilibrium (also called steady state or balanced growth path), where both the ratio of capital stock to labour expressed in efficiency units, K/(L.E) and output to labour expressed in efficiency units (or output per effective worker), remain constant over time”*

virtually all official long term scenarios including, for instance, the very long term scenarios of: the OECD (2012), the European Commission (Carone et al., 2006), and the Dutch Government (Smid 2005; and Huizinga and Folmer, 2012). The exponential nature of the presently applied GDP scenarios becomes very clear from the studies of the IPCC (2000, 2007) that cover most of today's official GDP scenarios.



Source: IPCC (2000, p.119).

Figure 4-10: Mainstream per Capita GDP Growth Assumptions



Source: IPCC (2007, p.180).

Figure 4-11: Mainstream Global GDP Output Scenarios

Figure 4-10 shows the results of the IPPC (2000) study on the applied per capita economic growth scenarios for the World economy as well as for the industrial (IND) and developing (DEV) countries. Figure 4-11 shows the applied growth scenarios for the World GDP up to the end of the 21st century. Both figures clearly point out the exponential nature of the present scenarios that were considered by the IPCC (2007) report.

To understand why virtually all official scenario studies tend to apply ongoing very long term exponential growth rates I have looked at the main arguments behind the applied scenario assumptions. These arguments become clear from the background reports of the scenarios for the European Commission and the Dutch Government, that state the following:

- Carone et al. (2006, p.28-29) indicate that: *"The EPC-AWG agreed that a prudent assumption for TFP would be that country-specific TFP growth would converge by 2030-2050 to the past TFP growth rate recorded for the EU as a whole over a long period (1970-2004), i.e. 1.1% per annum, with the speed of the convergence process perhaps dictated by the size of the initial gap in TFP levels. According to DG ECFIN's AMECO database, this average rate is almost identical to that experienced in the leading economy in the world, i.e. the US, in the very long run (since the 1960s). However it is slightly lower than that seen in the US more recently (around 1.2% since 1990 compared with 0.8% in the EU15)".* It is therefore assumed that exponential growth will continue in the future – and that future growth rates can be based on a long term average of the historical growth rates.
- The Dutch WLO scenarios (up to the year 2040) and the Dutch Delta Scenarios (up to the year 2100) apply similar assumptions based on the work of Smid (2005) who indicates that the average annual labour productivity growth rate for the Netherlands was 1.2% from 1870-1913, 1.3% from 1913-1950, 4.8% from 1950-1973, and 1.8% from 1973-1988; and that even higher rates were obtained for the EU and the US as the Dutch started from a relatively high level after their golden age. For that reason he argued – in line with the views of today's mainstream economists – that the 0.5% growth rate in the period from 1995-2003 was not only extraordinary low from an historical, but also from an international perspective. For this reason he suggested to apply higher labour productivity growth rates of 1.2% to 2.1%.

I consider the above argumentation wrong for four reasons. First of all it ignores the existence of technological limits and assumes labour productivity to keep growing at an exponential rate. This implies that labour productivity will eventually reach infinitive levels, which I consider impossible; Secondly, forefront economic research (i.e. based on semi-endogenous growth models) has already acknowledged the existence of diminishing returns to scale in the knowledge-creation function; Thirdly, one can already find some empirical evidence that the economy may no longer be growing at an exponential rate (see Annex B); and fourthly, if one applies such reasoning one should at least look further back in time to recognise the existence of very long periods of time in which virtually no growth occurred. The 2.1% exponential growth rate, that is applied in the official Dutch scenario studies, implies that some 770 years from now just one person is able to produce the entire output of today's Dutch economy[58]. It is sensible to question whether this this is realistic.

[58] A similar argument was also made by Murphy (2012) who amongst others mentioned that an ongoing growth of energy output (that is related to economic output), by an annual rate of 2.3%, would according to the laws of thermodynamics make the oceans boil some 400 years from now.

4.6.2 Alternative views on economic growth

Today's mainstream views assume technological development (i.e. TFP) and economic output (i.e. GDP) to keep growing at an exponential rate virtually forever (or at least without considering ultimate limits)[59]. Though the front running U.S. economy has been growing at a rate of almost 2% over the last two centuries, there is no universal law supporting ongoing exponential economic growth – and there is also nothing in Solow's (1956) theory that points in this direction. Solow regarded technological growth as an exogenous variable that he was unable to predict inside his model. Other methods would be required to estimate the growth of the TFP. The field of technological forecasting attempted to forecast the TFP by means of technological transition curves (i.e. S-curves) in the 1960s and 1970s, but transition S-curves cannot be forecasted accurately before the inflection point is considerably passed, which was clearly not yet the case at that time. The failure to forecast economic growth by means of technological S-curves, as well as the desire of policy makers to take factors from inside the economy into account triggered economists to develop (the first generation of) endogenous growth models in the 1980s[60], but these models also unintentionally created the unfounded belief that the economy in advanced nations is slowly moving towards a fixed equilibrium growth rate on the very long term. From this stage onwards the finite boundary thinking physicists and exponential growth thinking economists started to live in a different world that is reasoning from a different paradigm. Supported by a long period of exponential growth (since the beginning of the Industrial Revolution) the rather optimistic belief that the economy can keep growing at an exponential rate became the mainstream view, and those endorsing the physical limit paradigm were put aside as pessimists[61].

The negative attitude towards those endorsing the physical limit paradigm was amongst others fuelled by the *"Limits to Growth"* study of Meadows et al. (1972) who applied a system dynamics model to indicate the catastrophic very long term effects of exponential growth in a finite world (they modelled up to the year 2100). Paradoxically the output of this study, that applied exponential growth rates for various aspects of our world (such as population, industrial output, resources, and pollution) was perceived as too pessimistic by those who otherwise perceive exponential economic growth quite plausible. The report triggered a great international debate that is still going on today. On the one hand this debate strengthened the belief in the mainstream ongoing exponential growth paradigm while on the other hand it also enhanced the sustainability discussion that is mainly driven by physical limit thinkers. It can therefore be concluded that this debate helped to drive the two paradigms apart.

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[59] I contacted Professor Verspagen (Professor in Economics of Knowledge and Innovation at the UNU-Merit University and Maastricht University) who explained that most of today's economists will not claim growth of labour productivity to go on forever, but just don't take the ultimate limit values into account in their models as their models are not intended to deal with very long term effects.

[60] Romer (1994, p.3) indicated that: *"The phrase 'endogenous growth' embraces a diverse body of theoretical and empirical work that emerged in the 1980s. This work distinguishes itself from neoclassical growth by emphasizing that economic growth is an endogenous outcome of an economic system, not the result of forces that impinge from outside. For this reason, the theoretical work does not invoke exogenous technological change to explain why income per capita has increased by an order of magnitude since the industrial revolution"*.

[61] Quite illustrative for this practice is the fact that I was also once called a Malthusian pessimist in one of the discussions on economic growth during the execution of this study.

People seem to fear for a world without economic growth, but this is not necessary as Jackson (2009) explains how it still remains possible to live a prosperous and meaningful life in absence of economic growth. Jackson argues that technological improvements alone are insufficient to offset the negative effects of ongoing economic growth. Our global society needs to redefine its economic principles. In that respect the world should be better off aiming for prosperity without chasing materialistic economic growth. He shows this is possible.

Meadows et al. (1972), Jackson (2009) and others (see for instance www.growthbusters.org) looked at the issue of ongoing exponential economic growth from the perspective of finite limits to the bearing capacity of the world and our modern society. This perspective is however still miles away from the perspective that is applied by mainstream economists that endorse the paradigm of ongoing exponential economic growth. In order to bridge the gap between these two different paradigms I will first continue with a more economic discussion of the physical limits paradigm that is based on the work of Kahn et al. (1977), Ayres (1990, 2006), Van Duijn (2007), Gordon (2012), and Kwasnicki (2013) – and then address some more recent developments in the field of economics.

The physical limits paradigm from a more economic perspective

Kahn et al. (1977) assumed the world economy to move along a very long term S-curve that started some 200 years ago and that will possibly end some 200 years from now. In their view the growth of the world economy should be placed in the light of the 'Great Transition' that roughly takes place throughout the Industrial Age (period from 1800 to 2000) and the subsequent Information Age (period from 2000 to 2200). An important implication of this view is that population, labour productivity, and economic output cannot continue to grow forever. This implies that the state-of-the-art labour productivity in frontier countries should follow some kind of transition S-curve for which it is impossible to be specific on the shape and length of the curve, but for which one can assume the output to move eventually towards a horizontal asymptote that represents the maximum attainable output per worker.

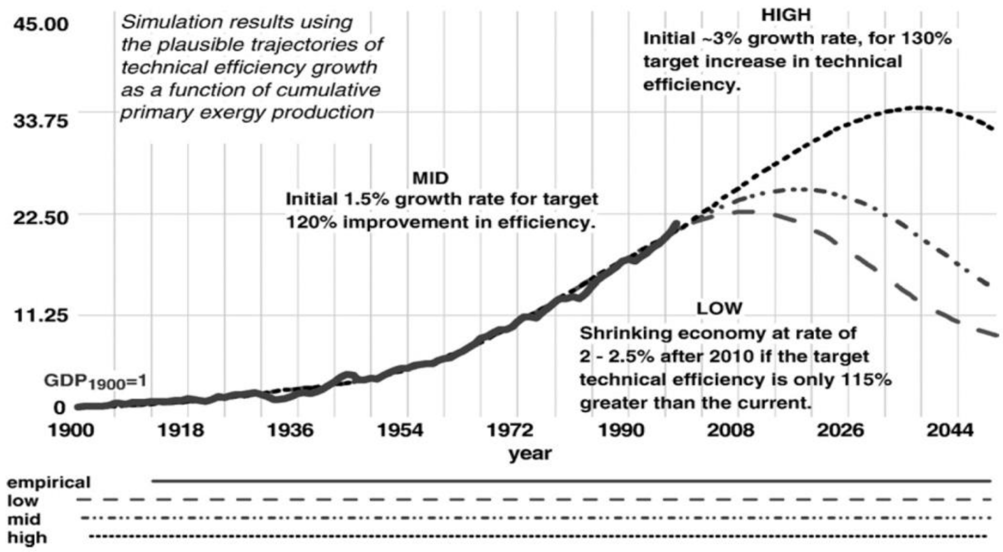
Kwasnicki (2013) also assumed the output of the world economy to follow an S-shaped logistic growth path (see Figure 4-9) and thereby endorses the 'Great Transition' theory.

Van Duijn (2007) argues that economic growth in western countries such as the Netherlands is likely to end. The most important reasons are the decreasing working age population as well as the reduced possibilities to obtain higher levels of labour productivity. Especially in the services sector the possibilities to improve labour productivity are limited. He further points out that: *"Economic Growth is quite a modern understanding. In the works of the classical economists of the eighteenth and nineteenth century (David Hume, Adam Smith, David Ricardo, John Stuart Mill, Karl Marx) it does not appear"* (p.180, translated). In fact: *"We are moving towards a condition in which economic growth is no longer evident. For us this is something new, but for previous generations – those living in the fifties of the twentieth century and all centuries before – economic growth has never been self-evident. In this respect we are returning to historically more normal times. The age of growth of the second half of the twentieth century was the exception, not the rule"* (p.197, translated).

Ayres (2006) clearly breaks with the prevailing views on economic growth as he writes that: *"Perpetual economic growth is an extrapolation from history and a pious hope for the future, not a law of nature"* (p.1190). He regards economic output as a continuous approach to an ever-advancing equilibrium (that may at some stage fall back into decline). The historical growth of the TFP should be related to a number of real growth drivers that occurred since the beginning of the Industrial Revolution. "*These include:*

1. *Division of labour (job specialization), as emphasized long ago by Adam Smith;*
2. *International trade (globalization) as it allows economies of scale and international division of labour;*
3. *Monetization of formerly unpaid domestic and agricultural labour, as a consequence of urbanization;*
4. *Saving and investing (the traditional driver of growth);*
5. *Borrowing from the future (by the creation of new forms of unsecured credit in massive amounts), also tends to increase consumption in the present without creating anything new;*
6. *Extraction of high quality and irreplaceable natural resources and destruction of the waste assimilation capacity of nature;*
7. *Increasing technological efficiency of converting resource (especially fossil fuel) inputs to "useful work" and power"* (p.1190).

Ayres argues that most of the abovementioned drivers are now showing signs of exhaustion and that some of them may even start to have a reverse effect on economic growth. Having entered a stage in which the transition S-curves of most of the abovementioned drivers have well passed their inflection point it now becomes possible to develop technological forecast models, that are able to provide technological projections of the future state of the TFP. This enabled Ayres (2006) to develop a model that was used to prepare a set of very long term projections for the U.S. economy up to the year 2050. Ayres thereby finally achieved what was still impossible in the 1960s and 1970s and gives the field of technological forecasting back its position in the modelling of economic growth. Figure 4-12 indicates the historical fit of the model as well as three different very long term scenarios for the U.S. economy[62].

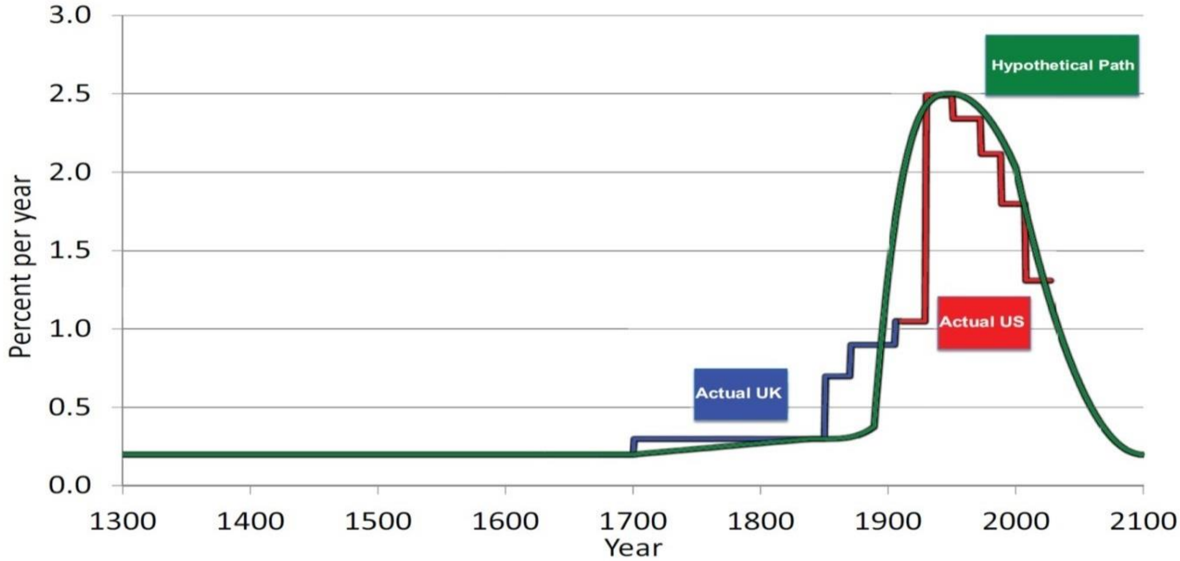


Source: Ayres (2006, p.1195).

Figure 4-12: GDP Scenarios for the U.S. Economy from 2000 - 2050

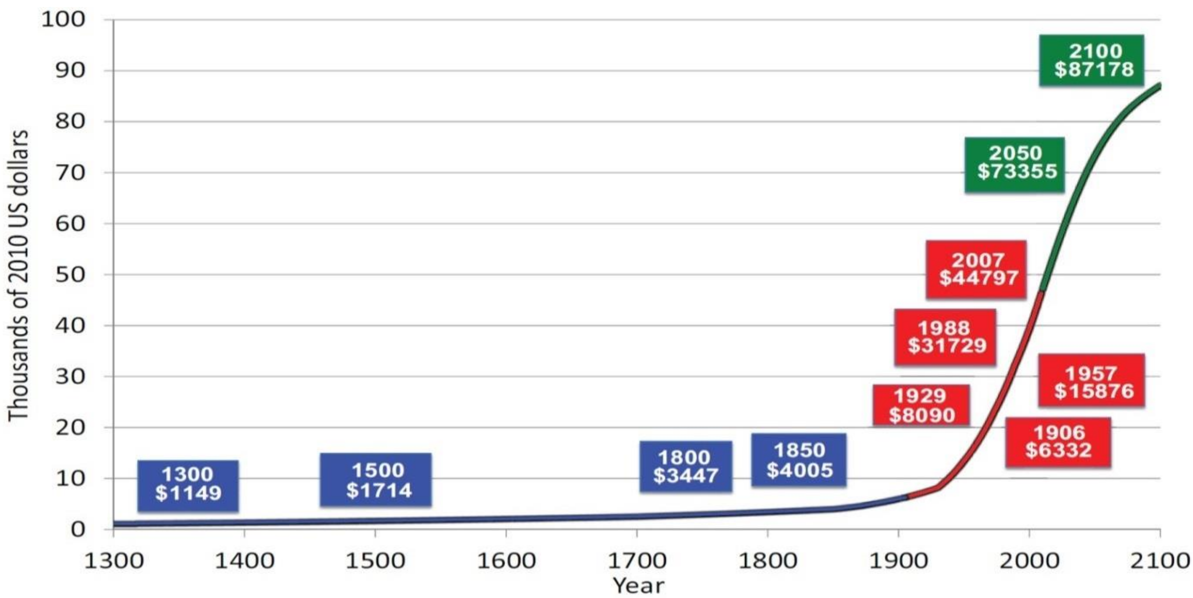
[62] The excellent historical fit of this transition model does not necessarily imply that it is also a good predictor, but the further one moves along the S-curve, the better the projections will become.

In a similar way Gordon (2012) also questioned the mainstream assumption of ongoing economic growth in frontier technology countries. He suggested that the growth rate of the U.S. economy (the world's leading economy) may continue to decline throughout the 21st century. Gordon also concludes that the growth potentials of six major transitions since the Industrial Revolution are now reaching exhaustion. He subtracted the effects of these six growth drivers (i.e. demographics, education, inequality, globalisation, energy, and debt) from the average 1987-2007 U.S. per capita growth rate and found that the U.S. per capita GDP growth may drop to a level of about 0.2 percent per year towards the end of the 21st century. This would represent an epochal decline in growth from the U.S. record over the past 150 years. The hypothetical growth path of his very long term scenario is indicated in Figure 4-13. The implications on the overall GDP per capita levels are indicated in Figure 4-14.



Source: Gordon (2012b, p.4), adjusted size.

Figure 4-13: Growth in real U.S. GDP per Capita with Actual and Hypothetical Paths



Source: Gordon (2012b, p.4), adjusted size.

Figure 4-14: Actual and Hypothetical Levels of U.S. GDP per Capita

Figure 4-13 and 4-14 are quite similar to Figure 4-6 and 4-7. The work of Gordon (2012) is therefore also very much in line with the ‘Great Transition’ theory.

It should finally be noted that the views of Ayres (2006) are also related to a new conceptually distinct field of ecological economics that amongst others aims to incorporate thermodynamic insights with respect to energy and entropy into economic theory (see e.g. Kuemmel, 1986; Ayres, 1998; Ayres and Warr, 2009; and Kuemmel, 2011). This paradigm no longer considers energy and raw earth materials as intermediate products, that can be “produced” in any desired quantity (or form) by deployment of the primary production factors labour and capital, but instead treats: (1) energy as a scarce resource with diminishing energy returns to energy inputs over time (as rich energy mining areas with a high energy return on energy invested are gradually depleting); and (2) minerals (in particular rare earth metals) as scarce resources for which the mines gradually become depleted and recycling can only offer a partial solution as it is impossible to recycle these materials for the full 100%. These more recent views have in common that they also foresee a declining growth, but they work bottom up and no longer start from an assumption on the overall shape of the very long term transition S-curve.

Recent developments in the field of economics

The first generation of endogenous growth models applied a simple (short term) assumption of constant returns to scale in the knowledge creation domain. Though these models are not intended to prepare very long term economic growth projections they have unintendedly contributed to the shift from the former physical (exogenous neo-classical) paradigm on economic growth to the mainstream exponential (endogenous neo-classical) paradigm on economic growth, that is still applied in virtually all official very long term economic growth scenarios. However, the assumption of constant returns to scale in the knowledge creation domain has already been questioned and put aside by forefront economists who observed that this assumption is not in line with empirical observations (see Jones, 1995b).

Starting with the work of Jones (1995a) in the mid-1990s, economists have now developed a second-generation of endogenous growth models, that is referred to as the semi-endogenous growth models. Semi-endogenous growth models are intended to take decreasing returns to scale in the knowledge-creation function into account by assuming the discovery rate of new ideas to depend on: (1) the number of people conducting research (which is ultimately limited by exogenous population growth); and (2) the stock of ideas that has been accumulated over time (for which it is assumed that a larger stock of existing ideas makes it harder to discover new ideas). The second assumption implies that semi-endogenous growth models comply with the physical paradigm that technical growth is a transition phenomenon, and that labour productivity will eventually grow towards a fixed maximum attainable steady state output level (if it does not fall into decline).

The present focus of semi-endogenous economists is directed at the question how long the economy can remain growing at the historical growth rates that have been observed over the past 150 years (i.e. about 2% for the U.S.). Fernald and Jones (2014) point out that technological growth in the U.S. could now start to decrease because the strong growth over the 18th and 19th century in the average years of per capita education as well as in the number of researchers reaches their limits. This implies that it may no longer be possible to keep compensating the diminishing returns to scale in the knowledge creation function by an increased number of researchers. However, this effect may still be offset ‘temporarily’ (e.g. for a few decades) by a strong increase in the number of researchers in developing countries, as well as by – more speculatively – new developments in artificial intelligence.

I therefore conclude that today's mainstream (endogenous neo-classical) views of ongoing exponential growth are still in line with the outdated first generation of endogenous growth models, whereas forefront economists have already put aside the assumption of ongoing exponential growth in the knowledge-creation function some 20 years ago. Today's persistent mainstream views may however start to change in the near future as economists have recently, following the work of Summers (2014), started to discuss the possibility that the economy is drawn into a Secular Stagnation (see also Teulings and Baldwin, 2014).

4.6.3 Redefining the economic growth paradigm

The physical views on economic growth as well as the more recent theoretical and empirical insights from field of endogenous growth modelling underline the necessity to redefine the mainstream paradigm of ongoing exponential growth. This section therefore proposes a 'new' post-neo-classical paradigm on economic growth, that in line with the classical views on economic growth assumes the maximum attainable output level to be restricted by limitations in the available production factors. The main difference is however that, similar to the neo-classical views on economic growth, this post-neo-classical paradigm also allows economic growth to result from technological development, but unlike the neo-classical paradigm the post-neo-classical paradigm is very specific on the assumption that there are decreasing returns to scale in the knowledge-creation function – and the fact that this implies that the labour productivity rate follows some kind of S-shaped very long term transition curve (for which the shape and length cannot be defined on forehand). This new post-neo-classical economic growth paradigm is defined in the following text box.

Defining a new post-neo-classical paradigm on economic growth:
For the preparation of very long term economic growth projections I propose to define a new post-neo-classical paradigm on economic growth that departs from the same neo-classical Solow (1956) model but imposes one additional restriction namely that the state-of-the-art labour productivity in technological frontier countries is ultimately constrained by physical limits and therefore follows some kind of S-shaped transition curve that moves towards a still unknown (and unpredictable) horizontal asymptote on the very long term (say a few hundred to a thousand years from now). This paradigm is in line with the physical views on economic growth and the more recent insights from the field of semi-endogenous economic growth modelling, but it clearly breaks with the mainstream neo-classical view of ongoing exponential growth that has been widely adopted since the development of the first generation of endogenous growth models in the 1980s.

Note that I could have referred to this paradigm as the semi-endogenous neo-classical growth paradigm (as at it is very much alike), but that I choose not to do so because: (1) the word 'post' is better able to make clear that this paradigm breaks with the mainstream neo-classical views of ongoing exponential growth; and (2) it is intended to reflect the general assumption that useful knowledge development and labour productivity growth are eventually limited by physical constraints. The latter also implies that the use of this paradigm does not prescribe the use of semi-endogenous growth models, as one can also apply: technological forecasting techniques; other new methods that are now being developed along the lines of ecological economics; or possibly also some other future models that can, for instance, be based on a merger of ecological economics and semi-endogenous growth models.

The very long term projections that will be presented in this thesis have been developed in line with the post-neo-classical paradigm on economic growth. This choice has clearly affected the obtained transport projections and scenario quantifications, but it has no effect on the answer to the main research question as it does not affect the applied methodology.

4.7 Concluding Summary

This chapter addresses the third general sub question (GSQ 3): *"What are the main trends and drivers for the very long term development of the world economy (i.e. the main driver of the transport system)?"*. The aim of this chapter is to identify the main trends and drivers of the world economy throughout the 21st century and to explain why I think a different paradigm on economic growth should be adopted.

4.7.1 Main trends and drivers of the world economy

A clear definition of 'the long term' does not exist as the perception of time depends on the inertia of the process under consideration. I defined the long term as a period of 5 to 30 years ahead and the very long term as a period of 30 to 200 years ahead. Insight in long term developments can be obtained from Megatrends. Megatrends relate to fundamental processes of transformation with a broad scope and a dramatic impact that take place over a time span of at least a decade. For dealing with very long term issues even longer trends need to be considered, which are the 'Kondratieff waves' and the 'Secular trend' (i.e. trend over ages).

Kondratieff (1926) was amongst the first to publish on the existence of an about 50 years lasting economic cycle that can be observed in the world economy since the beginning of the Industrial Revolution. His work has been confirmed and updated by many others and still provides a useful framework for looking at the dynamics of very long term developments. There is clear empirical evidence that major social-, technological-, and economic changes play an important role in the cyclical behaviour of the Kondratieff waves. Periods of economic growth and expansion are punctuated with phases of fundamental change in the structure of the economy, the technology base, and the social institutions. At a certain stage the dominating socio-techno-economic paradigm, that has led to the previous upswing period, reaches its limits of social acceptability and environmental compatibility and begins to saturate. At that time the world has to wait for a new paradigm to become strong enough to replace the old one. Similar dynamics can also be observed today.

According to several authors the 2009 crisis marked the start of the downswing period of the present 5th Kondratieff wave. Though not explicitly stated this wave is generally considered to be driven by what I refer to as the broad concept of **'Globalisation'**. Being confronted with the main disadvantages of a 200 year long period of unsustainable expansion of human activities taking place since the beginning of the Industrial Revolution, the next Kondratieff wave is expected to be driven by the broad concept of **'Sustainability'**. Important drivers of the 6th Kondratieff wave can therefore be linked to issues like: recycling, sustainable energy, reduction of fuel consumption, and use of environmental friendly modes of transport.

Kondratieff waves provide valuable information on the direction and timing of future trends. Given the fact that the diffusion processes of the 5th Kondratieff wave are now reaching saturation, a new period of major inventions and innovations is expected over the next two decades. It will however take considerable time until these new innovations are sufficiently mature to become the new socio-techno-economic backbone of the next 6th Kondratieff wave. The next upswing period is roughly expected to take place in the period from 2030 to 2055.

Apart from these so called Kondratieff cycles one should also consider the very long Secular trend over the ages. This trend started in the Middle Ages and developed through the

Renaissance and Age of Enlightenment into the Industrial Age. The beginning of the 21st century is assumed to mark the end of the Industrial Age and the world is now presumed to enter a new so called Post-Industrial Nomocratic Age (in which Nomocratic stands for knowledge based). In the pre-industrial period the main source of power was related to the possession of land, during the Industrial Age it shifted to energy and capital, and in the future it is likely to shift towards information, skills, and knowledge.

Kahn et al. (1977) placed the very long term Secular trend in an even broader perspective by presuming that the world is going through a 400 year lasting transition period. *"Some 200 years ago we were all poor and at mercy of the forces of nature while some 200 years from now we will be rich and in control of the forces of nature"*. Kahn et al. (1977) refer to this transition period as the 'Great Transition'. An important implication of this 'Great Transition' view is that the world is moving towards a new reality in which population and economic growth cannot be sustained forever. This implies that economic output per capita and hence labour productivity are slowly moving towards a maximum attainable very long term output value. I endorse the view that the average state-of-the-art labour productivity follows a very long transition S-curve in which the growth of the maximum attainable output per worker is finally levelling-off, but it should be noted that this view differs from today's mainstream paradigm of ongoing exponential economic growth.

4.7.2 Reflection on prevailing economic growth paradigm

The classical views on economic growth assumed the maximum attainable output level to be restricted by limitations in the available production factors (i.e. land, labour, and capital). The subsequent neo-classical views on economic growth are founded on the work of Robert Solow. According to Solow (1956) economic growth can be regarded as a function of labour, capital, and the state of technology, that is referred to as 'Total Factor Productivity' (TFP). The output per worker depends on the level of capital relative to each worker (for which there is an optimum referred to as steady state or balanced growth path) and the state of technology. In other words the GDP output per worker increases as a result of technological development and deepening of the capital stock. Once a country has reached its balanced growth path it can only raise its output per worker by raising the state of technology.

Solow regarded technological growth as an exogenous variable that he was unable to predict inside his model. Exogenous growth was therefore initially defined by means of technological forecasting (i.e. forecasting transition S-curves) in the 1960s and 1970s. However, in the 1980s economists developed (the first generation of) endogenous growth models that were able to relate the growth of the TFP to drivers from inside the economy (e.g. the percentage of GDP spend on research). These models unintentionally created the unfounded belief that the economy in advanced nations is slowly moving towards a fixed equilibrium growth rate on the very long term. Supported by a long period of exponential growth (since the beginning of the Industrial Revolution) this belief became the mainstream view.

The assumption of ongoing exponential growth is now adopted in virtually all official long term scenarios including the Dutch WLO scenarios (up to the year 2040) and the Dutch Delta Scenarios (up to the year 2100) that both assume labour productivity to remain growing at an exponential rate of 1.2% to 2.1% throughout the century. If one would extend the 2.1% annual growth assumption much further into the future this would imply that some 770 years from now just one person is able to produce the entire output of today's Dutch economy. It is sensible to question whether this is realistic.

Though not being mainstream there exist a number of economists with a more 'physical' view on economic growth. Ayres (2006) for instance noted that *"Perpetual economic growth is an extrapolation from history and a pious hope for the future, not a law of nature"*. He warns that *"a continuation of exponential growth until 2100 cannot be taken for granted"*; Van Duijn (2007) indicates that *"We are moving towards a condition in which economic growth is no longer evident. [...] The age of growth of the second half of the twentieth century was the exception, not the rule"*; Gordon (2012) forecasted the U.S. per Capita GDP to grow by just a factor two throughout the 21st century; and Kwasnicki (2013) tried to estimate the world GDP by means of an overall S-shaped transition function. Some of these views (such as those of Ayres) also belong to a new conceptually distinct field of ecological economics that is now developing with the aim to incorporate, amongst others, thermodynamic insights with respect to energy and entropy into the economic theory. This field has in common that it also foresees a declining growth, but it works bottom up and no longer starts from an assumption on the overall shape of the very long term transition S-curve.

In addition modern endogenous economists have already concluded some 20 years ago that the assumption of constant returns to scale in the knowledge creation function (as applied in the first generation of endogenous growth models) is not in line with empirical observations (Jones, 1995). For this reason they have developed a new generation of so called semi-endogenous growth models that do take decreasing returns to scale in the knowledge-creation function into account and thereby comply with the insights from the physical paradigm that technological growth is a transition phenomenon (that follows a transition S-curve) – and that labour productivity will eventually grow towards a maximum attainable steady state output level (if it does not fall into decline). The forefront question in this field is nowadays how long the economy can keep growing at a constant rate by increasing the level of education and the number of researchers in order to compensate for the effects of decreasing returns to scale. Fernald and Jones (2014) indicate that the about 150 year period of persistent 2% exponential growth in the U.S. is now likely to come to an end, though it may be possible to 'temporarily' extend this period for say a few more decades.

On top of this some economists have recently started to discuss the possibility that the economy is drawn into a Secular Stagnation (Summers, 2014).

Taking these insights into account I think it is clear that a new paradigm on economic growth should be adopted and I therefore defined: *a 'new' post-neo-classical paradigm on economic growth that departs from the same neo-classical Solow (1956) model but imposes one additional restriction namely that the state-of-the-art labour productivity in technological frontier countries is ultimately constrained by physical limits and therefore follows some kind of S-shaped transition curve that moves towards a still unknown (and unpredictable) horizontal asymptote on the very long term (say a few hundred to a thousand years from now).* This paradigm is in line with the physical views on economic growth and the more recent insights from the field of semi-endogenous economic growth modelling, but it clearly breaks with the mainstream neo-classical view of ongoing exponential economic growth.

The very long term projections that will be presented in this thesis have been developed in line with the post-neo-classical paradigm on economic growth. This choice has clearly affected the obtained transport projections and scenario quantifications, but it has no effect on the answer to the main research question as it does not affect the applied methodology.

4.7.3 Answer to General Sub Question 3

In answer to GSQ 3, I conclude that there are sufficient options to gain insight in the development of the main drivers of the world economy throughout the 21st century. Long term economic drivers can be related to so-called Megatrends, that relate to fundamental processes of transformation with a broad scope and a dramatic impact that take place over a time span of at least a decade. In addition one can look at very long term economic cycles that are referred to as Kondratieff waves and last for about 50 years. According to several authors the 2009 crisis marked the downswing period of the 5th Kondratieff that was driven by the broad concept of 'Globalisation'. The upswing period of the next 6th Kondratieff wave, that is likely to be driven by 'Sustainability', is roughly expected in the period from about 2030 to 2055. When looking further ahead one needs to consider even longer trends. In this respect one can consider the 'Secular trend' over the ages. The 'Secular trend' indicates a strong growth of population and economic output since the beginning of the Industrial Revolution. Kahn at al. (1977) placed this trend in the broader perspective of the 'Great Transition', an about 400 years lasting transition period in which population, economic output, and hence also labour productivity grow towards a fixed but still unknown final limit value. I endorse the view that the average state-of-the-art labour productivity rate follows a very long transition S-curve in which the growth of the maximum attainable output per worker is finally levelling-off, but this view differs from today's mainstream neo-classical paradigm of ongoing exponential economic growth that is adopted in virtually all official long and very long term scenarios. There are however good reasons to question the exponential growth paradigm as: (1) a few economists point out that there are physical limits to technological development and economic growth; (2) modern semi- endogenous economists have already concluded some 20 years ago that the assumption of constant returns to scale in the knowledge creation function should be replaced by a diminishing growth function; and (3) some economists have recently started to discuss the possibility that the economy is drawn into a Secular Stagnation. I therefore consider it necessary to rejected the mainstream exponential growth paradigm and adopt a 'new' post-neo-classical economic growth paradigm that departs from the same neo-classical Solow (1956) model but imposes one additional restriction namely that the state-of-the-art labour productivity in technological frontier countries is ultimately constrained by physical limits and therefore follows some kind of S-shaped transition curve that moves towards a still unknown (and unpredictable) horizontal asymptote on the very long term (say a few hundred to a thousand years from now). The very long term projections in this thesis have been developed in line with the post-neo-classical paradigm on economic growth. This choice has clearly affected the obtained transport projections and scenario quantifications, but it has no effect on the answer to the main research question.

Literature:

Adams, C., and S. Mouatt (2010) *The information revolution, information systems and the 6th Kondratieff cycle*, MCIS 2010 Proceedings, September 2010.

Allianz Global Investors (2010) *The sixth Kondratieff – long waves of prosperity*, Analysis & Trends, January edition.

Armstrong, J.S. (1985) *Long-Range Forecasting, From Crystal Ball to Computer*, John Wiley & Sons, New York.

Ayres, R.U. (1990a) *Technological Transformations and Long Waves. Part I*, Technological Forecasting and Social Change, vol. 37, no. 1, pp. 1-37.

Ayres, R.U. (1990b) *Technological Transformations and Long Waves. Part II,* Technological Forecasting and Social Change, vol. 37, no. 2, pp. 111-137.

Ayres, R.U. (1998) *Eco-thermodynamics: economics and the second law*, Ecological Economics, vol. 26, no. 2, pp. 189-209.

Ayres, R.U. (2006) *FROM MY PERSPECTIVE - Turning point: The end of exponential growth?*, Technological Forecasting & Social Change, vol. 73, pp. 1188–1203.

Ayres, R.U. and B.S. Warr (2009) *The economic growth engine: How energy and work drive material prosperity*, Cheltenham, UK and Northampton MA, Edward Edgar Publishing, US.

Besomi, D. (2005) *Clément Juglar and the transition from crises theory to business cycle theories,* paper prepared for a conference on the occasion of the centenary of the death of Clément Juglar, Paris (www.unil.ch/webdav/site/cwp/users/neyguesi/public/D._Besomi_).

Bruce, E.T. (2004) *Integrated 1000-year planning*, Futures, vol. 36, no. 1, pp. 91-108.

Dal-Pont Legrand, M., and H. Hagemann (2007) *Business Cycles in Juglar and Schumpeter,* (from www.unil.ch/webdav/site/cwp/users/neyguesi/public/bc/Juglar_Schumpeter.pdf).

De Groot, B., and P.H. Franses (2009) *Universal Cycle Periods*, NRI Research Paper Series, No. 09-06, Nyenrode Research and Innovation Institute, Breukelen, The Netherlands.

DeLurgio, S.A. (1998) *Forecasting Principles and Applications*, international editions 1998, Mcgraw-Hill College.

Fernald, J.G. and C.I. Jones (2014) *The Future of US Economic Growth*, American Economic Review: Papers and Proceedings, vol. 104, no. 5, pp.44-49.

Freeman, R., and B. Berelson (1974) *Human Population*, Scientific American, September 1974, pp. 36-37.

Gordon, R.J. (2012a) *Is U.S. Economic Growth Over? Faltering Innovations Confronts the Six Headwinds*. Working Paper 18315, National Bureau of Economic Research, Cambridge, USA.

Gordon, R.J. (2012b) *Is U.S. Economic Growth Over? Faltering Innovations Confronts the Six Headwinds*. Centre for Economic Policy Research, vol. 63.

Grübler, A. (1990) *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport*, Physica-Verlag Heidelberg.

Grübler, A., and N. Nakićenović (1991) *Long Waves, Technology Diffusion, and Substitution*, IIASA, Laxenburg, Austria.; reprinted from Review XIV(2), Spring 1991, pp. 313-342.

Huizinga, F.H., and K. Folmer (2012) *CPB notitie betreft: Invulling macro beeld Delta scensrio's*, Centraal Planbureau.

IPCC (2000) *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, [Nakicenovic, N. and R. Swart (eds.)], Cambridge University Press: Cambridge, UK and New York, 570 p.

IPCC (2007) *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Pachauri, R.K, and A. Reisinger (eds.)], IPCC, Geneva, Switzerland.

Jackson, T. (2009a) *Prosperity without growth? The transition to a sustainable economy*, Sustainable Development Commission, http://www.sd-commission.org.uk/.

Jackson, T. (2009b) *Prosperity without growth, Economics for a finite planet*, Earthscan, London, Uk.

Jones, C. I. (1995a) *R&D-based models of economic growth*, Journal of Political Economy, vol. 103, no. 4, pp. 759-783.

Jones, C. I. (1995b) *Time Series Tests of Endogenous Growth Models,* Quarterly Journal of Economics, vol. 110, no. 2, pp. 495-525.

Kahn, H., W. Brown, and L. Martel (1977) *The Next 200 Years, A Scenario for America and the World,* The Hudson Institute, Associated Business Programmes Ltd., 17 Buckingham Gate, London, United Kingdom.

Kitchin, J. (1923) *Cycles and Trends in Economic Factors,* The Review of Economies and Statistics, The MIT Press, vol. 5, no. 1 (January), pp. 10-16.

Korotayev, A.V., and S.V. Tsirel (2010) *A Spectral Analysis of World GDP Dynamics: Kondratieff Waves, Kuznets Swings, Juglar and Kitchin Cycles in Global Economic Development, and the 2008-2009 Economic Crisis,* Structure and Dynamics, vol. 4, no. 1. Retrieved from http://www.escholarship.org/uc/item9jv108xp.

Kondratieff, N.D. (1926) *Die langen Wellen der Konjunktur,* Archiv fűr Sozialwissenschaft, vol. 56, pp. 573-609.

Kondratieff, N.D. (1935) *The Long Waves in Economic Life,* Summarised English translation of German 1926 article by W.F. Stolper, The Review of Economic Statistics, vol. 17, no. 6.

Kuemmel, R. (1986) *Energy, technical progress and economic growth*, in *Energy Decisions for the Future*, Miyata M. and K. Matsui (eds.), Institute of Energy Economics, Tokyo.

Keummel, R. (2011) *The Second Low of Economics: Energy, entropy and the origins of wealth*, The Frontiers Collection, Springer, New York, Dordrecht, Heidelberg and London.

Kuznets, S. (1930) *Secular Movements in Production and Prices, Their Nature and their Bearing Upon Cyclical Fluctuations,* Boston, MA: Houghton Mifflin Co.

Kwasnicki, W. (2013) *Logistic growth of the global economy and competitiveness of nations*, Technological Forecasting and Social Change, vol. 80, pp. 50-76.

McCraw, T.K. (2006) *Schumpeter's Business Cycles as Business History,* Business History Review, Vol. 80 , summer ed., pp. 231-261, The President and Fellows of Harvard College.

Meadows, D. H., D. L. Meadows, J. Randers, and W.W. Behrens III (1972) *The Limits to Growth,* Universe Books, New York.

Moody, J.B., and B. Nogrady (2010) *The Sixth Wave: How to Succeed in a Resource-limited World*, Vintage Books, Sidney, Australia.

Murphy, T. (2012) *Exponential Economist Meets Finite Physicist*, Do the Math Blog, http://physics.ucsd.edu/do-the-math/2012/04/economist-meets-physicist/.

Naisbitt, J. (1982) *Megatrends, Ten New Directions Transforming Our Lives,* Warner Books.

Naisbitt, J., and P. Aburdene (1990) *Megatrends 2000, Ten New Directions for the 1990's,* William Morrow Inc., New York.

OECD (2012) *Looking to 2060: Long-term global growth prospects*, OECD Economic Policy Papers, no. 3.

Romer, P.M. (1994) *The Origins of Endogenous Growth*, Journal of Economic Perspectives, vol. 8, no. 1, pp. 3-22.

Schumpeter, J.A. (1931) *The Theory of the Business Cycle,* Keizaigaku Ronshu – The Journal of Economics, vol. 4, pp. 1-18 (provided by www.schumpeter.info/text2~1.htm).

Schumpeter, J.A. (1939) *Business Cycles – Volume 1*, McGraw-Hill, reprinted by Porcupine Press inc., 1982.

Schumpeter, J.A. (1939) *Business Cycles – Volume II,* McGraw-Hill.

Schumpeter, J.A. (1954) *History of Economic Analysis,* George Allen & Unwin, London.

Smid, B. (2005) *Arbeidsproductiviteit op lange termijn in historisch en international perspectief*, CPB Memorandum, vol. 107, Jan 14th.

Solow, R.M. (1956) *A Contribution to the Theory of Economic Growth*, The Quarterly Journal of Economics, vol. 70, no. 1, pp. 65-94.

Spies, P.H. (1998) *Millenial Megatrends: Forces Shaping the 21st Century,* Keynote address to the Annual Conference of the International Association of Technological University Libraries (IATUL), June 1st, University of Pretoria, South Africa.

Summers, L.H. (2014) *U.S. Economic Prospects: Secular Stagnation, Hysteresis, and the Zero Lower Bound*, Business Economics, vol. 49. no. 2, pp. 65-73.

Tarascio, V.J. (1988) *Kondratieff's Theory of Long Cycles,* Atlantic Economic Journal, vol. 16, no. 4, pp. 1-10.

Teulings, C. and R. Baldwin eds. (2014) *Secular Stagnation: Facts, Causes, and Cures*, Centre for Economic Policy Research (CERP), London.

Tinbergen, J. (1981) *Kondratiev Cycles and So-Called Long Waves: The early research,* Futures, vol. 13, no. 4, pp. 258-263.

United Nations (2004) *World Population to 2300,* UN Department of Economic and Social Affairs, New York.

Van Duijn, J. (2007) *De groei voorbij, Over de economische toekomst van Nederland na de booming nineties*, De bezige bij, Amsterdam.

Van Wyk, R.J. (1984) *Panoramic Scanning and the Technological Environment,* Technovation, vol. 2, no. 2, pp. 101-120.

Verspagen, B. (1992) *Endogenous Innovation in Neo-Classical Growth Models: A Survey*, Journal of Macroeconomics, vol. 14, no. 4, pp. 631-662.

Z-Punkt (2008) *Megatrends, Köln*, Germany, http://www.z-punkt.de/fileadmin/be_user/D_Publikationen/D_Giveaways/web_Megatrends_de_105x130.pdf

Websites:

IIASA (accessed: 2009) *IIASA's World Population Program,* [www.iiasa.ac.at/research/pop]

Investopedia (accessed: 2014) *Definition of Neoclassical Growth Theory,* [www.investopedia.com/terms/n/neoclassical-growth-theory.asp]

Maddison, A. (accessed: 2009) *Historical Data on Population and GDP,* [www.ggdc.net/Maddison]

5 Dealing with Very Long Term Policy Issues

"An old Arab proverb says that, "he who predicts the future lies even if he tells the truth.""
- Peter Schwartz (The Art of the Long View, 1991, p.6)

5.1 Introduction

In order to select the most appropriate methods for the evaluation of policies with a very long term impact, policy makers (such as Rijkswaterstaat) and researchers in the field of policy making require insight in the various methods that exist for looking far ahead and taking very long term effects into account. This chapter addresses the fourth general sub question (GSQ 4): *'What are the most appropriate methods for looking far ahead (i.e. towards the end of the 21st century) and dealing with the inevitable high levels of uncertainty, that are related to such a very long term planning horizon?'*. It provides insight in the broader field of saying something about the future, the available methods for developing a long term view, the various ways to classify uncertainty, the available policy options for dealing with uncertainty, and the appropriate decision criteria. Section 5.2 starts with a discussion on the topology that is applied in the field of *'saying something about the future'*; Section 5.3 continues with a discussion on forecasting-, foresight-, and futures research methodology; Section 5.4 deals with the various ways to classify uncertainty; Section 5.5 addresses the available policy options for dealing with uncertainty; Section 5.6 combines the obtained insights into a clear policy guideline for selecting the most appropriate methods for looking far ahead and dealing with uncertainty; and Section 5.7 finally contains a concluding summary that provides an answer to GSQ4.

5.2 The field of saying something about the future

The field of *'saying something about the future'* appears to be as cloudy as the future itself. Over the years the field has been given so many names that Cornish (1978, p.155) already spoke of *"A field in search of a name"*[63]. Marien (2002, p.263) called it a *"very fuzzy multi-*

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[63] According to Wikipedia (2009) *"The discipline (of futures studies) goes by different names, depending on the cultural context. Such names include future studies, foresight, futurism, futurology, prospective (in France), and prospectiva (in Latin America). Futures studies has become the common term in the English-speaking world, while futurologists themselves often speak of strategic foresight. Practitioners of futures studies classify themselves as futurists or foresight practitioners (previously futurologists)"*.

field", and Börjeson el al. (2005) indicate that *"among futurists themselves there is no consensus on how to categorise and delineate futures studies"*. This section investigates the topology that is used in the field and concludes with my own interpretation of the topology.

5.2.1 Topology applied in the field of saying something about the future

Duin (2006, p.38) provides a description of the history of the field of saying something about the future in which he mentions a vast number of different words including: *futures research, futures studies, futures management, foresight, futurology, futurism, conjecture, technological forecasting, technology forecasting, forecasting, prospectivism, prognostics, prospective study, and long range planning*. Over the years many new names have been given for various reasons and sometimes the meaning of the terminology has also evolved over time. As a result there is overlap in terminology and the boundaries are often vague. Besides this *"Futurists have not reached consensus on the name or definition of their activity"* (Glenn et al., 2009a, p.64). It is therefore challenging to give an unambiguous outline of the applied topology.

According to Encyclopedia Britannica *futurology* is: *"the study of current trends in order to forecast future developments"*. With respect to the origin of the field it states: *"While the speculative and descriptive aspects of futurology are traceable to the traditions of utopian literature and science fiction, the methodology of the field originated in the 'technological forecasting' developed near the end of World War II"*. However, from the footnote on the previous page I conclude that futurology attempted to become a professional field of research, but that it could not get rid of its old meaning, and that the terminology therefore shifted towards futures studies, futures research, and (strategic) foresight.

Futures research (or futures studies) is likely to be the broadest nametag for the field of saying something about the future in a disciplined way. Slaughter (2009, p.7) provides a broad definition stating that *"Futures studies reflects on how today's changes and continuities become tomorrow's reality"*. According to Duin (2006, p.29) futures research comprises both fiction and non-fiction as he writes: *"Futures research, which was originally triggered by the ideas and novels of Jules Verne, soon began to adopt an increasingly scientific approach"*. Nowadays futures research is no longer intended to include fictive elements. Masini (1998) distinguishes between: futures study, prospective study, and futures research. She argues that: futures study is the broadest possible domain of disciplined futures thinking; prospective study is more or less synonym, but more orientated to the making of the future instead of knowing and understanding it; and futures research is exclusively reserved for knowledge and understanding of the future itself (which many believe is not even possible). Masini's distinction between futures study and futures research is similar to the belief of Jouvenel who argues that the future can only be conjectured, but not known (Malaska, 2001, p.228). However according to Malaska (2001, p.229):*" in standard sciences it is generally held that scientific interest in knowledge is to know in order to be able to understand, and to understand in order to predict"*. This is why Malaska (2001, p.230) regards the term futures research as *"the most rigorously disciplined part of futurology"*.

The term *foresight* is applied to clearly distinguish from futurology and to some extent also from futures research. Foresight provides a range of likely futures while futurology attempts to provide a definitive picture of the future. The difference with futures research is that foresight relates to the process of providing a coherent and functional forward view while *"Futures studies examine a broad range of not only possible, but also probable, preferable, and wildcard futures, and typically attempt to gain a holistic or systematic view based on insights from a range of different disciplines"* (Slaughter, 2009, p.8). In this sense foresight relates to a specific approach in a broader field of futures studies, but others still regard foresight and futures studies as interchangeable terms (Riedy, 2009, p.42). Martin (1995, p.140) indicates that foresight *"is the process involved in systematically attempting to look longer into the long-term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging of generic technologies likely to yield the greatest economic and social benefits"*. Cuhls (2003, p.96) calls this the *'classical'* definition and suggests an alternative less specific definition by Coates (1985, p.30): *"Foresight is the overall process of creating an understanding and appreciation of information generated by looking ahead"*. The *Strategic Foresight Group*[64] defines foresight as *"forecasting with insight"*. The word *strategic* is used to indicate that foresight is about strategic issues. To conclude with a definition by Slaughter (p.8): *"Strategic foresight is the ability to create and maintain a continuous high-quality, coherent and functional forward view, and to use the insights arising in useful organizational ways"*.

Forecasting considers the process of making statements about events which have not yet been observed (Wikipedia, accessed: 2012). Forecasts may refer to estimates of time series, cross-sectional or longitudinal data. Cuhls (2003, p.95) defines forecasting as: *"the estimation of the short-, medium- or long-term future in a specific research area or according to the questions posed by means of scientific methodology"*. In general a forecast refers to a single best estimate of the expected future developments, but forecasting literature sometimes also refer to the use of scenarios to develop different forecasts (e.g. a low, medium, and high forecast). Armstrong (2001, p.517) warns not to use scenario techniques to provide forecasts because *"If you do, you are likely to be both wrong and convincing"*. Forecasting techniques can be used to quantify scenarios, but this does not hold the other way around.

In the past the terminology *technology forecasting* and *technological forecasting* was also frequently used. According to Schon (1967, p.759) technological forecasting means: *"the forecasting of technological change. […] A technological forecast, therefore, is the forecast of the invention, innovation, or diffusion of some technology"*. One of the purposes of developing diffusion models was to incorporate technology driven (economic) growth into the forecast and to allow for the development of forecasts with a longer planning horizon. For several reasons technological forecasts often fail (Rosenberg, 1995, p.15-21). Amongst others this has to do with the fact that most technological growth and substitution models require insight in the type of growth curve and the final performance level of the technology (DeLurgio, 1998, p.645). According to Makridakis et al. (1998, p.452) *"Technology is not the only factor affecting the long run, […] many of the tools and techniques advocated in technological forecasting did not provide more accurate predictions about the long-term and have been, in consequence, abandoned. Today, we prefer to simply talk about 'forecasting the long run'"*. Others such as DeLurgio (1998, Chapter 15) remain using the terminology of technological forecasting for the S-shaped growth and substitution models.

5.2.2 The new topology definition that is applied in this thesis

I conclude that the topology for describing the field of *'saying something about the future'* is still vague and contains considerable overlap in the applied terminology. For that reason I will

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[64] The Strategic Foresight Group (SFG) is an Indian Think Tank established in 2002 that undertakes forward-looking research in geopolitical, economic, technological and societal changes. The SFG advises government bodies all over the world (Source: www.strategicforesight.com and Wikipedia, both accessed: in 2009).

now define a new topology definition by means of a conceptual model, that I will refer to as the *'Futures Research Pyramid'*. This model aims to comply (as good as possible) with the existing terminology, but avoids overlap between the various subfields. The conceptual model of the futures research pyramid is presented in Figure 5-1.

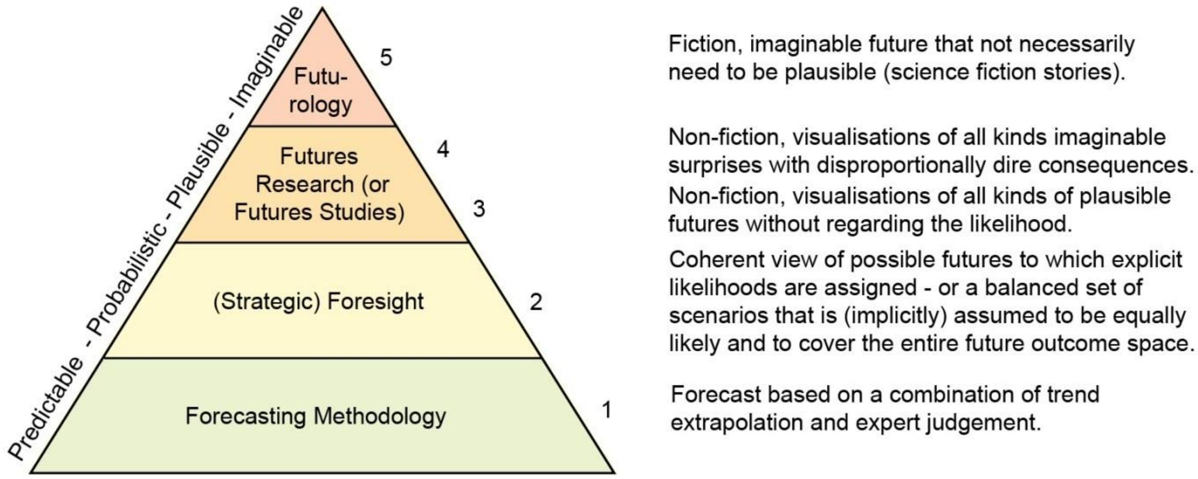

Figure 5-1 Futures Research Pyramid

The Futures Research Pyramid is somewhat comparable to Maslow's (1954) pyramid of human needs. Each level builds on the previous levels below. The higher the hierarchy of the level, the less certain the future is assumed to be. At the bottom of the pyramid one finds the area for which most insights in the future are assumed to be available. The most uncertain and unpredictable views of the future are located in top of the pyramid. The model recognises five levels at which insight in the future can be obtained, of which the first four levels will turn out to correspond with the levels of uncertainty discussed in Section 5.4.1.

Level 1: Forecasting methodology aims to provide a single reliable estimate of the future state of the system on the basis of trend extrapolation techniques and expert judgement. Forecasts are intended to provide, with a high level of certainty, a best estimate of rather detailed aspects of the system under consideration, a few time periods ahead.

Level 2: Foresight aims to develop a coherent forward view of possible futures. The word coherent refers to the fact that the forward view is intended to cover the full expected range of likely futures, and that it is clear about the likelihood of these futures. Obvious examples of foresight methodology are: probabilistic projections, and scenarios for which the likelihood is explicitly stated. Less obvious is the use of a balanced set of scenarios that is implicitly assumed to be equally likely and to cover the entire future outcome space. For these scenarios nobody is actually saying that they are equally likely nor that they are intended to cover the entire future outcome space, but it still turns out to be the way that they are treated[65].

[65] There is a thin line between the development of a balanced set of equally likely scenarios that are intended to cover the entire future outcome space (i.e. Level 2 methodology) and the development of an exploratory set of scenarios that is intended to indicate a number of plausible developments (i.e. Level 3 methodology). In practice this will need to become clear from the context of the concerned scenario study.

Level 3 and 4: Futures research methodology aims to provide a systematic view of plausible future developments without considering the likelihood that these developments will happen. Within the futures research methodology a distinction can be made between usual plausible futures (e.g. presented as storyline scenarios) and imaginable surprises (e.g. presented as wildcard scenarios). I will classify the usual plausible futures as level 3 futures research methodology and the imaginable surprises as level 4 futures research methodology.

Level 5: Futurology refers to imaginable futures that not necessarily need to be plausible (i.e. science fiction stories). This level is not expected to be of any use for the development of a systematic forward view and will therefore not be taken further into consideration.

5.3 Methodologies for Looking Ahead

This section provides an analysis of forecasting, foresight, and futures research methodology reported in literature, and concludes with a selection of methods that I consider the most relevant for developing a very long term forward view.

5.3.1 Forecasting methodology

This section provides a discussion on the various methods and models reported in forecasting literature. It aims to provide an outline of the available forecast methodology.

Classification of forecasting methodology

There are several ways to classify forecasting methodology. An obvious way is to distinguish between *quantitative* and *qualitative* methods. Quantitative forecasts are applied when sufficient quantitative data is available. Qualitative forecasts are applied in cases where little or no quantitative data is available, but sufficient qualitative data exists. Makridakis et al. (1998, p.8) also includes a third category referred to as *unpredictable* which deals with the situation in which little or no information is available. Others such as DeLurgio (1998, p.22) and Levenbach et al. (2006, p.28-31) categorize techniques for dealing with unpredictability amongst the qualitative methods. An alternative option is to distinguish between *statistical* and *judgemental* methods. I prefer the latter option as it clearly distinguishes between *'hard'* statistical trend extrapolation methods and *'soft'* methods that are based on judgement.

Statistical forecast models

Statistical forecast models can be subdivided into *univariate time series forecast models* and *multivariate explanatory or causal forecast models*.

Univariate forecasting models (or time series models) use past internal patterns in the data to forecast the future. Univariate methods model time series entirely as a function of their own past values, with no outside explanatory variables. For this reason I will refer to them as *trend extrapolation models*. The simple methods such as *naïve methods* (use previous value), *moving average estimates*, and *exponential smoothing* are discrete models designed to forecast only a few periods (or steps) ahead. They are not useful for obtaining a long term view. Wilson (2009, p.58) indicates that methods suitable to forecast longer time spans include *regression analysis, decomposition methods* and *autoregressive integrated moving average models (ARIMA)*. However, it should be noted that these models are still based on mere trend extrapolation, and therefore they may still not be very suitable for the development of a very long term view, in particular not when trend breaches can be expected.

Multivariate forecasting models (or explanatory or causal models) define the cause and effect relationship in a system. Some multivariate models reflect on the true causes and effects, but many others are only focussed on the statistical properties of the forecast accuracy (i.e. significance of the estimated parameters). For the development of a very long term view the more theory-based causal models are likely to be the most promising. However these models will often require exogenous input of the explanatory variables such as for instance a GDP forecast (or scenario). Exogenous input is not required for auto regressive models that are entirely based on historical data, such as for instance the Multiple ARIMA and Vector Auto Regressive (VAR) models, because the causal relations that are applied in these models are related to lagged values of the system variables themselves. This implies that the latter models are still based on mere trend extrapolation, and for this reason I do not consider them suitable for the development of a very long term view. A special type of multivariate models are the *cyclical models*. These models try to predict turning points in the economy by using leading indicators, rates of change, and long wave theories (DeLurgio, 1998, p.24). However cyclical forecast models have not proven to function well. In fact, economists have not been very successful in predicting crashes of the stock market. Armstrong therefore (2001, p.233) warns not to forecast cycles unless they can be known with reasonable certainty (such as four-year Olympic Games or variance in overall power demand over the day). Makridakis et al. (1998, p.461) also indicate that (economic) *"Cycles cannot be predicted quantitatively as their length and depth are not constant"*.

Judgemental forecast methods

Judgemental methods are applied in cases where judgement becomes the primary source of information because: there is little relevant numerical data, past data may not exist, or the forecast horizon is so far in the future that historical data becomes irrelevant (DeLurgio, 1998, p.625). The use of judgemental forecasts is discussed by Armstrong (2001), DeLurgio (1998), Hanke and Wichern (2009), Levenbach and Cleary (2006), and Makridakis et al. (1998). DeLurgio (1998, p.653) classifies judgemental methods into: *subjective judgement and estimates*, *explorations of alternative futures*, *normative models*, and *S-growth curves*. The forecasting of S-growth curves is also referred to as technological forecasting.

Subjective judgement (or expert judgement) is often applied to develop long term forecasts. Estimates can be made by an individual or a group of experts. Most methods rely on a group decision process as they assume a group of experts to provide more accurate estimates than a single expert. Commonly used techniques are the *Panel Consensus* method (or *Jury of Executive Opinion*), the *Delphi* method, and the *Nominal Group Process* method[66]. The Panel Consensus method can be as simple as having a group of experts sitting together around a table defining the forecast collectively. To avoid possible negative effects of group dynamics the *Delphi* method was developed by RAND researchers in the 1950s (Lempert at al. 2003, p.16). Instead of bringing experts together to discuss a subject, the Delphi method provides questionnaires to the experts with the admonishment not to discuss the problem amongst each other. In each next round the summarized findings are distributed and the experts are requested to reconsider their previous estimate. The Nominal Group Process method is positioned in-between the Panel Consensus method and the Delphi method. The experts are

[66] For the Panel Consensus method reference can be made to DeLurgio (1998, p.629-630), Wilson et al. (2009, p.18) and Levenbach et al. (2006, p. 28-29). The use of the Delphi technique is discussed by DeLurgio (1998, p. 636-637), Wilson et al. (2009, p.18-19), Levenbach et al. (2006, p. 29), and Armstrong (2001, p. 125-144). The Nominal Group Process is discussed by DeLurgio (1998, p. 639).

initially asked to write down their opinions after which the information is shared and a final consensus is (hopefully) reached by means of an open discussion.

For the *exploration of alternative futures* DeLurgio (1998, p.632-641) and Makridakis et al. (1998, p.459-477) refer to the use of *(long term mega economic) trends*, *(historical) analogies*, and the development of *scenarios*. Wilson et al. (2009, p.22-24) also refers to the use of analogies, but places this in the concept of product development (insight required for the development of S-curves). In addition to the above DeLurgio (1998, p.638) refers to the use of the *cross impact analysis*, *case studies*, and the *analytical hierarchy process*. Wilson et al. (2009, p.30) discusses a method called *morphological research*. Cross impact analysis defines interrelationships between possible future events and can therefore be seen as the qualitative counterpart of the use of causal relations. Case studies, analytical hierarchy process and morphological research methods compare new technologies to old ones and are therefore somehow comparable to the use of analogies.

Normative methods, that are referred to as backcasting (not being forecasting), are discussed by DeLurgio (1998, p.641-643) who describes them as *"methods for defining how desired futures might be made to occur"*. These futures *"are based on the premise that the future can be influenced much more than many assume is possible"*, and that *"Organizations can achieve desirable futures by first defining these futures and then taking the actions necessary to achieve those futures"*. For applying backcasting DeLurgio describes the *relevance tree*, a method conceptually similar to decision trees applied in decision theory. Decision trees are also discussed by Levenbach et al. (2006, p.30-31).

Remarkably DeLurgio (1998, p.643) also discussed the use of *system dynamics* in the section on normative methods. The logic behind this is probably that there are decision rules involved, but I would regard it a combination of causal forecast models and expert judgement (on the applied range for the estimated parameters used in the forecast). In addition it is worth mentioning the use of *game theory*. This theory involves multiuser decisions and system dynamics. The use of the game theory is discussed by Armstrong (2001, p.22).

Technological growth and substitution growth models (S-curve growth models) are generally classified amongst the judgemental models as they require insight in the type and maximum level of the curve. Grübler (1990, p.12-21) describes a range of (biological) growth and substitution models. Growth models include the three parameter logistic (Pearl) curve[67], the positively skewed growth curve proposed by Floyd (1968), the Gompertz (1825) curve, and the modified exponential curve[68]. Substitution models include the Fisher and Pry model (1971) and the more flexible substitution model of Sharif and Kabir (1976). In addition it is worth mentioning the Bass (1969, 2004) model for new product introductions. The Bass model was first published in 1969 and thereafter republished in 2004. The Bass model is also discussed by Wilson et al. (2009, p.135).

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[67] The logistic Pearl curve was first proposed by Verhulst (1838) as a model for human population growth and then rediscovered by Pearl (1925) for the description of biological growth processes.

[68] The logistic (Pearl, 1925) curve and the Gompertz (1825) curve are also discussed by Delurgio (1998, p.645-653) and Wilson et al. (2009, p.125-138). Wilson et al. also discuss the Bass Model for product substitution.

5.3.2 Long term forecast methods

Forecasting literature provides a wide range of possible techniques for anticipating future developments. To investigate which of these methods could be useful for the development of a long- and very long term view, I analysed 12 forecasting textbooks and 2 leading journals on forecasting. The selection of the analysed textbooks includes the books recommended at www.forecastingprinciples.com as well as a few other textbooks that were available at the Delft University Library. Half of these books turned out to make no explicit reference to any methods relevant for long term forecasting. The other books provided some useful clues. The findings from the analysis of the 12 forecasting textbooks are presented in Table 5-1.

Table 5-1: Long Term Forecasting Methods described in Forecasting Textbooks

No.	Reference	Long Term	Issues discussed with respect to Long Term Forecasting
1	Armstrong, J.S, ed. (2001)	N/A Note: Armstrong (1985) states > 2 years	*Discussion of forecasting principles that, to a certain extent can also be applied to the long term (no explicit notice by authors)*: Use of scenarios is advocated to gain acceptance for forecasts, but not as method for preparing long term forecasts. Section on diffusion of innovations. Discussion of qualitative and judgemental methods of which some may also be applicable to long term forecasting.
2	Bails et al. (1993)	> 2 years	*No explicit reference made to long term forecasting.*
3	Bowerman et al. (2005)	> 2 years	*No explicit reference made to long term forecasting.*
4	Clements et al. (1998)	N/A	*No explicit reference made to long term forecasting.*
5	DeLurgio (1998)	3 to 20 years	*Chapter on "Technological and Qualitative Forecasting Methods: Long-Term Forecasting" summarizes available techniques and compares forecasting methods for immediate, short term, medium term and long term issues*. Discussion of qualitative methods and technological S-curves that may also be applicable to very long term forecasting.
6.	Diebold (2004)	N/A	*No explicit reference made to long term forecasting.*
7	Hanke et al. (2008)	N/A	*No explicit reference made to long term forecasting*: Discussion of some techniques that may be applicable to very long term forecasting such as technological S-curves, use of judgemental forecasts, scenario's and Bayes' theorem.
8	Levenbach et al. (2005)	> 2 years	*No explicit reference made to long term forecasting*: Discussion of applicability of various techniques at various time horizons. Discussion of various methods that may be applicable to the long term such as qualitative forecasting methods, use of dynamic systems modelling, and causal relations.
9	Makridakis et al. (1998)	N/A	*Chapter on "Forecasting the long-term" provides some guidance:* Use of mega-trends, analogies, and scenarios as an attempt to visualise a number of possible futures and consider their implications.
10	Mentzer et al. (1998)	N/A	*No explicit reference made to long term forecasting.*
11	Pindyck et al. (1997)	N/A	*No explicit reference made to long term forecasting.*
12	Wilson et al. (2009)	N/A	*No explicit reference made to long term forecasting*: Use of techniques for various time horizons. Discussion of various methods that may be applicable to the long term such as qualitative forecasting methods, causal relations, and S-curves.

Forecasting textbooks generally refer to the long term as anything over 2 or 3 years in the future. This is clearly much shorter than the 5 to 30 year definition that I apply (see Chapter

4). It is therefore not very surprising that long term forecasting has not received much attention in textbooks. Makridakis (1998) was the only author that wrote a full chapter on long term forecasting. In this chapter he pointed in the direction of *long term trends, analogies*, and *scenarios*. Other textbooks referred to the use of *causal relations*, *long term (economic) trends*, *qualitative estimates (such as expert judgements*, *panel consensus*, *Delphi*, and *nominal group process*), *analogies*, *technological S-curves*, *Bayes' theorem*, and *system dynamics modelling*. The use of probabilistic (or Bayesian) forecasts was not mentioned once in the analysed textbooks. For this subject I refer to West and Harrison (1999).

The notion that long term forecasting methodology has not received much attention is also confirmed by a review of the scientific articles on long term forecasting, that were published in the *"Journal of Forecasting"* and the *"International Journal of Forecasting"*. Apart from some work on the use of scenarios hardly anything was published on the subject of long term forecasting. This was already mentioned by Fildes in 1986 who wrote in the editorial section of the 2nd volume of the *International Journal of Forecasting* (p.4) that *"The editors have not yet published much work directly addressing the question of how to improve long-range forecasts. Of course the work on judgement is potentially valuable. Articles published in "Futures" and "Technological Forecasting and Social Change" are rarely concerned with methodological issues. But improving long-term forecasting and identifying the bounds of uncertainty is important. Large sums of money are committed premised on just such forecasts. Our job as editors is to encourage rigorous research on longer-term problems"*. Twenty years later in a 25 year review of these two leading forecasting journals and their contribution to forecasting research Fildes (2006, p.420) had to reconfirm his previous statement as he wrote that *"There has also been little work on longer term forecasting issues"*.

5.3.3 Foresight and futures research methodology

A meta-scanning overview of the state of play in the futures field was presented by Slaughter in the journal *"Foresight"*. Slaughter (2009, p.6) indicates that *"Futures studies and, more lately, applied foresight, have been established for several decades. They have generated a rich and wide-ranging literature, a variety of methodologies and a spectrum of organizations engaged in many kinds of forward-looking work"*. From this statement I conclude that a clear distinction between futures research and foresight is often lacking. This section therefore provides a joint discussion of the methodology that is applied in both fields.

A profound discussion on foresight and futures research methodology is provided by The Millennium Project[69]. Their report on *"Futures Research Methodology Version 3.0 is the largest collection of ways to think about tomorrow ever assembled in history and is offered to improve our ability to make better decisions today to build a better future"* (Glenn et al., 2009b, p.17). Table 5-2 presents a list of methods that are covered by this document as well as a simple taxonomy, that distinguishes among quantitative and qualitative methods on the one hand, and normative and exploratory methods on the other hand.

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[69] The Millennium Project was founded in 1996 by amongst others the United Nations University. It is an independent futures research think tank that collected and assessed judgments from over 2,500 people since the beginning of the project. The work is distilled in the annual report on the *"State of the Future"*, and the *"Futures Research Methodology"* series (Source: www.millennium-project.org/millennium/overview.html).

Table 5-2: List of possible Foresight and Futures Research Methods

No.	Method	Quantitative	Qualitative	Normative	Exploratory
1	Agent Modelling		X		X
2	Causal Layered Analysis		X		X
3	Chaos and Non-Linear Systems	X			X
4	Cross-Impact Analysis	X			X
5	Decision Modelling	X			X
6	Delphi Techniques		X	X	X
7	Econometrics and Statistical Modelling	X			X
8	Environmental Scanning		X		X
9	Field Anomaly Relaxation		X		X
10	Futures Polygon	X	X	X	X
11	Futures Wheel		X	X	X
12	Genius Forecasting, Vision, and Intuition		X	X	X
13	Interactive Scenarios		X	X	X
14	Morphological Analysis		X	X	
15	Multiple Perspective		X	X	X
16	Participatory Methods		X	X	
17	Prediction Markets	X		X	
18	Relevance Trees		X	X	
19	Robust Decision making	X			X
20	Scenarios	X	X	X	X
21	Science and Technology Road mapping	X	X	X	X
22	Simulation-Gaming		X		X
23	State of the Future Index	X	X	X	X
24	Structural Analysis	X	X		X
25	Substitution Analysis				
26	Systems Modelling	X			X
27	Technological Sequence Analysis		X	X	
28	Text Mining		X	X	X
29	Trend Impact Analysis	X			X
30	Visioning		X	X	
31	Wild Cards	X	X		X

Source: Futures Research Methodology Version 3.0, Glenn et al. (2009, Chapter 1, p.8).

Though I must admit that I have not studied all the above listed methods in detail, I would like to point out a few methods that I consider most relevant for the development of a very long term view. Scenarios (no. 20) are generally considered the most appropriate way to think of all kinds of likely and/or plausible future developments – and in addition wild card scenarios (no. 31), that are by definition less likely than conventional scenarios, may also turn out to be very useful to think of possible surprises. The quantification of scenarios does however always rely on other methods. An obvious way to quantify scenarios is to apply expert judgment, that can for instance be obtained by applying Delphi techniques (no. 6). Another way to quantify scenarios is to apply systems modelling (no. 26). Systems modelling can either be used to quantify a single scenario – or to first develop a probabilistic projection, that can then be used for the quantification of a range of scenarios. In the latter case the quantitative values of the scenarios are assumed to remain within the bandwidth of the outer prediction intervals. The last option, that I would like to mention, is the use of econometrics and statistical modelling (no. 7). These methods may be of particular interest when they focus on theory based causal relations instead of statistical parameter optimisations.

5.3.4 Selected methods for looking far ahead

Not all the addressed methods for looking far ahead are equally relevant. This section elaborates on a selection of methods that I, on the basis of an analysis of the very long term studies discussed in Chapter 1, as well as on the basis of my personal experience with long term projections, consider the most relevant for the development of a very long term view.

Extrapolation of aggregated very long term trends

Trend extrapolation is probably the most obvious way to extend our views farther into the future. Forecasting literature provides a wide range of possible trend extrapolation methods ranging from simple naïve models to advanced multivariate autoregressive models. One should however be careful when extrapolating trends far into the future as trends may be subject to trend breaches. It is important to keep the right balance between the length of the anticipated time horizon and the level of detail taken into account in the forecast. Long term trends can only be extrapolated at a sufficient high level of aggregation, because detailed issues are more vulnerable to trend breaches. In addition one should always try to understand the underlying dynamics of the trend in order to avoid surprises. I further recommend the use of data series that are at least as long as the forecast period itself, and in case of cyclical movements even longer time series will be required. When looking for instance 20 years ahead the upward or downward trend can be severely affected by the movement of a longer, about 50 years lasting, Kondratieff wave (see Chapter 4). In such cases it may be more appropriate to look at least one full cyclical movement (i.e. 50 years) back in time.

Causal relations to other variables

Causal relations can provide powerful means for exploring future developments. The use of a causal relation is rather straight-forward. The first step is to investigate if there exist a causal relation between the variable for which an estimate is to be obtained (e.g. transport volumes), and another variable (or a set of variables) for which an estimate is already available or easier to obtain (e.g. economic output). The causal relation is then used to obtain a quantitative estimate of the explained variable on the basis of the explanatory variable for which a forecast or a scenario is available. Van Dorsser et al. (2012), for instance, applied this approach to develop a probabilistic forecast of the port throughput volumes in the Le-Havre Hamburg range on the basis of a probabilistic forecast of the regional GDP (see also Chapter 7).

Analogies and technological S-curves

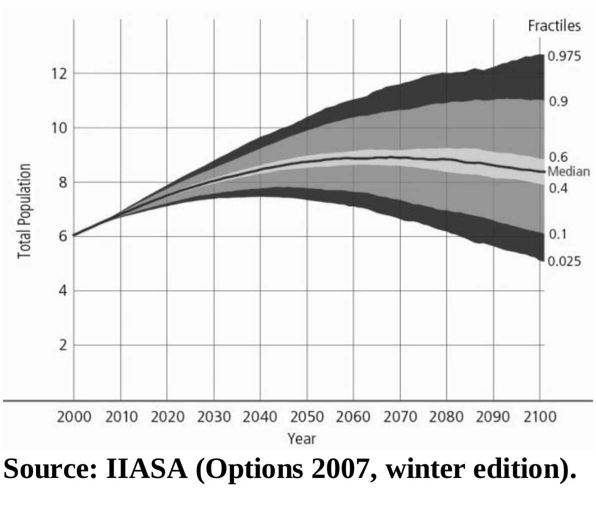
Technological S-curves are very useful when considering long term transition processes. The notion that a process follows a transition S-curve defines the basic dynamic behaviour of the system. It points out that the system grows exponentially at the offset, continues with a linear growth at the inflection point, and finally shows a decreasing growth in the last phase until it reaches a final stable output level (after which it may then eventually fall into decline). For new developments one can consider the use of analogies to get a feel for the possible speed and impact of the transition process under consideration, but one should realise that it is not possible to provide a sound forecast of the speed of the transition process nor the final output level of the transition S-curve until the inflection point has well been passed.

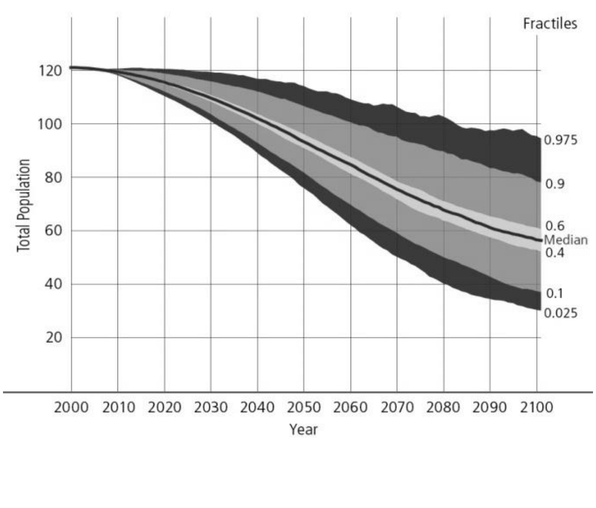
System dynamics modelling

In 1972 the Club of Rome (Meadows et al., 1972) attempted a first quantitative projection on the potential future of the world towards 2100, of which the results are based on a system dynamics model that applies exponential growth functions. The report showed that system dynamics modelling offers an interesting option to explore possible future developments in a systematic manner, but it also raised an intense discussion on the validity of quantitative very long term projections (see also Chapter 1). Following this discussion quantitative long term projections were no longer perceived credible – and the world shifted to the use of scenarios that rely on expert judgment. Loveridge (2009, p.xi) opposes against this movement away from systems modelling and argues that *"systems thinking [...] has been separated from futures studies far too long"* while *"foresight and systems thinking are tightly interrelated"*. In his book *"Foresight"* he aims to bring foresight and systems thinking closer together and to counter the fact that in his opinion: *"the community of institutional practitioners have chosen, dangerously and unwittingly I believe, to slide towards the more complicated activity of scenario planning which is inherently based on systems thinking"*. I also consider systems thinking and scenario planning complementary to each other. Analytical projection method are now once again gaining acceptance and credibility for dealing with issues that require a very long term view, such as population, energy demand, and climate change (see also Chapter 1). System dynamics models are therefore useful for the quantification of very long term scenarios and can be applied in two different ways. The first option is to use a system dynamics model to quantify a single scenario on the basis of predefined scenario assumptions. The second option starts with the de development of a very long term probabilistic projection and then continues with the development of a set of scenarios for which the quantifications lay within the bandwidth of the probabilistic projection.

Probabilistic projections

Probabilistic projections try to take all known uncertainties explicitly into account. The notion of these uncertainties can be either frequentistic or Bayesian. In the frequentistic notion the uncertainties refer to the frequency of occurrence whilst in the Bayesian notion probability is also regarded as a degree of personal belief and therefore subjective, unique and subject to change. West and Harrison (1999, p.20) state that *"Bayesian statistics is founded on the fundamental premise that all uncertainties should be presented and measured by probabilities"*. Bayesian input can be either based on *'hard'* statistics or *'soft'* judgemental estimates. One can therefore refer to *Bayesian projections* as all probabilistic projections that contain subjective elements, but in practice the field is much richer and covers all kinds of techniques for updating projections in case new information becomes available. To avoid confusion I will no longer use the word *'Bayesian'* and apply the word *'probabilistic'* instead. A good example of a probabilistic projection is the *'2007 update of probabilistic world population projections'* of the *'World Population Program'* of the International Institute for Applied Systems Analysis (IIASA). These projections are indicated in Figure 5-2.





Source: IIASA (Options 2007, winter edition).

Figure 5-2 Probabilistic Projection of World (Left) & East-European Population (Right)

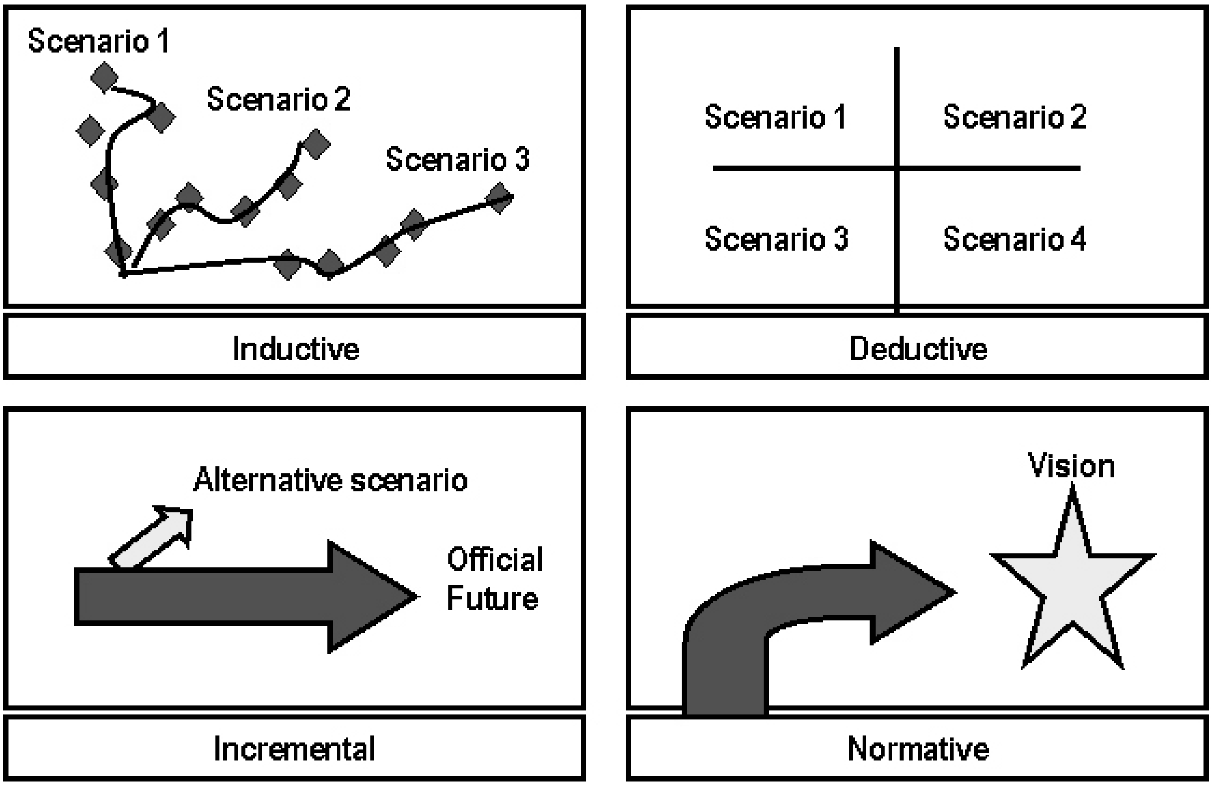
Probabilistic projections (or forecasts) do not only provide a central median estimate, but also a bandwidth for the level of uncertainty. IIASA (accessed: 2009) advocates the use of probabilistic[70] population forecasts in the following way: *"The common way to forecast future population is based on the assumptions of 'variants' (low, medium and high variants). These variants are said to cover a 'plausible range of future population trends.' The medium variant is usually the best 'guess' of what will happen. This approach is imprecise in the sense that it does not tell the user what 'plausible' means. And this approach is incomplete because it ignores uncertainties in mortality, fertility, and migration assumptions. And it is statistically deficient, because when high or low variants for world regions are computed by adding up the low or high variants of the country projections, the likelihood that all countries follow the same variant paths simultaneously is implausible. The population projections presented here avoid these problems of the 'variant approach' because they are explicit in stating probabilities; they fully incorporate uncertainties in fertility, mortality and migration; and they scale up from regions to the world in a statistically consistent manner"*.

I consider probabilistic projections useful to explore likely ranges of future developments, but one should keep in mind that probabilistic projections are based on the presumption that all uncertainties are known, and that an estimate for the level of uncertainty can be provided. When issues become so uncertain, that an estimate of the effects and/or likelihood can no longer be provided, it will become necessary to adopt a different approach. In that case a shift towards the use of storyline scenarios can be recommended.

<u>Storyline scenarios</u>
Schwartz (1991, p.4) indicates that (storyline) *"Scenarios are a tool for helping us to take a long view in a world of great uncertainty. The name comes from the theatrical term 'scenario' – the script for a film or play. Scenarios are stories about the way the world might turn out tomorrow, stories that can help us recognize and adapt to changing aspects of our present environment. [...] Scenarios are not predictions. It is simply not possible to predict the future with certainty. An old Arab proverb says that, "he who predicts the future lies even if he tells the truth." Rather, scenarios are vehicles for helping people learn. Unlike traditional business forecasting or market research, they present alternative images of the future; they do not merely extrapolate the trends of the present"*.

There are various ways to classify scenarios. Börjeson et al. (2005, p.14) distinguish between: predictive *forecasts* and *what if scenarios*; explorative *external* and *strategic scenarios*; and normative *preserving* and *transforming scenarios*. Davis (2002, p.3) points out that there are many ways of building scenarios and refers to a standard taxonomy of *inductive* versus *deductive*, and *incremental* versus *normative* scenarios. Inductive scenarios emerge from discussion and exploration of drivers and trends, while deductive scenarios choose two or more of those drivers to structure scenario worlds. Incremental scenarios are similar to the 'official future' (the one written in strategic plans) but different enough to move an organisation in a different direction. Normative scenarios are the realm of visioning. These are the futures that the developer believes 'should' happen. The four different types of scenarios that can be developed according to this taxonomy are indicated in Figure 5-3.

[70] According to IIASA the word "probabilistic" implies that they try to explicitly quantify the uncertainties involved in the population projections presented (http://www.iiasa.ac.at/Research/POP/proj01/index.html#why).



Source: http://thinkingfutures.net/resources/scenario-planning/, accessed: 2012. Originally adopted from Davis (2002) *Scenarios as a Tool for the 21st Century*, Shell International Ltd.

Figure 5-3: Scenario Topology according to Davis

An interesting property of scenarios is that, unlike forecasts, they cannot be wrong as long as the internal storyline is consistent. For that reason forecasts are sometimes presented as scenarios. In that case it is emphasised that the output of the forecast is still very uncertain.

Scenarios based on probabilistic projections

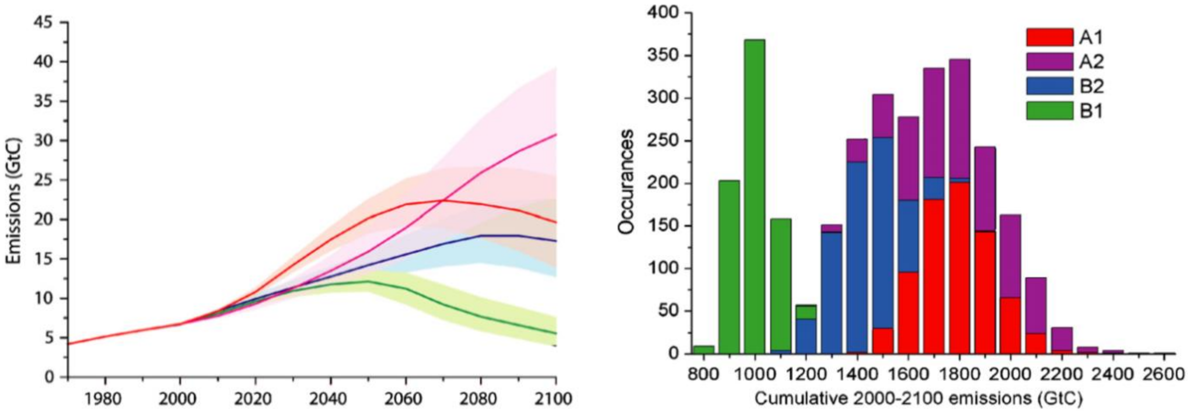
Probabilistic projections produce detailed figures that appear to be very accurate, but the estimates of the variables (mean and variance) may still be very rough and the projections may still remain subject to unforeseen (unknown) developments that are not included in the model. As a result policy makers may not fully understand the true uncertainties related to the use of these projections. To avoid misinterpretation, the output of probabilistic projections can also be presented as a range of possible scenarios. These scenarios are then intended to more-or-less cover the entire future outcome space of the projection. By doing so one still indicates the bandwidth of the forecast, but at the same time emphasises the fact that the projections are not that certain. The scenarios then implicitly provide a best estimate of the possible future developments based on all presently available information.

Probabilistic scenarios (or conditional probabilistic estimates)

The IPCC Special Report on Emissions Scenarios (Nakicenovic and Swart, eds. 2000) states an explicit policy of not attempting to assign probabilities to the different emission scenarios. Climate change research deliberately avoids assigning probabilities to the individual scenarios because *"all climate change models contain major simplifications (for example through parameterization of subgridscale processes) of the known physics and, moreover, do not represent all the processes of abrupt climate change (such as a collapse of the West Antartic Ice Sheet, or major releases of methane from the ocean floor or melting permafrost)"*

(Goodess et al., 2007, p.20). For such highly uncertain aspects (i.e. deep uncertainty) it is just not possible to provide a sensible order of magnitude estimate of the likelihood.

However, the fact that probabilities cannot be assigned to some highly uncertain aspects of our climate system does not imply that all statistical information related to other aspects is irrelevant. Climate researchers have therefore adopted probabilistic scenarios (or conditional probabilistic estimates) to present the statistical uncertainties of large ensembles of scenario runs stemming from various emission models in a probabilistic way. A good example of the use of probabilistic scenarios is given in Figure 5-4.



Note: The figures are presented to illustrate the use of probabilistic scenarios. The different colours in the left graph are related to the A1, A2, B1, and B2 climate scenarios of the IPCC (see legend in right figure).
Source: Van Vuuren et al. (2008, p.647)

Figure 5-4 Example of a Conditional Probabilistic Scenario Analysis

Van Vuuren et al. (2008, p.648-649) provide a clear discussion on the use and development of probabilistic scenarios. With respect to the methodological approach they conclude that: *"Conditional probabilistic scenario analysis can be used as a way to introduce statistical methods of uncertainty analysis, while recognizing deep uncertainties. Uncertainties represent a crucial element of scenario analysis. Two main methods are often presented as options for uncertainty analysis: the scenario approach and the fully probabilistic approach. This paper shows that it is possible to combine the two approaches (conditional probability analysis) in a way that allows formal analysis of those elements where meaningful probability estimates can be established, while still retaining the strong elements of a storyline approach to uncertainty. Storylines are a device for structured thinking about a future with deep uncertainty while also assumptions regarding the reasoning behind the choice of driving forces, parameter values, and modeling approaches are made more explicit. The added value of the conditional probabilistic approach compared to a non-conditional approach can also be observed from the analysis of most relevant uncertainties. These are shown to be a function of the storyline. Compared to the default alternative scenario method, the conditional probabilistic method (1) adds the strength of statistical methods in situations where they can meaningfully be applied, and (2) provides ranges for each scenario. The method, of course, also has also the limitations characteristic for the two methods it combines. In particular, it does not provide a single estimate of future emissions because no probabilities are assigned to the underlying storylines themselves. The method is also more elaborate than the default storyline-based alternative scenario method".* I consider the use of probabilistic scenarios quite elegant for the development of a very long term view in case of deep uncertainty, but the method also requires a considerable amount of mathematical efforts.

Wildcard scenarios

Dewar (2003) addressed the importance of wildcard scenarios as a method for dealing with inevitable surprises in long term policy analysis. Although the future is unknowable and surprises will occur "*certain kinds of surprises are avoidable, especially when using scenarios to help think about the future"* (p.1). Wildcard scenarios are intended to identify possible important surprises that may occur. They are meant to deal with at least some of the avoidable surprises to which all futures studies are subject. Wildcard scenarios are, by definition, less likely than other plausible futures. What makes them important are the cases where they produce disproportionally dire consequences. A possible way to identify wild card scenarios is to look at assumptions that may not occur (i.e. the assumption that something will happen turns out not to happen). If these assumptions lead to a completely different and unexpected future it makes sense to include them as a wildcard scenario and to think of causes for such trend breaking events to happen[71]. Once identified a wildcard scenario can help to think of actions to deal with the effects. Dewar (2003) argues that the use of wildcard scenarios should be limited to a few scenarios for which the consequences are very severe and dissimilar to those of the scenarios already identified; and to scenarios for which a plausible (failure) mechanism can be identified. In case too many wild card scenarios have been identified a sensible selection has to be made.

5.4 The Nature and Level of Uncertainty

The previous section discussed the available techniques for looking ahead, but in absence of a *'crystal ball'* there will always remain uncertainty and the decision maker will have to deal with it. This section provides the relevant background on the nature and level of uncertainty. Thereafter follows a section on the available policy options for dealing with uncertainty.

5.4.1 The nature and level of uncertainty

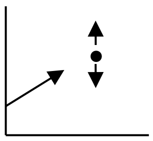
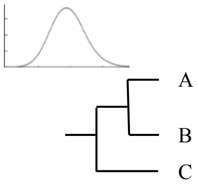
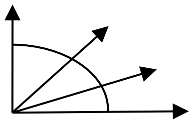
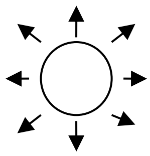
Agusdinata (2008, p.35) indicates that *"most literature has come to a general consensus regarding different aspects of uncertainty in policy making. These aspects cover the nature, location, and level of uncertainty*". He indicates that for the nature of uncertainty a distinction can be made between *epistemic uncertainty* resulting from imperfection in knowledge and *variability uncertainty* resulting from inherent variability in the system. Epistemic uncertainty can be reduced by increasing the available knowledge while variability uncertainty cannot be reduced. He makes a comparable distinction between *structural* and *parametric uncertainty* in prediction models. Structural uncertainties are related to the correct theoretic understanding of the subject while parameter uncertainty concerns the value of the parameters in the model. Agusdinata (2008, p.38) observed that *"Despite its importance however, this structural uncertainty has often been overlooked or taken for granted in analysis"*. The location of the uncertainty indicates if the uncertainty is within or outside the control of the policy maker. The level of uncertainty can vary between *complete deterministic understanding* (absolute certainty) and *complete ignorance* (unknown unknowns) of the system. Intermediate measurements of the level of uncertainty are: *statistical uncertainty*, *scenario uncertainty* and *recognized ignorance* (unknowable). Agusdinata (2008, p.37) indicates that: *"Statistical uncertainty can be addressed adequately in statistical terms (e.g. measurement errors). Scenario uncertainty can be represented by plausible (i.e. coherent and internally consistent) descriptions of how the system's external forces (e.g. energy prices) are manifested in the*

[71] This approach is quite similar to the approach advocated by Taleb (2007), as discussed in Section 5.4.3.

future and their resulting effects on the structure of the system. Recognized ignorance implies a fundamental uncertainty about the mechanisms and functional relationships being studied”.

Walker (2011) provides a clear structure for classifying policy issues according to their level of uncertainty. This structure identifies two extreme levels of uncertainty (complete certainty and total ignorance) and four intermediate levels.

Table 5-3: The Various Levels of Uncertainty

		Level 1	Level 2	Level 3	Level 4	
Complete Certainty	**Context**	A clear enough future (with sensitivity) 	Alternate futures (with probabilities)  	A multiplicity of plausible futures (unranked) 	Unknown future 	**Total ignorance**
	System model	A single system model	A single system model with a probabilistic parameterization	Several system models, with different structures	Unknown system model; know we don’t know	
	System outcomes	Point estimates with sensitivity	Several sets of point estimates with confidence intervals, with a probability attached to each set	A known range of outcomes	Unknown outcomes; know we don’t know	
	Weights on outcomes	A single estimate of the weights	Several sets of weights, with a probability attached to each set	A known range of weights	Unknown weights; know we don’t know	

Source: Based on Walker et al. (2013a), adjusted layout and reduced number of levels.

Table 5-3 presents an updated version of the four levels of uncertainty according to Walker (2011). For each level the following policy aspects are considered: (a) the context of the future world, (b) the model of the relevant system for that future world, (c) the outcomes of the system, and (d) the weights that the various stakeholders will put on the outcomes. Walker (personal communication in the year 2012) provides the following description for the various levels of uncertainty: *“Complete certainty is the situation in which we know everything precisely. It is not attainable, but acts as a limiting characteristic at one end of the spectrum. Level 1 uncertainty is any uncertainty that can be described adequately in statistical terms (e.g., historical weather patterns and river flows); Level 2 uncertainty represents the situation in which one is able to enumerate multiple alternatives and is able to rank the alternatives in terms of perceived likelihood; Level 3 uncertainty represents the situation in which one is able to enumerate multiple plausible alternatives without being able to rank the alternatives in terms of how likely or probable they are judged to be; Level 4 uncertainty implies the deepest level of recognized uncertainty; in this case, we know only that we do not know. We recognize our ignorance; Total ignorance is the other extreme on the scale of uncertainty. As with complete certainty, total ignorance acts as a limiting case”.*

It should be noted that in more recent work, Walker et al. (2012, 2013a) added a fifth intermediate level in-between the levels 2 and 3, as presented in Table 5-3. This level is intended to deal with alternative futures for which a ranking is still assumed to be possible, but to which no likelihoods are assigned. I nevertheless find this new intermediate ranking level somewhat illogical, as I will try to make clear by the following two arguments:

- **Argument 1:** Walker et al. (2013a) indicate that this new ranking level for instance applies to a situation in which three different transport scenarios are developed on the basis of three different GDP growth assumptions. In such a case the middle scenario could be considered the most likely, but isn't this bad practice? I think that one should either present this as a sensitivity analysis around the main forecast (i.e. Level 1); be specific about the assumed likelihood (i.e. Level 2); or state that one cannot judge the likelihood (i.e. Level 3).
- **Argument 2:** Suppose that one first develops a set of plausible scenarios (i.e. Level 3) and later decides to add a number of wildcard scenarios (that are by definition less likely). Would it then be logical to regard the future more certain after adding the set of wildcard scenarios, just because one can then make a ranking between normal plausible scenarios and 'less likely' wildcard scenarios? I don't think so.

For these reasons, as well as the reason that the new structure does not fit the structure that will be presented in Section 5.6, I decided to adopt the original structure of Walker (2011), that is based on four instead of five intermediate levels of uncertainty.

5.4.2 The notion of deep uncertainty

Lempert et al. (2003, p.xii) defined *'deep uncertainty'* as the condition *"where analysts do not know or the parties to a decision cannot agree upon (1) the appropriate conceptual models to describe interactions among a system's variables, (2) the probability distributions to represent uncertainty about key parameters in the models, and/or (3) how to value the desirability of alternative outcomes"*. They further indicate that: *"In particular, the long-term future may be dominated by factors that are very different from the current drivers and hard to imagine on today's experience"* (p. xii-xiii). Walker et. al. (2013a) refer to both Level 3 and Level 4 uncertainties as deep uncertainty[72]. They indicate that the *'cannot agree on'* portion of the deep uncertainty definition applies to Level 3 uncertainty, and that the *'do not know'* portion of the deep uncertainty definition applies to Level 4 uncertainty.

5.4.3 Great Intellectual Fraud and Black Swan Theory

There is always a possibility that something unexpected will happen. Taleb (2007) discusses the impact of the highly improbable. He criticises the way statisticians deal with uncertainty by means of Gaussian-bell shaped curves (or normal distribution) and calls this the Great Intellectual Fraud (GIF). Taleb describes two provinces of the world which he calls *Mediocristan* and *Extremistan*. In Mediocristan things are non-scalable and statistics follow the laws of the bell shaped curve, which implies that: *"When your sample is large, no single instance will significantly change the aggregate or total"* (p.32). In Mediocristan the average rules and only marginal steps are made. However, with respect to predicting the future these laws should not be bluntly applied as: *"History and societies do not crawl. They make jumps. They go from fracture to fracture, with a few vibrations in between. Yet we (and historians)*

[72] Please be aware that the levels 3 and 4 mentioned in this section are similar to the levels 4 and 5 as applied in Walker et al. (2013a), that is based on the new five level scheme.

like to believe in the predictable, small incremental progression" (p.11). Taleb argues that the world is ever getting more uncertain and moving towards Extremistan[73]. In Extremistan things are scalable and the impact of the rare event rules. This means that *"In Extremistan, inequalities are such that one single observation can disproportionately impact the aggregate, or the total"* (p.33). Taleb argues that applying Gaussian rules to Extremistan situations will lead to significant underestimation of the probability.

Taleb defines rare events with a disproportional impact on the aggregate as Black and Gray Swans[74]. A Black Swans is characterized by three attributes: *"First it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility. Second, it carries an extreme impact. Third, in spite of its outlier status, human nature makes us concoct explanations for occurrence after the fact, making it explainable and predictable"* (p.xvii-xviii). The triplet is then summarized as: *"rarity, extreme impact, and retrospective (though not prospective) predictability"* (p.xviii). Taleb further indicates that the *not happening* of the highly expected is also a Black Swan as he writes: *"Note that, by symmetry, the occurrence of the highly improbable is the equivalent of the non-occurrence of a highly probable one"* (p.xviii).

The message of Taleb's book is to warn people not to be fooled by historical data (and Gaussian statistics). To explain this Taleb discusses the life of a turkey. Based on a lifetime experience the turkey will expect to be fed the next day, but this suddenly changes at the unexpected event of thanksgiving. The message made is not to become like a turkey. He suggests to neutralize Black Swans by making them gray. Taleb defines Gray Swans as: *"Black Swans that we can somewhat take into account – earthquakes, blockbuster books, stock market crashes – but for which it is not possible to completely figure out the properties and produce precise calculations"* (p.309). In this respect the difference between a Black Swans and Gray Swans is that: *"A Gray Swan concerns modelable extreme events, a Black Swan is about unknown unknowns"* (p.272). It should be noted that the approach suggested by Taleb is quite similar to the use of wildcard scenarios as discussed in Section 5.3.4.

5.5 Policy Options for dealing with Uncertainty

This section starts with the identification of the available policy options for dealing with uncertainty, and continues with a discussion on the most appropriate policy options for dealing with each of the four levels of uncertainty that were defined in the previous section.

5.5.1 Identifying available policy options for dealing with uncertainty

Each level of uncertainty is likely to require a different policy approach. For this reason it is worthwhile to look at various options to deal with uncertainty in policy making. Agusdinata (2008, p.7-10) provided a useful structure for characterising policy approaches under conditions of uncertainty (see Figure 5-5). In this structure he categorised the policy options along two dimensions, which are: (1) *the nature of the decisions made*, and (2*) the type of actions to deal with uncertainty*. The nature of the policy refers to the way of dealing with

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[73] I do not agree that the world is getting ever more uncertain. If the world has passed the inflection point of the Great Transition (as discussed in Chapter 4) it may now become more predictable.

[74] The term 'Black Swan' is capitalized to distinguish it from the 'black swan' example stemming from Popper's (1935) philosophy of falsification in scientific research.

uncertainty. This can be either a static or a dynamic approach. Actions can be taken that change the system or do not change the system. Only those policies that are meant to change the system will be further discussed in the remainder of this section.

Change in the system	('optimal' policy approach) • Predict the future and implement 'optimal' policy for that future	(static robust policy approach) • Identify plausible futures and find policy that works acceptably well across most of them	(adaptive policy approach) • Adapt policy over time as conditions change and learning takes place
No change in the system	(do-nothing policy approach) • No policy until the uncertainty is resolved		(delay policy approach) • Do more research • Negotiate with other parties for a consensus or compromise
	Static policy		**Dynamic policy**

Source: Agusdinata (2008, p.8), reduced content.

Figure 5-5 Categories of Policy Approaches under various Conditions of Uncertainty

The *'optimal' policy approach* is characterised by policy makers that optimize their decisions on the basis of a 'best estimate' of the system behaviour. This approach typically deals with the future by applying the following two steps: (1) prepare a definite forecast of the future, and then (2) optimise the policy on the basis of the forecast.

The *static robust policy approach* searches for policies that perform well across a range of plausible futures. This approach typically deals with the future by applying the following two steps: (1) define a range of plausible scenarios, and (2) search for robust policies that perform well across most of the anticipated plausible futures.

The *adaptive policy approach "allows policymakers to cope with uncertainties that confront them by creating policies that respond to changes over time and that make explicit provision for learning"* (Walker et al., 2001, p.282). In adaptive policymaking the decision process is specified at the outset of the policy formulation. Instead of making 'final' decisions (that are likely to be changed on an ad-hoc basis) the process is specified and only time critical decisions are made at the outset of the policy. During the process the effects are carefully monitored and predefined mitigating actions are undertaken in case the policy gets off course. Lempert et al. (2003, p.57-62) indicate that the notion of adaptability is fundamental to long term policy analysis as they write that: *"In prediction-based policy analysis, the far horizon is often determined by how far one can accurately forecast"* while in long term policy analysis *"that horizon shifts to how far into the future today's actions can influence events"*.

I would like to add a fourth policy option to the three active policy options defined in Figure 5-5. This option will be referred to as *'risk management'*, which is in fact a separate research discipline with substantial literature that has not been taken into account in the structure presented by Agusdinata. Risk management policies can be located in-between optimisation- and robust policies. They can for instance be applied to policies dealing with public safety or large investment projects. The strength of the risk management approach is that it explicitly deals with the perceived uncertainty levels of the projections. By doing so it allows cost effective risk mitigation measures to be taken.

I think that each level of uncertainty (as defined in Table 5-3) can be related to a single approach defined in this section. For Level 1 uncertainties the *'predict and act'* approach is quite sensible. For Level 2 uncertainties I would recommend *'risk management'*. Level 3 uncertainties can still be dealt with by a *'static robust policy'*, and for Level 4 uncertainties the *'adaptive policy making'* approach can be suggested. There is little need to elaborate on the predict and act approach, but I find it necessary to discuss the modelling approaches for Level 2, 3, and 4 uncertainty in more detail.

5.5.2 Level 2: Risk management and the use of probabilistic projections

Risk management is based on the concept and theory of probability and provides an alternative way for dealing with uncertainties. According to Ahl (1996, p.256) risk management involves *"the pragmatic decision-making process concerned with regulating the risk"*. The main vehicle for this process is the (formal) risk assessment which can be defined as *"the process of identifying a hazard and evaluating the risk of a specific hazard, either in absolute or relative terms"*. A risk assessment can be either qualitative or quantitative.

According to Kaplan and Garrick (1981) a quantitative risk assessment should answer the following three basic questions:

- What can go wrong?
- How likely is it to go wrong?
- What will be the consequences if it does?

<u>Probabilistic risk analysis</u>

Bier (1997, p.68-69) elaborates on the subject of quantitative risk assessments and indicates that a Probabilistic Risk Analysis (PRA) is generally designed to model the response of a complex engineered system (such a nuclear reactor) to disturbances during operations. It integrates the knowledge about the reliability of the subsystems in order to provide a holistic view on the reliability of the entire system. By doing so it should identify the types and levels of damage that could result from different responses and indicate the likelihood of the various failure modes. For the preparation of a low probability high impact risk analysis (such as a nuclear meltdown) fault trees and event trees can be used. *"Fault trees are constructed using inductive or "backward" logic. In other words, the process starts with a hypothesized system or subsystem (the so called "top event") and works backward to identify which combinations of component failures could give rise to that top event"* (p.72). *"By contrast, event trees are constructed using deductive or "forward" logic. Rather than hypothesizing a system failure, the process starts by hypothesizing an initiating event (i.e., a departure from normal operations) and then works forward by identifying all possible combinations of subsequent events (i.e., successes or failures of particular components or subsystems) and determining which sequences of events could cause failure of the system as a whole"* (p.72-73).

Probabilistic scenario analysis

Probabilistic Scenario Analysis (PSA) is a method for applying quantitative risk assessments quite similar to the engineering approach discussed above. *"It is an excellent tool for estimating the probability or frequency of an unwanted event occurring"* (Ahl, 1996, p.259). Oryang (2002) indicates that the method *"was first used in 1940's to assess the risks associated with the development and use of the atomic bomb. In the 1950's it was used to assess the what-if scenarios of nuclear proliferation. By 1960 it was being used in financial analysis, engineering applications and general economic evaluations. It is the method most used in conducting quantitative risk assessments in plant and animal health. It has been well tried and proved useful in many fields"*. The method combines scenario analysis with probabilistic risk analysis. The method starts with identifying potential hazards that may initiate an event. These initiating events may lead to a pathway of success or failure which can be indicated by an event tree (or scenario tree). The event tree contains initiating events, nodes, and endpoints. If everything goes well the hazard does not occur in the endpoint. This is referred to as the 'success scenario'. The analysis is developed in such a way that the combined probability of occurrence and non-occurrence at each node is equal to one. North (2006) indicates that in case of various initiating events and/or sequences use can be made of influence diagrams. These diagrams link all related events to each other. However, with interlinked events, the number of calculations may quickly become very large and specific mathematical software will be required.

Risk based decision making

Risk based decision making can be much more than just avoiding risks and mitigation of low probability high impact hazards. Risk based methods can also be used to balance the risk levels in order to optimize the performance (risk seeking). Particularly in the investment and banking sector, risk taking is part of the game. For this kind of risk based decision making advanced tools (such as the Excel Add-on module @Risk) can be applied to develop probabilistic projections (e.g. of the expected profit of an investment). These projections are by nature very well suited to indicate the likelihood of future system outcomes. However, if not all the underlying assumptions are unambiguous and completely certain there is a risk of overconfidence in the model. Risk based decision making is therefore well suited for normal levels of uncertainty, but not suitable for high levels of uncertainty.

Limitations to risk management

Despite its wide range of possibilities there are certainly also limitations to the use of risk management. According to Molak (1997, p.9) *"Risk Management can, under some circumstances, make general predictions about the outcome of our decisions; sometimes we can only obtain a very rough feeling about the possible outcomes. While in physical sciences the predictions are usually very accurate, in risk analysis our predictions could have a range of several orders of magnitude".* As long as one recognizes the uncertainty levels related to risk management there is no problem. *"However, to pretend that we possess the knowledge and power to shape the processes of society entirely to our liking, knowledge, which in the real world we do not possess, is likely to do a great deal of harm"*. Therefore *"The most important thing is to always make risk assessments transparent to the public with all the assumptions and parameters clearly stated"*. In this respect *"The thought process that goes into evaluating a particular hazard is more important than the application of some sophisticated mathematical technique or formula, which often may be based on erroneous assumptions or models of the world"*. From the above it can be concluded that one should not go blind on the outcome of the risk assessment. It is a very sensible tool for dealing with Level 2 uncertainties, but higher levels of uncertainty require a different approach.

5.5.3 Level 3: Robust scenario planning and exploratory modelling

In case of deep uncertainty (i.e. Level 3 and Level 4 uncertainties) Walker et al. (2013a) indicate that: *"Instead of determining the 'best' predictive model and solving for the policy that is optimal (but fragilely dependent on assumptions), in the face of deep uncertainty it may be wiser to seek among the alternatives those actions that are most robust — that achieve a given level of 'goodness' across the myriad models and assumptions consistent with known facts (Rosenhead and Mingers 2001). This is the heart of any robust decision method. A robust policy is defined to be one that yields outcomes that are deemed to be satisfactory according to some selected assessment criteria across a wide range of future plausible states of the world".* Walker et al. (2013a) suggest to use robust scenario planning and exploratory modelling techniques for Level 3 uncertainties, and to use adaptive policies for Level 4 uncertainties. The latter will be discussed in Section 5.5.4.

Robust scenario planning

Robust scenario planning combines the strengths of scenario planning (see for instance Schwartz, 1991; and Van der Heijden, 1996) with the development of robust policies. The development of robust policies requires a different approach to uncertainty than the approach applied in predict-and-act (Level 1) and risk-based (Level 2) policy making. Instead of aiming to ex-ante optimise the expected future performance of the system (on the basis of the applied model description), robust scenario planning aims to identify a broad range of plausible futures in order to look for static robust policies that work out well amongst most of them. Robust scenario planning assumes that, although the likelihood of the future worlds is unknown, a range of plausible futures can be specified well enough to identify a (static) policy that will produce acceptable outcomes in most of them (Walker et al., 2013a).

Exploratory modelling

The concept of exploratory modelling was developed by Bankes (1992, 1993). Bankes (1993) distinguishes between consolidative and exploratory modelling. Consolidative modelling is defined as: *"Building a model by consolidating known facts into a single package and then using it as a surrogate for the actual system"* (p.435) in other words: *"Consolidative modeling is the design of models driven by what is known*" (p.439). The construction of a single consolidative model requires sufficient data for validation. If validation is not possible there is a risk of *"false reduction"* or *"The belief that the more details a model contains, the more accurate it will be. This reductionism is false in"* the sense *"that no amount of detail can provide validation, only the illusion of realism"* (p.439).

Exploratory modelling challenges the use of a single model to predict the systems behaviour. *"Uncertainty, or lack of knowledge, implies that there are many models that might plausibly represent the system of interest. Conversely, what is known constrains the set of models that can be considered plausible"* (Bankes, 1993, p.441). Exploratory modelling explores a wide range of plausible futures. Each of the plausible futures serves as 'one mirror' to look at the behaviour of the system. Under conditions of deep uncertainty multiple mirrors provide a more reliable 'picture' than a single mirror does (Agusdinata, 2008, p.54). *"Exploration need not be restricted to the values of numeric parameters, but can also be conducted across different sorts of nonparametric uncertainty. For example, members of the ensemble of plausible models might have differing numbers of variables, differences in data flow graphs, or computational algorithms"* (Bankes, 1993, p.442). Lempert, et al. (2003, p.xiii) propose to consider large ensembles (hundreds to millions) of scenarios referred to *'landscapes of plausible futures'* and to seek for robust strategies by interactive exploration of the multiplicity of plausible futures. Agusdinata (2008, p.62) elaborated on the subject of

'Exploratory Modelling and Analysis' and listed various ways to construct large ensembles of plausible futures that can be applied to develop robust policies on the basis of an exploratory modelling exercise. These options are indicated in Table 5-4.

Table 5-4: Ways to construct Large Ensembles of Plausible Futures

Elements	Ways to construct large ensembles of plausible futures
Scenarios	• Use different numbers and combinations of scenario variables; • Use different levels of aggregation (may include operations such as summation, multiplication, and integration); • Use different value ranges for each scenario variable.
System structure	• Use different functional or causal relationships; • Use different behavioural rules; • Use different parametric values; • Use different internal variables; • Use different theories about the same phenomenon.
Outcomes of interest	• Use different outcomes of interest; • Use different proxies for one outcome indicator.
System boundary	• Vary what is considered to be a scenario, an internal system parameter and an outcome variable.
Value system	• Use different decision criteria. This may include the use of the different value systems of multiple stakeholders; • Use different weights or ranges for decision criteria.

Source: Agusdinata (2008, p.62), minor adjustments made.

I regard exploratory modelling as a powerful decision making tool that allows the policy maker to develop robust policies that perform well along large ensembles of plausible scenarios. The downside is however that the policy making process becomes very complex and analytical, where in case of robust scenario planning it is still more understandable.

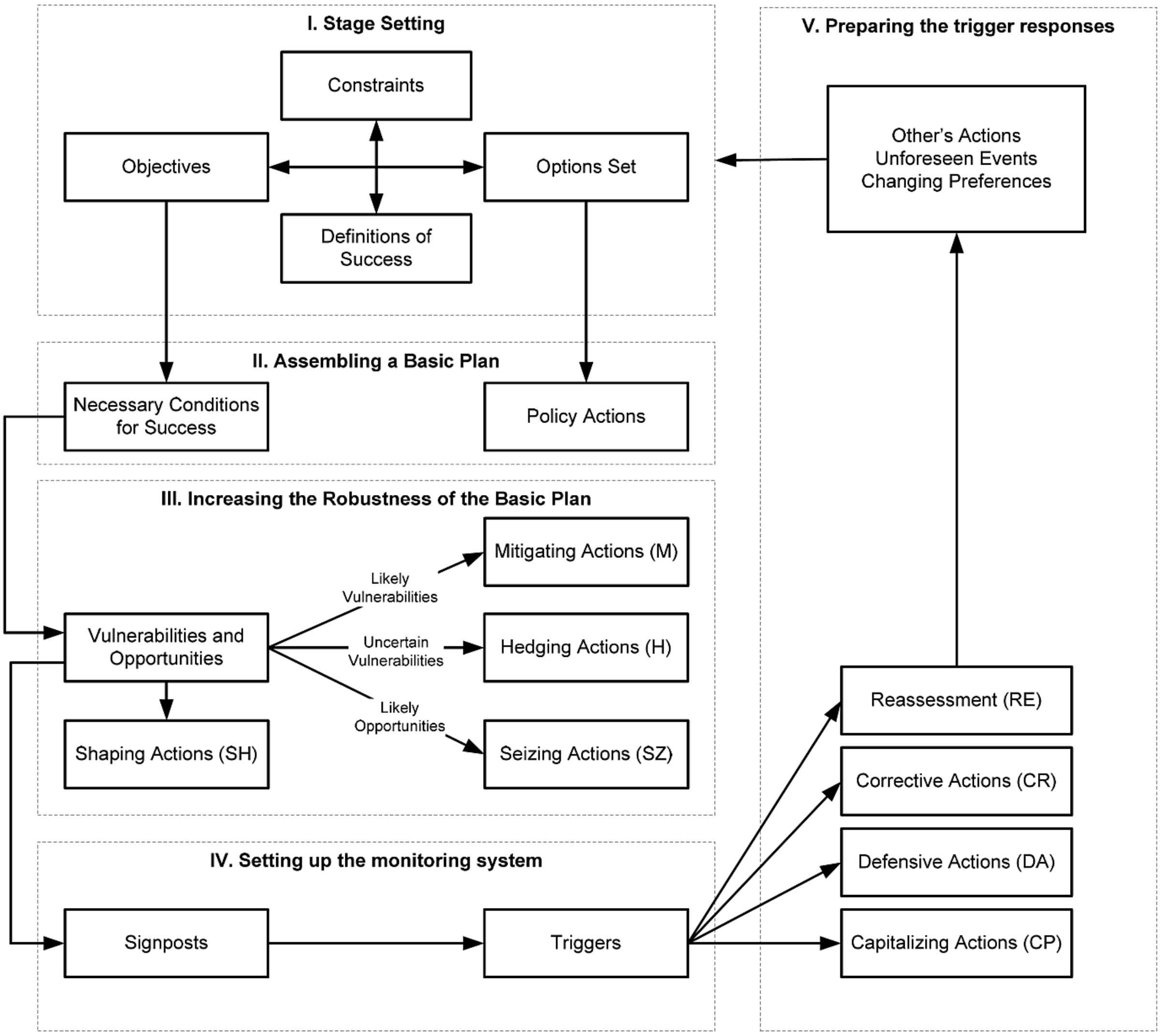
5.5.4 Level 4: Adaptive policy making and scenario discovery

For policies dealing with the most profound levels of uncertainty (i.e. Level 4, but in some cases possibly also Level 3) it may at a certain stage no longer be possible to construct a single static policy, that performs well along the many plausible future scenarios that have been identified for the policy analysis. In such cases the adaptive approach is likely to be the most effective, in particular when it is combined with scenario discovery.

<u>Adaptive policy making</u>

For dealing with situations in which it is no longer possible to develop a single robust policy Walker et al. (2001) developed an adaptive approach that allows *"policy makers to cope with uncertainties that confront them by creating policies that respond to changes over time and make explicit provision for learning. The approach makes adaptation explicit at the outset of policy formulation. Thus, the inevitable policy changes become part of a larger recognised process and are not forced to be made repeatedly on an ad hoc basis"* (p.283). The adaptive policy making approach involves fundamental changes to the following three major elements of policymaking: the analytical approach, the types of policies considered, and the decision making process. The dynamic nature of the adaptive policy process allows uncertainties to be resolved over time rather than instantly. *"It explicitly recognises the value of additional information at different steps in the process, and the trade-offs in time and money to collect it. Further, it is designed to incorporate the actions and reactions of other players. In sum, it is a systematic method for developing and implementing a policy over time that is based on a* *clear set of constraints and objectives and that involves monitoring the environment, gathering information, and adjusting and re-adjusting to new circumstances"* (p.284).

Unlike static policies the adaptive approach is designed to be incremental, adaptive, and conditional. The analysis and choice of an adaptive policy therefore requires a new policy-making process that takes the uncertainties and dynamics of the problem explicitly into account. The structure of the adaptive policy making process is indicated in Figure 5-6.



Source: Walker et al. (2013b, p.286).

Figure 5-6: The Adaptive Policy Making Process

The adaptive policy making process comprises two phases. The first phase concerns the *'design of the policy'*. This phase consists of a number of concrete steps that are undertaken by the policy maker to define the policy and set the rules for its implementation. The next phase consists of the *'implementation of the policy'*. This phase consists of the actual sequence of events, inferences, and actions that represent the execution of an adaptive policy. During the design phase the policy maker sets the stage, assembles a basic policy, and thinks through the vulnerabilities, signposts, triggers, and actions that can be taken to mitigate, hedge, or correct the policy. If all goes well the policy maker will just monitor the outcome of the system and apply the predefined actions. Only in case the predefined actions turn out to be inadequate to obtain the final objective a reassessment will be necessary. The conditions for reassessing the policy are defined explicitly in the policy structure. A detailed discussion on the various steps in the planning process is provided by Walker et al. (2013b).

Scenario discovery

In order to improve the formulation of an adaptive policy it is important to understand those conditions that can lead to failure of the system (i.e. the need for a reassessment), and those measures that can be taken to keep the policy on track. In this respect it is worth mentioning the use of scenario discovery techniques, which can be regarded as the wildcard counterpart of exploratory modelling (similar to the use of wildcard scenarios in normal scenario planning). Scenario discovery, applies similar techniques as for explanatory modelling, but aims at investigating those areas where failure of the system may be expected to occur. Walker et al. (2013b) indicate that: *"In many applications of Scenario Discovery, the runs of interest are determined based on the failure to meet pre-specified objectives. The mindset behind Scenario Discovery is one of the most important defining differences between traditional ex-ante policy analysis and the analysis underlying the design of robust plans. In the former, scenarios would be specified and plans would be evaluated on how well they performed across the scenarios. The "best" (static robust) plan would be the one that performed the best across all of the scenarios. In contrast, Scenario Discovery is performed to identify the scenarios in which a plan would perform poorly. These scenarios highlight the vulnerabilities of the plan. Then, actions are specified to protect the plan from failing"*. These actions can then be implemented in the formulation of adaptive policies.

Tipping points and adaptation pathways

In addition to scenario discovery one may also consider the identification of tipping points (i.e. those conditions that result in failure of the applied policy). On the basis of the insights obtained from these tipping points clear adaptation pathways can be developed that may add to the formulation of successful adaptive policies (see also Walker et al., 2013b).

5.5.5 Decision criteria for the evaluation of policy relevant effects

The various policy making approaches require different decision criteria for the evaluation of policy relevant effects. For optimization policies the principle of maximization of desired output (such as profit, or utility) is generally applied. Agusdinata (2008, p.45) indicates that there exists a range of alternative decision criteria that can be applied in case of uncertainty in policymaking. These include:

- Wald's maxi-min criterion – Suggests that the worst scenarios will occur and that under such unfavourable circumstances decision makers try to make sure that the policy outcome should be the least bad. It appeals to pessimistic (risk averse) decision makers who subscribe the adage *'better safe than sorry'*.
- Maxi-max criterion – Opposite of Wald's criterion, examines the maximum outcome of all policy options under favourable conditions. It appeals to optimistic (risk seeking) decision makers who believe that *'nothing ventured, nothing gained'*.
- Hurwicz optimism-pessimism criterion – Suggests a middle way between the optimistic and pessimistic stance by assigning a weight that reflects a decision maker's attitude towards risk. When the weight is 1 (extreme risk averse), the Hurwicz' criterion is reduced to the maxi-min criterion. When the weight is 0 (extreme risk seeking) it reduces to the maxi-max criterion.

- Savage's mini-max (regret) criterion – Suggests that decision makers should consider the opportunity loss or regret of an option. The regret value implies the difference between the outcome of a policy option compared to the outcome from the best alternative in a certain circumstance. Decision makers should then compare maximum regrets of policy options across all circumstances and choose the option that minimizes the maximum regret.

Agusdinata (2008, p.45) indicates that *"it has been argued that, under a condition of deep uncertainty, the regret function is most appropriate"*. Loulou and Kanudia (1999, p.220) indicate that *"The Minimax Regret criterion, also known as Savage criterion, Raiffa [21,22], is one of the more credible criteria for selecting decisions under uncertainty, i.e. when the likelihoods of the various possible outcomes are not known with sufficient precision to use the classical expected value or expected utility criteria"*[75]. Lempert et al. (2003, p.55) indicate that *"Long recognized as an important objective, robustness has not been widely used in quantitative studies because it is computationally harder to implement than optimization. In recent years, however, new approaches have begun to transcend previous limitations"*. They further indicate that *"Kouvelis and Yu (1997) have developed methods for robust discrete optimization that provide analytic mini-max solutions to a variety of problem types without any needs to assign priors to alternative scenarios. Their work also draws on the scenario-planning literature for methods to help choose the scenarios that are inputs to their analysis"*. The use of the regret criterion is however not limited to scenarios as they write in the next sentence that *"Researchers have also developed methods to find strategies robust against multiple priors, using formal treatments based on Bayesian analysis (Berger, 1985) and robust control theory (Zhou, Doyle, and Glover, 1996)"*.

In line with the above I conclude that it is common to apply the optimisation criterion in case of optimisation policies; the Hurwicz optimism-pessimism criterion for risk management approaches; and Savage's mini-max (regret) criterion for static robust and adaptive policies.

5.6 Guideline for Looking Ahead and Dealing with Uncertainty

This chapter studied the scientific ways for looking ahead and dealing with uncertainty in policy making. It turned out that there are many methods available, but that the fields of looking ahead and dealing with uncertainty are still completely separated from each other and not structured in an integrated consistent way. I therefore propose a clear integrated structure for looking ahead and dealing with uncertainty that serves as a guideline for dealing with very long term policy issues.

5.6.1 Guideline for looking ahead and dealing with uncertainty

This section propose a clear policy guideline, that indicates the appropriate methods for looking ahead and dealing with uncertainty as well as the appropriate decision criteria for the evaluation of the relevant outcomes of interest. A different approach is suggested at each level of uncertainty. The proposed structure is indicated in Table 5-5.

[75] Loulou and Kanudia refer to Raiffa, H. (1968).

Table 5-5: Guideline for Looking Ahead and Dealing with Uncertainty

Level of uncertainty	Proposed methods for looking ahead and visualizing the future	Proposed policy approach for dealing with uncertainty	Proposed decision criteria
Level 1: clear enough future.	Forecasting Methodology: (advanced) trend extrapolation techniques.	Optimal policy approach: predict the future and implement an ‘optimal’ policy for the future.	Utility maximisation: maximisation of desired output (e.g. profit or utility).
Level 2: alternative futures (with probabilities).	Foresight Methodology: probabilistic forecasts or scenarios for which the likelihood is intended to cover the entire outcome space (e.g. scenarios based on the output of a probabilistic forecast).	Risk management approach: minimize risks (or maximize benefits) by implementing cost effective mitigation actions.	Specific risk attitude: criteria depending on specific risk attitude of the policy maker (Hurwicz optimism-pessimism criterion).
Level 3: multiplicity of plausible futures.	Futures Research Methodology: a plausible range of scenarios that is intended to explore the corners of anticipated future developments, plausible storyline scenarios, or plausible probabilistic scenarios.	Static robust policy approach: identify plausible futures and find a policy that works acceptably well across most of them (e.g. by using exploratory modelling techniques).	Regret minimization: use of Savage’s mini-max criteria.
Level 4: unknown future (deep uncertainty).	Futures Research Methodology: as for Level 3, but with inclusion of wildcard scenarios to deal with ‘Gray Swans’. Clear notion that ‘Black Swans’ may occur.	Adaptive policy approach: adapt policy over time as conditions change and learning takes place. Extend analysis with scenario discovery.	Regret minimization: as for Level 3, combined with an adaptive decision making structure.

The presented guideline is of course not cast in stone, but I consider it a reasonable starting point for policy makers to select the right approach for their issue under consideration. The following policy approaches may be suggested at the various levels of uncertainty:

- **Level 1:** For issues that are clear enough to be adequately predicted on the basis of historical data I recommend the use of forecasting methods in combination with an ‘optimal’ policy approach that aims to maximise the expected utility (e.g. profit).
- **Level 2:** In case it is still possible to assign likelihoods to alternative futures I recommend using foresight methodology in combination with risk management. The applied decision criterion will depend on the risk attitude of the policy maker.
- **Level 3:** As long as it is still possible to imagine all kinds of plausible futures without regarding the likelihood I recommend the use of futures research methodologies (mainly scenarios) in combination with the development of static robust policies (i.e. by applying robust scenario planning). An obvious approach would then be to search for robust policies that perform well along: a number of plausible scenarios, that explore the corners of the anticipated future developments; a broad range of plausible storyline scenarios; or landscapes of hundreds to millions of plausible scenarios, that are obtained from exploratory modelling techniques. For the evaluation of robust policies the regret minimisation criterion is generally considered the most appropriate.
- **Level 4:** For dealing with the most profound levels of deep uncertainty I suggest to develop wildcard scenarios in addition to a range of usual plausible scenarios. Wildcard scenarios allow us to think of highly improbable but still imaginable events that have a major impact (i.e. Gray Swans). It should further be recognised that there may also occur events that cannot be imagined (i.e. Black Swans). Conditions of deep

> uncertainty will force the policy process to become more flexible. I therefore suggest to apply adaptive policies in combination with exploratory modelling and scenario discovery techniques. For the evaluation of alternative policy options the regret minimisation criterion is generally considered the most appropriate.

Kwakkel et al. (2012) indicate that adaptive policies may be expected to outperform static robust policies in long term planning issues. This implies that it may also be useful to consider adaptive policies for issues with a Level 3 uncertainty. In this respect the policy maker will have to balance between the increased complexity of the policy making process on the one hand, and the additional benefits (or savings) on the other hand. This judgement will have to be made by the policy maker on a case by case basis.

5.6.2 Dealing with the very long term policy issues of Rijkswaterstaat

Until now I have not paid attention to the implications of applying a very long time horizon to the policy making process of Rijkswaterstaat. By intuition one would say that the farther one looks ahead the more uncertain the future becomes. However, a very long time horizon does not necessarily imply a very high level of uncertainty. For each given time horizon there is a trade-off (inverse relation) between the level of detail taken into account and the uncertainty level of the projection. Very long term projections require the level of detail to be sufficiently reduced. This implies that the length of time that can be anticipated at a certain level of uncertainty depends on the amount of detail that is required for the description of the policy issue under consideration.

In order to deal with policies that have a very long term impact, such as those related to the issue discussed in this thesis, I suggest to start considering the problem at the highest possible level of aggregation and to stepwise ‘zoom in’ to obtain a more detailed view. For some aggregated issues such as population, economic output, or even the aggregated total freight transport demand in a large region such as Western Europe, it may still be possible to apply a Level 2 (foresight) approach and to develop a very long term probabilistic projection. When the policy evaluation process requires a more specific view of the future (e.g. to define the specific transport flows at the network level) it becomes necessary to scale up to a Level 3 or even a Level 4 approach. In case of Level 3 uncertainties it is sensible to develop robust policies along a range of plausible scenarios (e.g. based on robust scenario planning and/or exploratory modelling techniques). For Level 4 uncertainties one should consider a shift towards adaptive policies, supported by wildcard scenarios and/or exploratory modelling in combination with scenario discovery techniques. For the evaluation of policies that affect the very long term development of the IWT system at the network level a Level 3 approach may still be sufficient. In cases where it concerns more specific issues (e.g. the development of a single infrastructure object) it may be necessary to scale up to a Level 4 approach.

For the quantification of explorative very long term scenarios it is sensible to start with an aggregated probabilistic projection, that is based on Level 2 foresight, and to develop scenario quantifications that lay within the bandwidth of this projection. This approach has also been applied for the quantification of the scenarios in Chapter 14. It has the clear benefit that it reduces the bandwidth of the scenario quantifications compared to the approach in which the scenario quantifications are based on aggregation of disaggregated scenario quantifications. In addition to the use of Level 2 foresight, the outcome of long term forecasts can also be used to obtain detailed quantifications for the development of the system throughout the initial stage (e.g. the first 30 years) of the very long term scenario. Forecasting and foresight techniques are therefore both very useful for the quantification of very long term scenarios.

5.7 Concluding Summary

This chapter addresses the fourth general sub question (GSQ 4): *"What are the most appropriate methods for looking far ahead (i.e. towards the end of the 21st century) and dealing with the inevitable high levels of uncertainty, that are related to such a very long term planning horizon?"*. I studied the broader field of saying something about the future, the available methods for looking ahead, the various ways to classify uncertainty, the available policy options for dealing with uncertainty, and the appropriate decision criteria. On the basis of this analysis I conclude with a clear policy guideline for selecting the most appropriate methods for looking ahead and dealing with uncertainty.

5.7.1 Methods for looking ahead and dealing with uncertainty

The topology for describing the field of saying something about the future is still vague and contains considerable overlap in the applied terminology. To avoid confusion I suggested a new unambiguous definition of the topology. This definition is clarified by the 'Futures Research Pyramid' and consists of the following mutually exclusive subfields: 'forecasting', 'foresight', 'futures research (or futures studies)', and 'futurology' (see Figure 5-1).

According to this new topology definition: Forecasting methodology provides a definite estimate of the expected future trend based on 'hard' statistical trend extrapolation methods and 'soft' judgemental methods, that rely on expert judgement; Foresight provides a coherent view of possible futures in which likelihoods are explicitly or implicitly assigned to the possible future developments; Futures research deals with visualisations of all kinds of plausible futures without considering the likelihood; and Futurology is about imaginable futures that not necessarily need to be plausible (i.e. science fiction).

Forecasting, foresight, and futures research literature indicate a number of methods that I consider relevant for the development of a very long term view. These include: extrapolation of highly aggregated long term trends, causal relations to less specific parameters, analogies and technological S-curves, systems dynamic modelling, probabilistic projections, scenarios based on probabilistic projections, plausible storyline scenarios, probabilistic scenarios (or conditional probabilistic estimates), and wildcard scenarios.

There are various ways to classify uncertainties. I consider the level of uncertainty the most relevant for the issue addressed in this thesis. Walker (2011) distinguishes among the following four levels of uncertainty: Level 1: a clear enough future; Level 2: alternate futures (with probabilities); Level 3: a multiplicity of plausible futures; and Level 4: an unknown future. Lempert et al. (2003) refer to 'deep uncertainty' as a condition where analysts do not know or the parties to a decision cannot agree upon: (1) the appropriate conceptual models to describe interactions among a system's variables; (2) the probability distributions to represent uncertainty about key parameters in the models; and/or (3) how to value the desirability of alternative outcomes. Walker et. al. (2013) points out that the 'cannot agree on' portion of the deep uncertainty definition applies to Level 3 uncertainty, while the 'do not know' portion of the deep uncertainty definition applies to Level 4 uncertainty.

Taleb (2007) warns for highly improbable rare events with a disproportional impact on the aggregate, that he calls 'Black Swans'. A Black Swan is characterized by three attributes: (1) it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility; (2) it carries an extreme impact; and (3) in spite of its outlier status, human nature makes us concoct explanations for occurrence after the fact, making it explainable and predictable. Taleb further considers Gray Swans which he defines as modelable extreme events. A Gray Swan concerns modelable extreme events, a Black Swan is about unknown unknowns.

The various levels of uncertainty require different policy approaches. Agusdinata (2008) provides a useful structure for dealing with uncertainties, consisting of: ‘an optimal policy approach’, ‘a static robust policy approach’, and ‘an adaptive policy approach’. I added the ‘risk management approach’ and suggested that the different policy approaches can be related to the different levels of uncertainty (i.e. Level 1: ‘optimal policies’; Level 2: ‘risk management’; Level 3: ‘static robust policies’; and Level 4: ‘adaptive policies’).

The optimal policy approach is characterised by policy makers that optimise their decisions on the basis of a single ‘best estimate’ (or forecast) of the behaviour of the system. The risk management approach considers both the likelihood and impact of the anticipated future events and tries to mitigate the risks (or optimise the output at a given risk level). The static robust policy approach searches for policies that perform well across a broad range of plausible futures. For such policies the use of plausible scenarios and/or exploratory modelling techniques can be considered. In case of policies dealing with the highest levels of uncertainty it may at a certain stage no longer be possible to construct a single static policy that performs well across the many possible future scenarios that can be thought of. For these situations Walker et al. (2001, 2013a) suggest an adaptive policy making approach. This approach can be supported by exploratory modelling and scenario discovery techniques.

There exist various decision criteria that can be applied for the evaluation of the different policy outcomes. It is common to apply the optimisation criterion for optimisation policies, the Hurwicz optimism-pessimism criterion in case of a risk management approach, and Savage’s mini-max (no-regret) criterion for static robust and adaptive policies.

5.7.2 Guideline for selecting the most appropriate methods

On the basis of the above analysis I conclude that there are sufficient methods available for looking far ahead and dealing with the inevitable high levels of uncertainty that are related to a very long term planning horizon, but that the fields of looking ahead and dealing with uncertainty are still completely separated from each other and not structured in an integrated consistent manner. I therefore propose a new more integrated structure for looking ahead and dealing with uncertainty, that can be used as a guideline for policy makers in general, and for Rijkswaterstaat in particular. This guideline is indicated in Table 5-5.

For each given time horizon there is a trade-off (inverse relation) between the level of uncertainty and the level of detail that can be taken into account. This implies that the length of time that can be anticipated at a certain level of uncertainty depends on the amount of detail required for the description of the policy issue under consideration.

In order to deal with policies that have a very long term impact, such as those related to the issue discussed in this thesis, I suggest to start considering the problem at the highest possible level of aggregation and to stepwise ‘zoom in’ to obtain a more detailed view. For some aggregated issues such as population, economic output, or even the aggregated total freight transport demand in a large region such as Western Europe, it may still be possible to apply a Level 2 (foresight) approach and to develop very long term probabilistic projections. When the policy evaluation process requires a more specific view of the future (e.g. to define the specific transport flows at the network level) it becomes necessary to scale up to a Level 3 or even a Level 4 approach. In case of Level 3 uncertainties it is sensible to develop robust policies along a range of plausible scenarios (e.g. based on robust scenario planning and/or exploratory modelling techniques). For Level 4 uncertainties one should consider a shift towards adaptive policies, supported by wildcard scenarios and/or exploratory modelling in combination with scenario discovery techniques. For the evaluation of policies that affect the very long term development of the IWT system at the network level a Level 3 approach may still be sufficient. In cases where it concerns more specific issues (e.g. the development of a single infrastructure object) it may be necessary to scale up to a Level 4 approach.

For the quantification of explorative very long term scenarios it is sensible to start with an aggregated probabilistic projection, that is based on Level 2 foresight, and to develop scenario quantifications that lay within the bandwidth of this projection. This approach has also been applied for the quantification of the scenarios in Chapter 14. It has the clear benefit that it reduces the bandwidth of the scenario quantifications compared to the approach in which the scenario quantifications are based on the aggregation of disaggregated scenario assumptions. In addition to the use of Level 2 foresight, the outcome of long term forecasts can also be used to obtain detailed quantifications for the development of the system throughout the initial stage (e.g. the first 30 years) of the very long term scenario. Forecasting and foresight techniques are therefore both very useful for the quantification of very long term scenarios.

5.7.3 Answer to General Sub Question 4

In answer to GSQ 4, I conclude that there are sufficient methods available for looking far ahead and dealing with the inevitable high levels of uncertainty, that are related to a very long term planning horizon, but that the fields of looking ahead and dealing with uncertainty are still completely separated from each other and not structured in an integrated consistent manner. I therefore propose a new more integrated structure for looking ahead and dealing with uncertainty, that can be used as a guideline for policy makers. The suggested approach depends on the level of uncertainty: in case of a Level 1 uncertainty (i.e. a clear enough future) one can forecast the effects and implement an 'optimal' policy; for Level 2 uncertainties (i.e. alternative futures with known probabilities) one can apply probabilistic estimates in combination with a risk management approach; for Level 3 uncertainties (i.e. multiplicity of plausible futures) one can develop robust policies that perform well along a wide range of plausible scenarios; and in case of Level 4 uncertainties (i.e. completely unknown future) one can apply an adaptive policy making approach. In order to deal with policies that have a very long term impact I suggest to start considering the problem at the highest possible level of aggregation and to stepwise 'zoom in' to obtain a more detailed view. For some aggregated issues such as population, economic output, or even the aggregated total freight transport demand in a large region such as Western Europe, it may still be possible to apply a Level 2 (foresight) approach and to develop very long term probabilistic projections. When the policy evaluation process requires a more specific forward view it becomes necessary to scale up to a Level 3 approach, that involves the development of plausible scenarios. In that case it may be sensible to start with an aggregated probabilistic projection (Level 2) and to develop scenario quantifications that lay within the bandwidth of this projection. In case even more specific developments are concerned one needs to scale up to a Level 4 approach. In that case one should consider a shift towards adaptive policies, supported by wildcard scenarios and/or exploratory modelling in combination with scenario discovery techniques. For the evaluation of policies that affect the very long term development of the IWT system at the network level a Level 3 approach may still be sufficient, though in some cases it may be necessary to scale up to a Level 4 approach.

Literature:

Agusdinata, B. (2008) *Exploratory Modeling and Analysis: A promising method to deal with deep uncertainty,* TRAIL Thesis Series Volume T2008/17, Trail Research School, Delft, The Netherlands.

Ahl, A.S. (1996) *The Application of Probabilistic Scenario Analysis for Risk Assessment of Animal Health in International Trade*, Annals of the New York Academy of Sciences, vol. 791, pp. 255-268.

Armstrong, J.S. (1985) *Long-Range Forecasting, From Crystal Ball to Computer*, John Wiley & Sons, New York.

Armstrong, J.S, ed. (2001) *Principles of Forecasting: A Handbook for Researchers and Practioners*, Kluwer Academic Publishers, Boston/Dordrecht/London.

Bails, D.G., and L.C. Peppers (1993) *Business Fluctuations: Forecasting Techniques and Applications*, Second Edition, Prentice Hall, Englewood Cliffs, New Jersey. Note: second edition also reprinted as paperback in 2007.

Bankes, S. (1992) *Exploratory Modeling and the Use of Simulation for Policy Analysis*, N3093, RAND, Santa Monica, Calif.

Bankes, S. (1993) *Exploratory Modeling for Policy Analysis*, Operations Research, vol. 41, no. 4, pp. 435-449.

Bass, F.M. (1969) *A new product growth for model consumer durables*, Management Science, vol. 15, no. 5, pp. 215-27.

Bass, F.M. (2004, republication of 1969 paper) *A New Product Growth Model for Consumer Endurables*, Management Science, vol. 50, no. 12, pp. 1825-1832.

Börjeson, L., M. Höjer, K. Dreborg, T. Ekvall, and G. Finnveden (2005) *Towards a user's guide to scenarios - a report on scenario types and scenario techniques*, version 1.1b, KHT Architecture and Built Environment, Stockholm, Sweden.

Bier, V.M. (1997) *An Overview of Probabilistic Risk Analysis for Complex Engineerd Systems*, in Molak (ed.) *Fundamentals of Risk Analysis and Risk Management*, Lewis Publishers, Boca Raton.

Bowerman, B.L., R.T. O'Connell, and A.B. Koehler (2005) *Forecasting, Time Series and Regression: An Applied Approach*, Fourth Edition, Thomson Brooks/Cole.

Clements, M., and D. Hendry (1998) *Forecasting Economic Time Series*, Cambridge University Press.

Coates, J.F. (1985) Foresight in federal government policymaking, Futures Research Quarterly, summer ed., pp. 29-53.

Cornish, E. (1978) *The study of the future. An introduction to the art and science of understanding and shaping tomorrow's world*. Washington: World Future Society.

Cuhls, K. (2003) *From Forecasting to Foresight Processes – New Particiative Foresight Activities in Germany,* Journal of Forecasting, vol. 22, no. 2-3, pp. 93-111.

Davis, G. (2002) *Scenarios as a Tool for the 21st Century*, Shell International Ltd. Paper originally presented at *Probing the Future Conference*, Strathclyde University, 12 July 2012.

Dewar, J. (2003) *The Importance of 'Wild Card' Scenarios*, NIC 2020 Project Inaugural Conference. Washington DC, National Intelligence Council.

DeLurgio, S.A. (1998) *Forecasting Principles and Applications*, international editions 1998, Mcgraw-Hill College.

Diebold, F.X. (2004) *Elements of Forecasting*, Third Edition, Tomson South-Western, Canada.

Duin, P. van der (2006) *Qualitative futures research for innovation*, Eburon Academic Publichers, Delft, The Netherlands.

Fildes, R. (1986) *EDITORIAL, Long-Term Forecasting and the Experts, International Journal of Forecasting*, vol. 2, no. 1, pp. 3-4.

Fildes, R. (2006) *The forecasting journals and their contribution to forecasting research: Citation analysis and expert opinion*, International Journal of Forecasting, vol. 22, no. 3, pp. 415-432.

Fisher, J.C., and R.H. Pry (1971) *A Simple Substitution Model of Technological Change*, Technological Forecasting and Social Change, vol. 3, pp. 75-88.

Floyd, A. (1968) *A Methodology for Trend-forecasting for Industry and Government: Methods and Applications*. Prentice-Hall, Englewood Cliffs, New Jersey.

French, S. (1993) *Decision Theory: An Introduction to Mathematics of Reality*, Chichester, Ellis Horwood Limitted.

Glenn, J.C., T.J. Gordon, and E. Florescu (2009a) *2009 State of the Future*, The Millennium Project, Washington, USA.

Glenn, J.C., and T.J. Gordon eds. (2009b) *Futures Research Methodology Version 3.0*, The Millennium Project, Washington, USA.

Goodess, C.M., J. All, M. Best, R. Betts, L. Cabantous, P.D. Jones, C.G. Kilsby, A. Pearman, and C.J. Wallace (2007) *Climate Scenarios and Decision Making under Uncertainty*, Built Environment, vol. 33, no. 1, pp. 10-30.

Gompertz, B. (1825) *On the nature of the function expressive of the Law of Human Mortality and on a new mode of determining the Value of Life Contingencies*, Philosophical Transactions , Royal Society, London. vol. 36, pp. 513-585.

Grübler, A. (1990) *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport*, Physica-Verlag Heidelberg.

Hanke, J.E., D.W. Wichern (2008) *Business Forecasting*, Ninth Edition, Pearson/Prentice Hall, Upper Saddle River, NewYork.

IIASA (2007) *The growing divergence in population trends and concerns*, in Options 2007: Global development challenges for science, winter edition, International Institute for Applied Systems Analysis, pp. 10-13.

Kahn, H., W. Brown, and L. Martel (1977) *The Next 200 Years, A Scenario for America and the World*, The Hudson Institute, Associated Business Programmes Ltd., 17 Buckingham Gate, London, United Kingdom.

Kaplan, S., and B.J. Garrick (1981) *On the quantitative definition of risk*, Risk Analysis, vol. 1, no. 1, pp. 11-27.

Kwakkel, J.H., W.E. Walker, and V.A.W.J. Marchau (2012) *Assessing the Efficacy of Adaptive Airport Strategic Planning: Results from Computational Experiments*, Environment and Planning B: Planning and Design, vol. 39, no. 3, pp. 533-550.

Lempert, R.J., S.W. Popper, and S.C. Bankes (2003) *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis.* RAND, Santa Monica.

Levenbach., H., and J.P. Cleary (2005) *Forecasting: Practice and Process for Demand Management*, Thomson Brooks/Cole, Belmont, CA.

Loulou, R., and A. Kanudia (1999) *Minimax regret strategies for greenhouse gas abatement: methodology and application,* Operations Research Letters, vol. 25, no. 5, pp. 219-230.

Loveridge, D. (2009) *FORESIGHT: The Art and Science of Anticipating the Future,* Routledge, New York.

Makridakis, S., S. Wheelwright, and R. Hyndman (1998) *Forecasting: Methods and Applications,* J. Wiley & Sons.

Malaska, P. (2001) *A futures research outline of a post-modern idea of progress,* Futures, vol. 33, pp. 225-243.

Marien, M. (2002) *Futures studies in the 21st Century: a reality based view*, Futures 34, vol. 3, no. 2, pp. 261-281.

Martin, B.R. (1995) *Foresight in science and technology*. Technology Analysis & Strategic Management, vol. 7, no. 2, pp. 139-168.

Masini Barbieri, E. (1998) *Futures research and sociological analysis. A draft of a discussion.* The XIV World Congress of Sociology, The International Sociological Association, RC07 Futures Research, 16 July-1 August 1998.

Maslow, A.H. (1954) *Motivation and Personality*, Harper, New York.

Meadows, D. H., D. L. Meadows, J. Randers, and W.W. Behrens III (1972) *The Limits to Growth,* Universe Books, New York.

Mentzer, J., C. Bienstock (1998) *Sales Forecasting Management*, Sage Pub, Thousand Oaks, CA.

Molak, V. (1997) *Fundamentals of Risk Analysis and Risk Management*, Lewis Publishers, Boca Raton.

Nakicenovic, N., and R. Swart, eds. (2000) *Special Report on Emission Scenarios (SRES)*, Cambridge University Press, Cambridge, UK.

North, D.W. (2006) Assessing Risks in Long-Term Planning: Probabilistic Scenario Analysis with Generalized Equilibrium Energy Models, RIMS VNIIGAZ/GAZPROM Conference, Moscow, February 2006, http://www.northworks.net/w_pub_vniigaz.htm.

Oryang, D. (2002) *Probabilistic Scenario Analysis (PSA) – A methodology for Quantitative Risk Assessment*, NAPRO PRA Symposium, Puerto Vallarta, Mexico, March 2002, www.nappo.org/PRA-Symposium/PDF-Final/Oryang.pdf.

Pearl, R. (1925) *The Biology of Population Growth*. Knopf, New York.

Pindyck, R., and D. Rubinfeld (1997) *Econometric Models and Economic Forecasts*, McGraw Hill.

Popper, K. (1935) *Logik der Forschung: Zur Erkenntnistheoried er modernen Naturwissenschaft,* Wien, Julius Springer.

Raiffa, H. (1968) *Decision Analysis,* Addison-Wesley.

Riedy, C. (2009*) The influence of futures work on public policy and sustainability,* Foresight, vol. 11, no. 5, pp. 40-56.

Rosenberg, N. (1995) *Why Technological Forecasting Often Fail*. The Futurist, July-August, pp. 15-21.

Rosenhead, J., and J. Mingers (eds.) (2001). *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty, and Conflict,* Wiley and Sons, Chichester, UK.

Schon, D.A. (1967) *Forecasting and Technological Forecasting,* in Daedalus, Vol. 96, no. 3, Towards the Year 2000: Work in Progress, The MIT Press on behalf of American Academy of Arts & Sciences.

Schwartz, P. (1991) *The Art of the Long View, Planning for the Future in an Uncertain World,* Doubleday, a division of Bantam Doubleday Dell Publishing Group, Inc., New York.

Sharif M.N., and C. Kabir (1979) *A Generalized Model for Forecasting Technological Substitutions*. Technological Forecasting and Social Change, vol. 8, no. 4, pp. 353-334.

Slaughter, R. (2009) *The state of play in the futures field: a metascanning overview,* Foresight, vol. 11, no. 5, pp. 6-20.

Taleb, N.N. (2007) *The Black Swan, The Impact of the Highly Improbable*, Penguin Books.

Van der Heijden, K. (1996) *Scenarios: The Art of Strategic Conversation*, John Wiley & Sons, Ltd, Chichester, England.

Van Dorsser, J.C.M. (2012) *Scheepvaartscenario's voor Deltaprogramma, 100 jaar later…. Rijkswaterstaat-DVS.*

Van Dorsser, J.C.M., M.A. Wolters, and B. van Wee (2012) *A Very Long Term Forecast of the Port Throughput in the le-Havre – Hamburg range up to 2100*, European Journal of Transport and Infrastructure Research, vol. 12, no. 1, pp. 88-110.

Verhulst, P.F. (1838) *Notice sur la loi que la population suit dans son accroissement,* Correspondence Mathématique et Physique, vol. 10, pp.113-121.

Vuuren, D.P. van, B. de Vries, A. Beusen, and P.S.C. Heuberger (2008) Conditional probability estimates of 21st century greenhouse gas emissions based on the storylines of the IPCC-SRES scenarios, Global Environmental Change, vol. 18, no. 4, pp. 635-654.

Walker, W.E., S.A. Rahman, and J. Cave (2001) *Adaptive policies, policy analysis, and policy-making,* European Journal of Operational Research, vol. 128, no. 2, pp. 282-289.

Walker, W.E. (2011) *Policy Analysis, 1962-2012: From predict and act to monitor and adapt*, farewell lecture at TU Delft, 19 October 2011.

Walker, W.E., V.A.W.J. Marchau, and J.H. Kwakkel (2012) *Chapter 9: Uncertainty in the Framework of Policy Analysis,* in *Public Policy Analysis: New Developments*, Thissen, W.A.H. and W.E. Walker (eds.), Springer.

Walker, W.E., R.J. Lempert, and J.H. Kwakkel (2013a) *Deep Uncertainty*, entry (pp. 395-402) in Gass, S.I and M.C. Fu (eds.), Encyclopedia of Operations Research and Management Science, Springer, New York.

Walker, W.E., M. Haasnoot, and J.H. Kwakkel (2013b) *Adapt or Perish: A Review of Planning Approaches for Adaptation under Deep Uncertainty*, Sustainability, vol. 5, pp. 955-979.

West, M., and Harrison, J. (1999) *Bayesian Forecasting and Dynamic Models*, Springer, New York.

Wilson, J.H., B. Keating, and John Galt Solutions Inc. (2009) Business Forecasting with ForecastX, McGraw-Hill/Irwin, Boston.

Websites:

Britannica Encyclopedia (accessed: 2009) *Futurology,* [www.britannica.com]

IIASA (accessed: 2009) *IIASA's World Population Program,* [www.iiasa.ac.at/research/pop]

Strategic Foresight Group (accessed: 2009) *Strategic foresight*, [www.strategicforesight.com]

Wikipedia (accessed: 2010) *Mandelbroth Set,* [www.wikipedia]

6 The Proposed Policy Framework

“Our life is what our thoughts make it.”
- Marcus Aurelius, Roman Emperor (121-180)

6.1 Introduction

The working arrangements between Rijkswaterstaat and the Dutch Ministry of Infrastructure and Environment are structured in such a way that construction and replacement of infrastructure is covered by the MIRT[76] programme, that deals with individual projects and has a time horizon of about 20 years. What lacks is an integrated policy framework that takes the very long lifetime of hydraulic structures into account and considers the necessary replacements as an opportunity to improve the IWT network at a systems level. This chapter proposes a possible approach for the evaluation of integrated policies with a very long term impact; and thereby addresses the first methodological sub question (MSQ 1): *‘How should Rijkswaterstaat structure its policy framework to allow for the ex-ante evaluation of integrated infrastructure development strategies with a very long term impact on the IWT system?’*.

Section 6.2 proposes a structure for the evaluation of integrated policies with a very long term impact on the IWT system; Section 6.3 indicates how alternative policy options can be developed for an integrated part of the IWT network; Section 6.4 addresses the main external developments, that can be expected to affect the overall very long term performance of the transport system, and the IWT system in particular; Section 6.5 concerns the modelling of the freight transport system; Section 6.6 defines the relevant policy outcomes of interest; Section 6.7 elaborates on the options to value (or weigh) policy alternatives with a very long term impact; and Section 6.8 contains a concluding summary that provides an answer to MSQ1.

6.2 Proposed Policy Framework

This section proposes a framework for the evaluation of policies with a very long term impact on the IWT system. It starts with an academic view on policy making, then presents a general framework for the evaluation of policies that affect the freight transport system, and finally concludes with a specific framework for policies that affect the IWT system.

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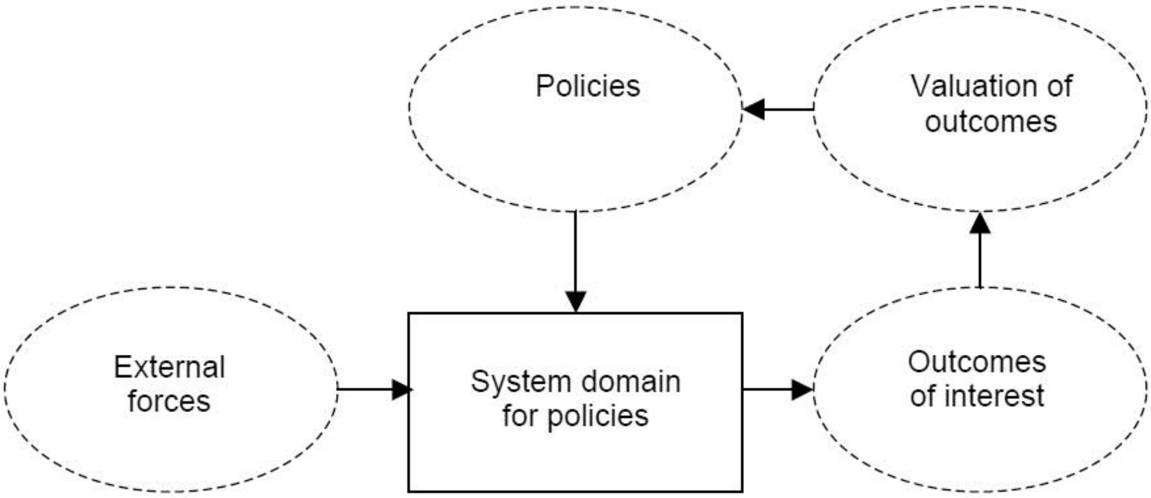
[76] The MIRT programme stands for *‘Meerjarenprogramma Infrastructuur, Ruimte en Transport’*, which is Dutch for *‘Multiannual programme for Infrastructure, Spatial Development, and Transport’*.

6.2.1 An academic view on policy making

The development of a clear policy framework for the evaluation of policies with a very long term impact requires insight in the policy making process. Such insights can for instance be obtained from the scientific work of Walker (2000), Lempert et al. (2003), and Agusdinata (2008); that will be discussed in this section.

Walker's integrated view on policy making

Marchau, et al. (2007, p.2) indicate that "*Policymaking on transport requires an integrated view with respect to the various alternative options, their possible consequences for transport system performance, and societal conditions for implementation. The basis for such a view has been provided by Walker (2000). According to this view, policymaking, in essence, concerns making choices regarding a system in order to change the system outcomes in a desired way".* Walker's (2000) integrated view on policymaking is indicated in Figure 6-1.



Source: Marchau, Walker, and van Wee (2007, p.3).

Figure 6-1: Walker's Integrated View on Policymaking

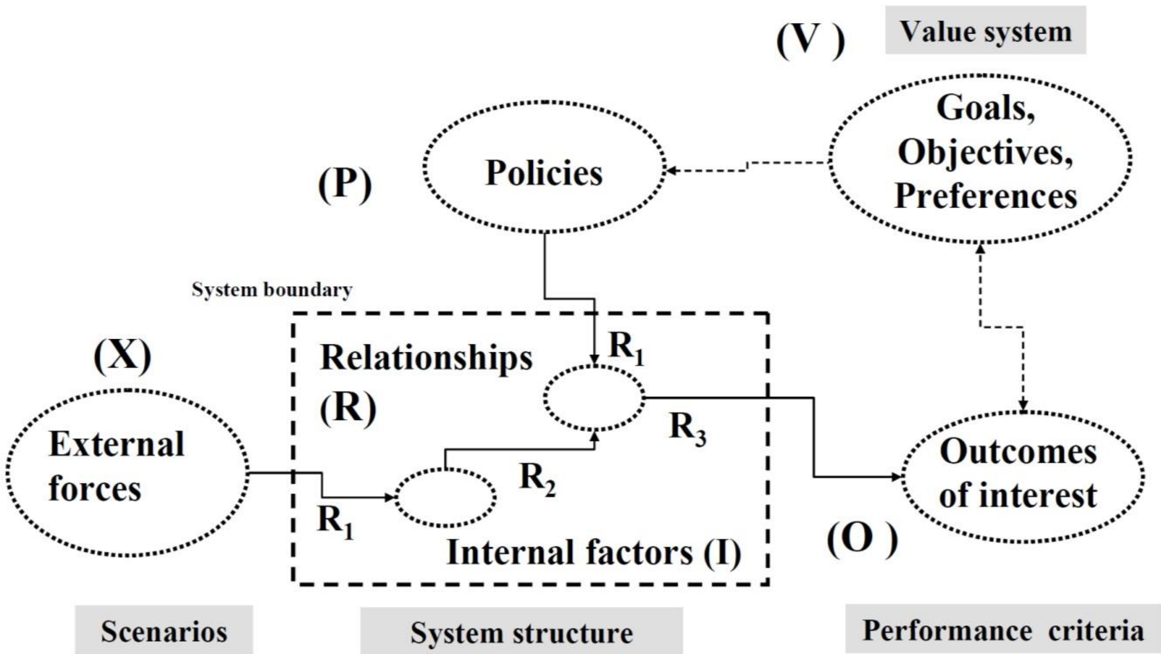
"At the heart of this view is the system comprising the policy domain, in our case the transport system. A transport system can be defined by distinguishing its physical components (e.g. loads, vehicles, and infrastructure) and their mutual interactions. The results of these interactions (the system outputs) are called outcomes of interest and refer to the characteristics of the system that are considered relevant criteria for the evaluation of policies. The valuation of outcomes refers to the (relative) importance given to the outcomes by crucial stakeholders, including policymakers. Two types of forces act on the system: external forces and policies. Both types of forces are developments outside the system that can affect the structure of the system (and, hence, the outcomes of interest to policymakers and other stakeholders). External forces refer to forces that are not controllable by the decisionmaker but may influence the system significantly, i.e. exogenous influences. A policy is a set of actions taken to control the system, to help solve problems within it or caused by it, or to help obtain benefits from it" (Marchau, et al., 2007, p.2).

Lempert's XLRM framework

Lempert et al. (2003) introduced the '*XLRM framework'* for long term policy analysis (LTPA). They indicate that *"To help guide the process of elicitation and discovery and to serve as a formal intellectual bookkeeping mechanism, it is useful to group the elements of the* *analysis into four categories. Policy levers ("L") are near-term actions that, in various combinations, comprise the strategies decisionmakers want to explore. Exogenous uncertainties ("X") are factors, outside the control of the decisionmakers, which may nonetheless prove important in determining the success of their strategies. In the language of scenario planning the Xs help determine the key driving forces that confront decisionmakers. Measures ("M") are the performance standards that decisionmakers and other interested communities would use to rank the desirability of various scenarios. Relationships ("R") describe the ways in which the factors relate to one another and so govern how the future may evolve over time based on the decisionmakers' choices of levers and the manifestation of the uncertainties, particularly for those attributes addressed by the measures"* (p. 70).

<u>Agusdinata's XPIROV framework</u>

Agusdinata (2008, p.59) combines the strengths of the policy frameworks of Walker (2000) and Lempert et al. (2003) by introducing the XPIROV notation in which the letters stand for e**x**ternal forces, **p**olicies, **i**nternal factors, **r**elationships, **o**utcomes of interest, and **v**alue system[77]. The policy framework of Agusdinata is indicated in Figure 6-2.



Source: Agusdinata (2008, p.59).

Figure 6-2 Agusdinata's XPIROV Framework.

Agusdinata (2008, p.59-60) indicates that the system domain, that is inside the dotted line presenting the system boundary, is at the heart of the policy framework. The primary elements in the XPIROV framework can be described as follows:

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[77] It should be noted that Walker (2011), applies the letter W for Weights instead of the letter V for Value system. I apply the letter V in this thesis, but I have no preference for the use of the letter V or W.

- *'Policies'* (P) are the set of instruments within control of the decisionmakers that can change the behaviour of the system;
- *'External forces'* (X) refer to factors outside control of the decisionmakers that can change the behaviour of the system;
- The *'system boundary'* defines the elements to be taken into account in the model that consist of *'internal factors'* (I) and *'relationships'* (R);
- The *'outcomes of interest'* (O) refer to a set of output characteristics of the system that is considered relevant for the evaluation of proposed policies;
- The *'value systems'* (V) reflects on the goals and preferences of the decision maker that are expressed by applying weights to the relevant outcome indicators.

Agusdinata (2008) used the XPIROV framework (in combination with exploratory modelling techniques) to deal with decision making under conditions of deep uncertainty (see Chapter 5). The notion that the XPIROV framework can be used in case of deep uncertainty implies that the framework can also be used for the evaluation of very long term policy effects.

6.2.2 General framework for policies affecting the freight transport system

I have used the XPIROV framework to develop a general policy framework for infrastructure policies, that have a very long term impact on the performance of the freight transport system. The obtained policy framework is indicated in Figure 6-3.

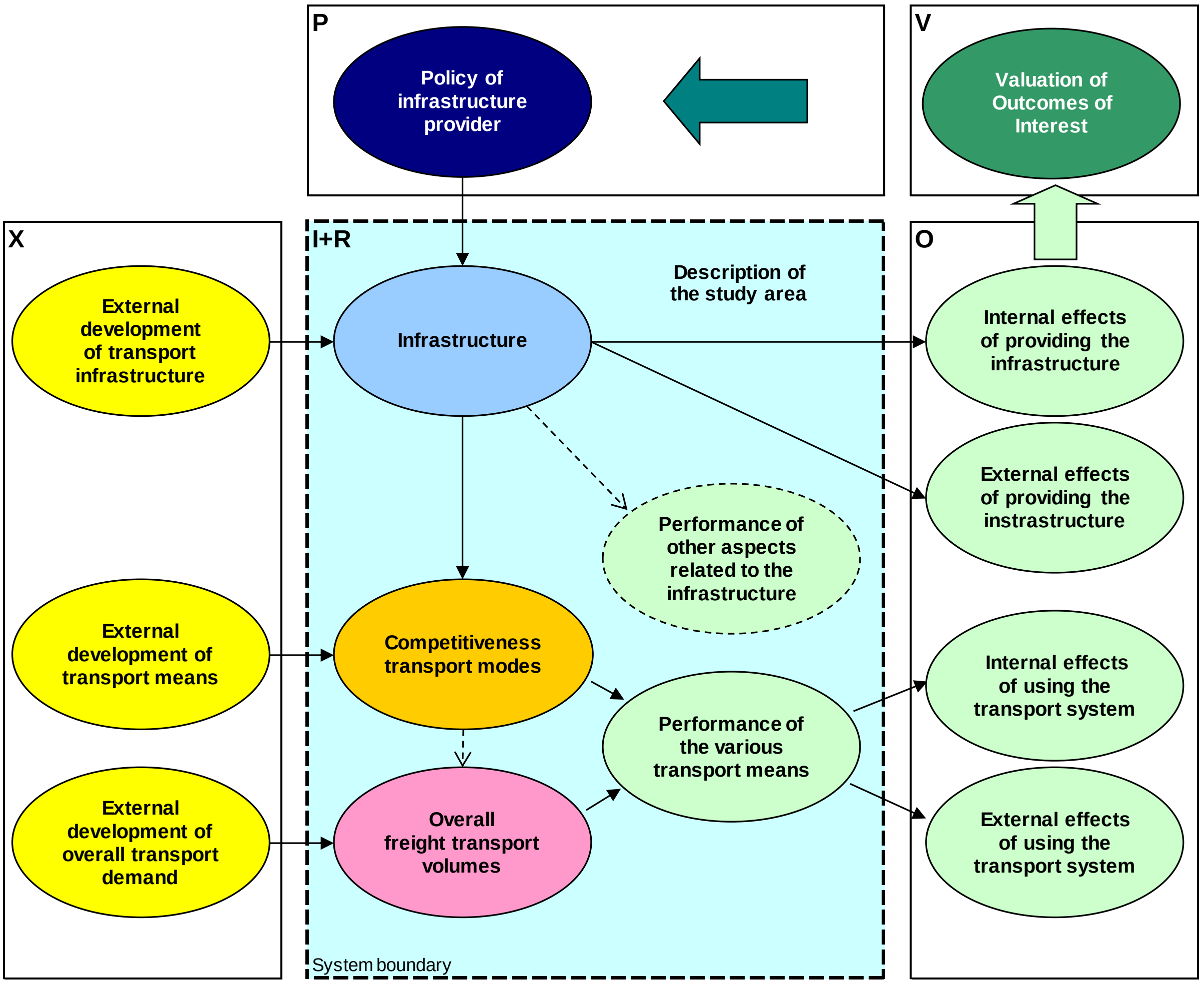


Figure 6-3: General Framework for Policies affecting the Freight Transport System

The identification of external developments (or external forces), internal factors, relationships, and outcomes of interest in the general policy framework is based on insights obtained from Chapter 3 and my personal understanding of the freight transport system.

The ***'proposed policies'*** **(P)** are located in top of the model. In general a distinction is made between: the *'status quo development'*, in which no policy changes are suggested; and the proposed policy options, that are compared to the status quo development.

The left side of the model shows the ***'external developments'*** **(X)** that are beyond control of the infrastructure provider. The *'external development of transport infrastructure'* concerns: (1) infrastructure developments that are outside the geographical area under control of the infrastructure provider (such as infrastructure in neighbouring countries); (2) infrastructure developments within the geographical area, but outside the reach of the infrastructure provider (such as the Dutch railway system that is managed by ProRail instead of Rijkswaterstaat); and (3) other external developments, that affect the performance of the infrastructure (such as the effects of climate change on the available water levels for IWT). The *'external development of transport means'* concerns the development of the overall performance of the transport means (such as technical specifications, capacity, and cost levels). These developments have a direct effect on the competitiveness of the individual transport means and thereby on the modal split, but via the price elasticities for transport they may also have an indirect effect on the overall transport volumes. The *'external development of overall transport demand'* concerns the development of overall freight transport demand for all modes of transport combined.

The ***'system domain' (I+R)*** is located at the heart of the model. It contains a description of the study area as well as the internal factors of which the system is composed, which are:

- the available infrastructure within the study area;
- the competitiveness of the various transport means;
- the overall freight transport volumes;
- the performance of the various transport means; and
- the performance of other aspects related to the infrastructure.

From the transport scenarios analysed in Chapter 3 it was understood that the structural effect of high oil prices on the level of GDP and freight transport is almost negligible (Janssen et al., 2006, p.94); and that *"demand for transport services is relatively insensitive to price"* (Petersen et al., 2009, p.43). This implies that it may be possible to eliminate the causal relation between transport prices and transport demand from the general model structure. I have therefore indicated this relation with dotted lines in the figure.

The ***'study area'*** is generally larger than the domain under control by the infrastructure provider. It does not only contain the area managed by the infrastructure provider, but also covers the surrounding regions that affect the transport flows in the area under consideration. The model element *'infrastructure'* deals with the availability and quality of the infrastructure provided in the study area, which is affected by the policy of the infrastructure provider and the external development of the transport infrastructure. The *'capacity and competitiveness of the transport modes'* is related to: (1) the external developments of the transport means; (2) the development of the overall freight transport volumes; and (3) the quality levels of the available infrastructure. The *'overall freight transport volumes'* are mainly driven by socio-economic developments, but they are also affected by the cost levels of transport. The *'performance of the various transport means'* can be defined by assigning the overall freight transport volumes to the various transport means on the basis of their relative performance and generalised cost levels. The system domain finally comprises the element *'performance of other aspects related to the infrastructure'*. This element concerns the effects of proposed policies on other objectives of the infrastructure provider (such as, in case of Rijkswaterstaat: safety against flooding and/or availability of fresh water for the waterway network; and flow of passenger traffic for the road network); as well as the effects on other aspects outside the core interest of infrastructure provider (such as economic spin offs, and/or recreational use of the system). The performance of these other aspects is not further taken into account in this thesis. It is therefore indicated with dotted lines and not linked to the outcomes of interest.

The ***'outcomes of interest'*** **(O)** are shown at the right side of the model. A distinction is made between *'internal effects'* and *'external effects'*. The internal effects relate to the transport system itself. They concern the changes in the construction and maintenance costs for the infrastructure provider, as well as the changes in the overall cost levels for the users of the transport system (both compared to the status quo in which no policy changes are applied). The external effects relate to changes in those costs (and benefits), that are imposed on society without being charged for by the transport activities that create them (see Chapter 3).

The model finally contains a ***'value system'*** **(V)** that gives a value to the various outcomes of interest. This value system deals with three important aspects, which are: (1) the identification of the various outcomes of interest; (2) the weighing of the various outcomes of interest amongst each other; and (3) the weighing of the various outcomes of interest over time.

6.2.3 Proposed framework for policies affecting the IWT system

A simpler framework and model structure is easier to implement than a more elaborate one. I therefore consider it sensible to reduce, as much as possible, the size and complexity of the model structure. This section addresses the options to reduce the scope of the general framework to the scope required for the evaluation of policies that affect the IWT system.

One may recall that a group of experts within Rijkswaterstaat desires to develop a more visionary and proactive very long term replacement strategy (see Chapter 1). When fully developed the applied methodology should be able to cover the entire infrastructure system, but the first stage, for which this thesis provides a preliminary study, is only concerned with the IWT system. This allows the following simplifications to be made:

- All policy effects stemming from non-transport related use of the waterway system can be excluded from the model;
- The external development of the transport infrastructure network will only need to be discussed in detail for the inland waterways.

The first simplification can be justified by the fact that the various functions of the waterways do not seem to affect each other much (see Chapter 2). The asset manager should however not lose the broader picture. I therefore suggest to keep the element *'performance of other aspects related to the infrastructure'* in the model and indicate it with dotted lines to remind that they will eventually also have to be taken into account. The second simplification implies that one can make the *'study area description'* less detailed for the other modes of transport, than for the IWT system. The simplified transport model can, for instance, contain a very specific description of the expansions and upgrades of the IWT infrastructure at the network level, while the changes to other transport networks are only described at a general level.

The above simplifications enabled me to propose a simpler, more specific, policy framework for the evaluation of infrastructure policies that affect the IWT system. The obtained framework is presented in Figure 6-4. Note that the direct *'internal and external effects of providing the infrastructure'* have been grouped to simplify the model representation.

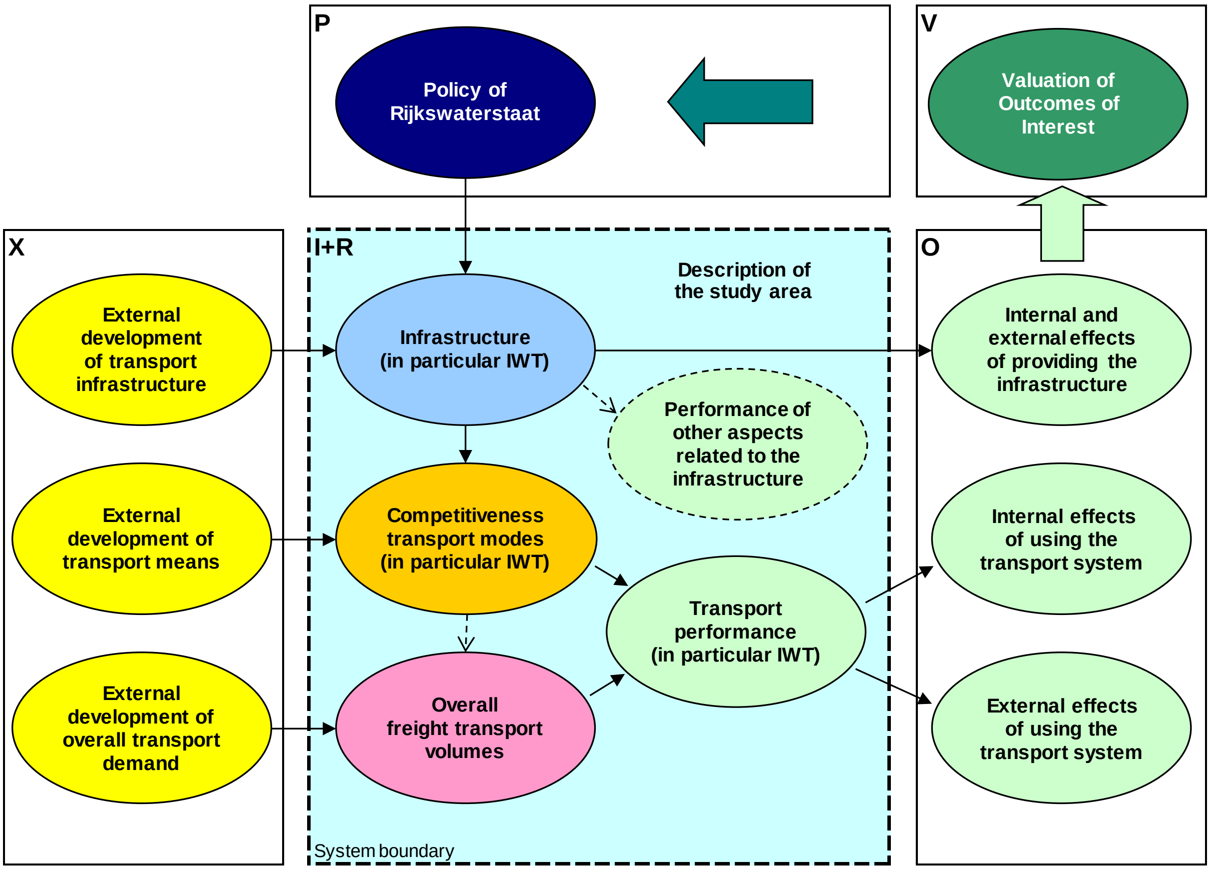


Figure 6-4: Proposed Framework for Policies affecting the IWT System

The proposed framework for policies affecting the IWT system contains a relatively straight-forward system description, that enables the step by step development and execution of the transport model within the system domain. The concerned policies (P), external developments (X), internal factors and relationships (I+R), outcomes of interest (O), and value system (V) of this framework are discussed in the remainder of this chapter.

6.3 Developing Alternative Policy Options

The development of integrated very long term infrastructure development policies (P) for a larger part of the waterway system requires a different approach than the approach presently applied by Rijkswaterstaat. Rijkswaterstaat therefore conducted a case study for the Dutch catchment area of the river Meuse to gain insight in the organisational challenges, that are related to the use of an integrated policy approach. On the basis of this case study De Haan and Nagtegaal (2010) proposed a possible approach for the development of integrated infrastructure development strategies, that contains the following six steps[78]:

[78] De Haan and Nagtegaal (2010, p.3-4, translated) applied the following topology: (1) Conceptual arrangement (in Dutch: inrichtingsconcept): general outline for the arrangement of the study area, that is developed from a

1. Select a sensible planning area. The size of the planning area should not be chosen too small, to allow the infrastructure objects to be studied in relation to each other, but also not too large, in order to keep sufficient feeling with the regional interests;
2. Develop a set of very long term scenarios for the external development of the planning area under consideration (including climate change and socio-economic drivers);
3. Develop a number of *‘conceptual arrangements’* that reflect the desired developments from a broad range of completely different angles and user functions;
4. Provide a transparent assessment of the conceptual arrangements in order to reflect on the ideas and give feedback to the various stakeholders involved;
5. Distil the common aspects (or building blocks) from the broad range of conceptual arrangements in order to develop a sensible set of specific plans (*‘area options’*) for the development of the infrastructure in the planning area;
6. Assess the various area options and develop a clear replacement strategy for the few most promising ones (including the phasing of the proposed policy).

The way that these individual steps were treated in the case study is further discussed in the remainder of this section. The discussion of the case study has been included because it serves as a guideline for the development of integrated development strategies, for which the options to develop a very long term evaluation framework are investigated in this thesis.

Step 1: Select a sensible planning area

The catchment area of the Dutch part of the River Meuse was selected as the planning area for the case study. This area contains six weirs that, given their age and lifetime, will need to be replaced in the period from the year 2020 to the year 2030. According to Den Heijer et al. (2010, p.11) it could make sense to replace these old weirs by fewer number of new ones, but this decision requires a broad view on the development of the entire river catchment area. It is therefore sensible to select the entire river catchment area as the planning area.

Step 2: Develop a set of very long term scenarios

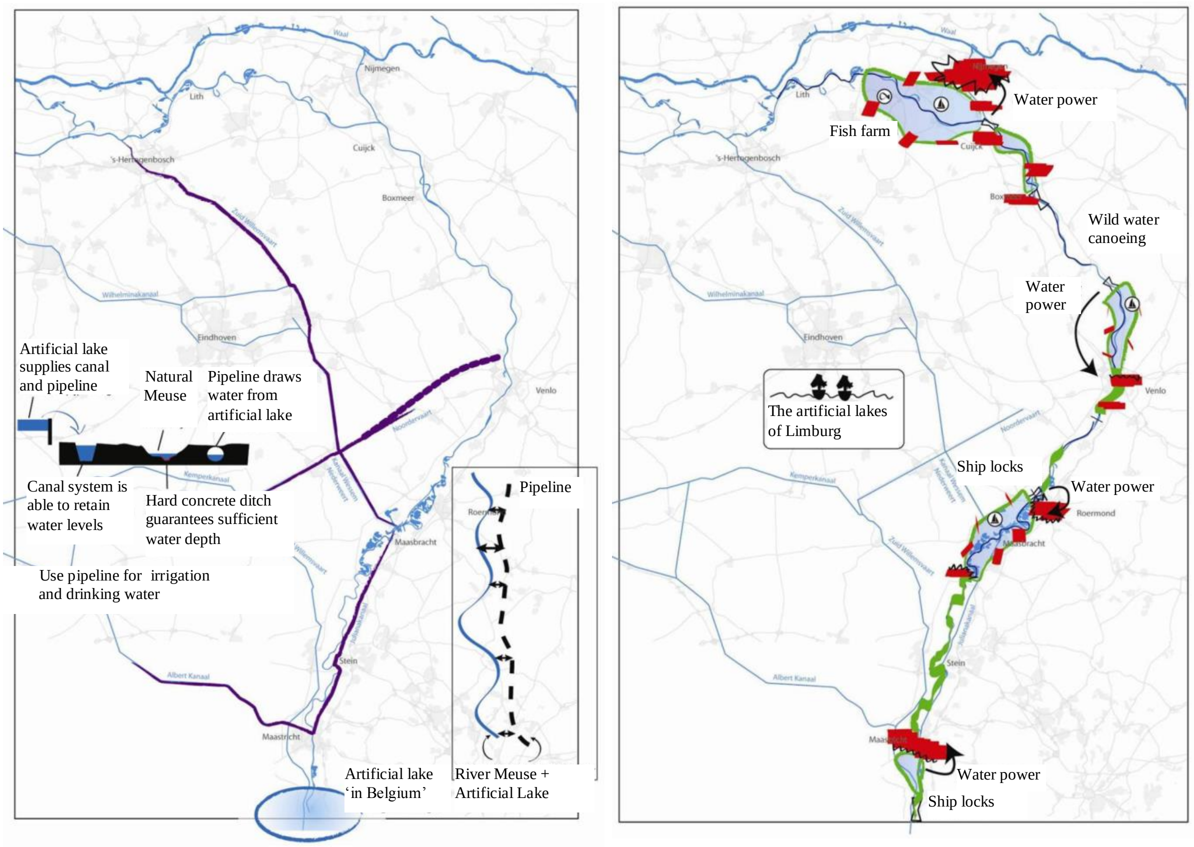
The second step concerns the development of a clear view on possible and/or plausible future developments (i.e. scenarios). Such a view can help stakeholders to think of desired futures for the region – and contributes to the creative process of developing spatial concepts in the next step. In addition the obtained scenarios can also be used for the evaluation of the conceptual arrangements and proposed area options in Step 4 and Step 6 of this approach.

Step 3: Develop a broad range of conceptual arrangements

When planning for a major rearrangement of the waterway system the effects on the living environment will also be considerable. This implies that many stakeholders are involved. In order to gain broad support for the final plans, it will be necessary to involve the stakeholders early in the process. An interesting way to create a broad commitment and allow stakeholders to bring in good ideas is to jointly develop a number of plans from completely different user perspectives. In addition stakeholders can also be given the possibility to sketch their own

broader regional focus – and takes into account the specific objects for which the asset managers are responsible; (2) Area option (in Dutch Areaalvariant): final arrangement of the specific objects in the region for which the asset managers are responsible; (3) replacement strategy (in Dutch: vervangingsstrategie): strategy for the implementation of an area option in which concrete actions, such as replacements, preparatory work, and lifetime increasing maintenance are taken into account and placed in time.

desired future for the region, that completely fits their ideals. This creative process allows Rijkswaterstaat to identify a broad range of possible policy alternatives. For the case study of the river Meuse an expert session was held, that was attended by a mixed group of experts with a different background on the inland waterway system and the river Meuse in particular. During this session six conceptual arrangements were developed. As an example, I have indicated two of these conceptual arrangements in Figure 6-5.



Source: De Haan and Nagtegaal (2010, p.12 and p.20), translated text.

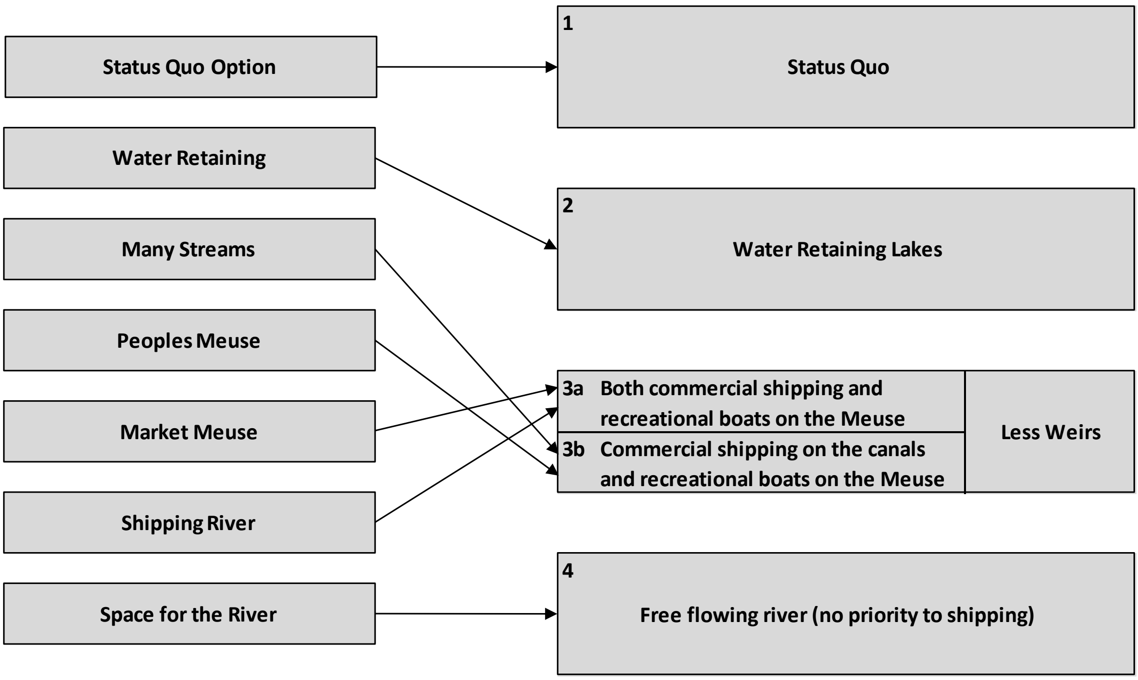
Figure 6-5: Example of two different Conceptual Arrangements for the River Meuse

The first arrangement *'Many Streams'* (left) aims to separate and optimise the different user functions of the waterways. Sufficient fresh water supply is guaranteed by developing a water retaining lake upstream in Belgium. Water is drained from this lake and transported by pipelines to the various water users (e.g. for irrigation). The canals of the Zuid Willemsvaart, as well as the surrounding canals, are upgraded to facilitate larger barges, that would otherwise sail on the river Meuse. These shipping canals are able to retain water and require only a relatively small amount of water inflow. The weirs on the Meuse are finally removed to obtain a natural free flowing river, in which a hard ditch is provided to offer sufficient water depth for water recreation. The second arrangement *'Water Retaining'* (right) is developed around the idea of retaining water in a number of lakes. These lakes offer sufficient draft for inland shipping and create new opportunities for water recreation and hydropower.

It should however be noted that the presented conceptual arrangements may not be feasible for political and/or technical reasons, but they at least indicate how one can think of a broad range of completely different conceptual arrangements.

Step 4: Provide a transparent assessment of the conceptual arrangements
The fourth step is meant to reflect on the various conceptual arrangements. In this step the various interests of the different stakeholders are recognised and converted into physical elements (building blocks) for the redevelopment of the area. In case certain interests cannot be fulfilled the stakeholders can be re-involved and asked to think of alternative ways to serve their needs within a given set of constraints.

Step 5: Distil the common aspects from the broad range of conceptual arrangements
On the basis of the identified building blocks a distinct number of substantially different area options is developed. The seven conceptual arrangements of the case study (including the status quo) were converted into five different area options. This is indicated in Figure 6-6.



Source: De Haan and Nagtegaal (2010, p.25, translated).

Figure 6-6: Relation between Conceptual Arrangements (left) and Area Options (right)

For each of the proposed area options a conceptual design is required to address the changes to the system and assess the expected costs and possible revenues.

Step 6: Assess the area options and develop clear replacement strategies
The final step in the process is related to the development of a few detailed replacement strategies for the most promising area options.

An interesting side conclusion of the case study is the notion that the required time to develop a new conceptual arrangement and get it accepted is likely to be a few decades. This implies that, given the fact that the replacements of the weirs on the Meuse are expected to take place between 2020 and 2030, Rijkswaterstaat is probably already too late to go through the full process of developing an integrated forward view.

6.4 Dealing with External Developments

External developments (X) relate to issues that affect the performance of the IWT system, but on which Rijkswaterstaat has little or no influence. This section addresses the main external developments that act on the IWT system. These developments will, to a large extent, define the future characteristics of the transport system. In addition to the external development of the *'transport demand', 'transport infrastructure'*, and *'transport means'*, that were already mentioned in Figure 6-4, this section will also explicitly address the very long term *'effects of climate change and morphological changes'* on the IWT system, that are, in fact, part of the larger external development of the overall IWT infrastructure.

6.4.1 External development of overall freight transport demand

The external development of the overall freight transport demand affects the overall transport volumes that take place within the study area. Ideally one would like to know precisely what types of commodities are transported between the various locations within the study area, but such high levels of detail cannot be forecasted at a very long time horizon. Van Dorsser et al. (2012) indicate that one can still develop an aggregated very long term forecast for the overall freight transport demand in a large integrated area such as Western Europe up to the year 2100, but that it makes no sense to develop more specific forecasts (e.g. for a specific commodity class or a much smaller study area) at such a very long time horizon.

Chapter 7 therefore develops an aggregated very long term probabilistic projection for the overall freight transport demand in Western Europe up to the year 2100.

6.4.2 External development of transport infrastructure

In line with the reduced scope of the framework for policies affecting the IWT system this thesis addresses: (1) the general development of all available freight transport infrastructures; and (2) the specific development of the IWT infrastructure at the network level.

With respect to the general development of freight transport infrastructures it should be noted that a new major transport infrastructure network has evolved about twice a century since the beginning of the Industrial Revolution (Grübler, 1990). The canals were developed first, after which the railroads, roads, and airways followed. Given the very long time period under consideration one may also expect new transport networks to evolve in the period up to the year 2100. Such new developments need to be identified.

Concerning the very long term development of the IWT system itself, it is important to realise that a renewed interest in IWT was observed in Chapter 2. This renewed interest may result in the further integration and upgrade of the European IWT network (e.g. by developing new infrastructure links such as the Canal Seine – Nord Europe). It is therefore important to study the possible upgrades and/or expansions of the European IWT system.

Chapter 8 elaborates on the development of future infrastructures and addresses the possible upgrades and/or expansions of the European IWT system.

6.4.3 Effects of climate change and morphology

The quality of the IWT network is not only affected by potential upgrades and/or expansions of the European IWT infrastructure. There are also a few other factors that may affect the performance of the IWT system in a negative way. These factors relate to climate change and adverse morphological developments. Both effects are likely to reduce the loading draft and capacity of inland barges (Turpijn, 2011).

Climate change causes extreme weather conditions and sea level rise. Extreme weather conditions result in problems with extraordinary high- and low river discharge volumes. Longer and more extreme periods of low river discharge may cause serious restrictions on the loading draft of barges. During periods of excessive rainfall high water levels will reduce the available height underneath bridges. This affects the loading capacity for certain types of cargo such as containers. In addition extremely high water levels may also cause a temporary blockage of the waterways (e.g. to avoid problems with dyke stability). Sea level rise affects the accessibility of port regions (e.g. due to more frequent closure of the Maeslant Barrier in Rotterdam) and therefore has a negative effect on shipping and inland shipping.

Adverse morphological developments concern changes to the structure of the river bottom that affect the sailing conditions for IWT, and in particular the available water depth. Adverse morphological changes can be caused by subsidence and/or unbalanced erosion. Subsidence refers to the lowering of a bottom level relative to a reference level (such as NAP). When different waterway sections are subsiding at a different pace natural barriers can evolve at so called 'hard spot' locations. Unbalanced erosion (i.e. different levels of erosion at different sections of the waterway) can also create barriers. In both cases the available water depth is reduced, which is bad for inland shipping.

The effect of climate change on the available water depth for IWT becomes even worse in combination with the adverse effects of morphological changes. It is therefore necessary to study these two effects in conjunction.

Chapter 9 addresses the adverse effects of climate change and morphological changes on the availability and use of the IWT system.

6.4.4 External development of transport means

The relative competitiveness of the various transport means is often defined in terms of generalised costs. *"Generalized Cost includes all costs that are involved in overcoming time and space that are taken into account in companies that try to minimize these costs while maintaining certain service levels, as required by their customers"* (Tavasszy et al., 2009, p.2). Generalised costs include amongst others: transport costs, value of time, value of reliability, costs of damage, storage costs, and costs related to administrative and logistic processes at the sending and receiving companies. In practice the transport costs appear to be the most decisive factor for logistic managers to decide on the applied mode of transport (Platz, 2009, p.370; Kreutzberger, 2008, p.990); but from personal discussions with shippers of cargo, I conclude that reduction of the carbon footprint is now also becoming gradually more important. For unimodal transport the relative competitiveness can be assessed by comparing the transport cost and capacity of the various transport means. For multimodal transport the handling costs and pre- and end-haulage costs also need to be taken into account.

The choice for the applied mode of transport is not much affected by the absolute cost levels, but mainly driven by the competitiveness (i.e. relative cost levels) of the various transport modes (i.e. road, rail, IWT, pipeline, and short sea shipping). For unimodal transport the competitiveness is mainly defined by the development of the vehicle capacity and the primary cost drivers (i.e. material-, land-, labour-, and capital costs, fuel/energy consumption, and taxation). For multimodal transport the pre- and end-haulage cost are also very important. These are a function of the distance to and from the multimodal transfer point. It is interesting to see how changes in the primary cost drivers will affect the modal split.

Chapter 10 therefore analyses the effect of major changes in the primary cost drivers and/or distances to/from the intermodal transfer points on the generalised cost levels of the various transport modes for continental cargoes, that are the most sensitive to such as shift. This provides valuable insight in the magnitude of a possible future modal shifts. In addition, the effects of a possible mental shift, in which shippers choose for the transport options with the lowest carbon emission levels rather than the lowest cost levels, are also analysed.

6.5 Modelling the System Domain

The system domain (I+R) contains the modelling heart of the policy framework. It consists of: (1) a transport model that defines the anticipated effects of proposed policies and external developments on the overall performance of the transport system (i.e. the specific transport flows at the network level); and (2) some additional models that can be used to define the other relevant outcomes of interests such as the external effects of transport.

Chapter 3 discussed a number of model approaches that were used in recent transport scenario studies. In general use is made of rather detailed long term transport models, that are able to forecast the transport flows for the different modes of transport at the network level up to some 30 years ahead. When looking even farther ahead a different modelling approach will be required. Chapter 11 therefore proposes an outline for a possible model structure. The options to implement this model structure are further discussed in Chapter 12.

The *'description of the study area'* defines the geographic regions that are taken into account by the transport model as well as the possible transport connections between these regions.

The model element *'infrastructure (in particular IWT)'* contains a detailed description of the infrastructure networks from which the basic properties of the transport connection, such as the *'distance'*, *'travel time'*, and '*service level'* (e.g. maximum allowed vehicle dimensions), can be obtained for the various modes of transport. Unlike long term transport models the perceived very long term transport model should also be able to take the effects of climate change on the IWT infrastructure into account.

The model element *'competitiveness transport modes (in particular IWT)'* defines the cost levels for the various means and modes of transport, as well as the overall transport costs and relative competitiveness of the various transport solutions (i.e. unimodal and intermodal) for the different transport connections between the various origins and destinations in the model. Hekkenberg (2013) indicated that the transport costs for waterborne freight transport are a clear function of the main dimensions of the inland barges and therefore highly dependent on the size of the waterways. This differs from road and rail transport were the cost structure is much more homogeneous and not that much affected by the type of road or railway track.

The model element *'overall freight transport volumes'* defines the total freight transport flows between the various origins and destinations within the model for all modes of transport combined. A complicating issue, in this respect, is the fact that the geographical location of the main production and consumption areas may change over time. Such changes are very hard (if not impossible) to forecast at a very long time horizon. This issue also needs to be addressed when developing a very long term transport model.

The model element *'Transport performance (in particular IWT)'* defines the transport performance for the available transport modes on the different transport connections between the various origins and destinations in the study area. It for instance reports on the transport performance in *'tonnes'* and *'tonne kilometres'*, the *'number of vehicle/barge moves'*, as well on the *'external effects of transport'*.

The model element *'performance of other aspects related to the infrastructure'* is not further discussed, because it will not be taken further into account in this study.

6.6 Defining the Outcomes of Interest

The *'outcomes of interest'* (O) refer to the characteristics of the system that are considered relevant for the evaluation of proposed policies. The Netherlands has clear guidelines for the evaluation of transport infrastructure projects, that specify the outcomes of interest that need to be taken into account. These guidelines were previously referred to as the OEEI and OEI methodology (see Eijgenraam et al., 2000; and Spit et al., 2008)[79]. The most recent guideline for conducting a social cost benefit analysis (SCBA) is provided by Romijn and Renes (2013). This guideline is also applicable to the evaluation of infrastructure projects (i.e. MIRT procedure) and requires a considerable amount of detail to be taken into account. For pre-assessing very long term strategic policy options in the early stages of the policy making process (that precede the MIRT procedure) I recommend a simplified approach for which less detail has to be taken into account.

For this simplified approach it is sensible to classify the effects in a similar way as for the evaluation of MIRT projects. Eijgenraam et al. (2000) indicates that the Dutch methodology for evaluating the costs and benefits of infrastructure projects distinguishes between *'direct'* and *'indirect'* effects on the one hand, and *'internal'* and *'external'* effects on the other hand. Direct effects are a direct result of the provision and use of new infrastructures. Indirect effects are not directly related to the provision and use of new infrastructures, but follow indirectly from the direct effects of these new infrastructures. Elhorst et al. (2004, p.9, translated) provided a sharper definition in a supplement study for the OEI. This definition states that *"indirect economic impacts are defined as impacts of the owner, operator and users of the project on markets other than the transport market"*. The difference between internal and external effects has already been discussed in Section 6.2.2.

The next question is what effects to include in the pre-assessment of integrated infrastructure policies with a very long term impact. I would argue that an evaluation of the very long term effects should include the most important aspects for both the present and future generations. For the present generation, that will be defined as the generation that benefits from the provided infrastructure, the direct costs and benefits stemming from the project are the most relevant. These include the cost of providing the infrastructure, the benefits of using the infrastructure, and the direct external effects related to the provision and use of the infrastructure. For future generations, that no longer benefit from the provided infrastructure (because it is no longer operational), only the very long term irreversible negative external effects will be relevant. I therefore propose to include at least the following effects in the strategic pre-assessment phase:

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[79] OEEI stands for: *'Research program Economic Effects Infrastructure'* (Dutch: *'Onderzoeksprogramma Economische Effecten Infrastructuur'*). OEI stands for: *'Review Effects Infrastructure'* (Dutch: *'Overzicht Effecten Infrastructuur'*).

1. Direct internal effects related to the provision of the infrastructure (i.e. life cycle costs of construction, maintenance, operations, and if applicable also demolition);
2. Direct internal effects related to the use of the infrastructure (i.e. changes in the overall transport costs for shipping of goods);
3. Direct (negative) external effects that are reversible (e.g. by undoing the investment) and only affect the present generation;
4. Direct irreversible negative external effects that are irreversibly passed on to future generations (or if possible the lifetime costs of mitigating the effects).

Item 1 to 3 relate to the net benefits of the project for the present generation. It are these effects that, in view of the present generation, have to provide sufficient benefits to justify the investment. For these items one can argue that: the longer the time horizon taken into consideration, the more likely the project will become feasible. The policy maker is therefore triggered to consider the entire lifetime of the investment in order to maximise the benefits in the SCBA. However, cutting off the time horizon in the project evaluation will not result in irresponsible decisions that can harm future generations. It is still acceptable to apply a shorter time horizon as long as the time horizon is similar for item 1, 2, and 3 – and as long as the possible costs of demolition at the end of the lifetime are included.

For item 4 the situation is different. This item relates to effects that are passed on to future generations. A good example of an irreversible negative external effect is the waste of a nuclear power plant, that can be expected to remain harmful for yet another 250,000 years (Feiveson et al., 2011, p.5). For infrastructure projects the irreversible negative effects are mainly related to an increase in greenhouse gas emissions. In line with a few other researchers I consider it immoral and irresponsible to impose irreversible negative external effects onto future generations without taking all relevant consequences into account, just because the effects would disappear in the discounted cash flow calculation (see Section 6.7). In fact, the negative very long term effects would not be negligible when a much lower discount would be applied[80]. I argue that all irreversible negative external effects should be taken into account in the evaluation – and that the length of time taken into consideration should not be cut off at any time horizon as this would imply a discrimination of the interests of future generations that live beyond the cut off level.

With respect to the first item it is logical to express the costs in real monetary units of a certain base year (e.g. Euros at constant prices of the year 2000). For estimating the cost levels simple unit rates can be applied. Examples of a case study in which unit rates are applied for a strategic pre-assessment of an integrated area are Den Heijer et al. (2010) and De Haan and Nagtegaal (2010). It should however be noted that the applied unit rates will change over time. A proper assessment requires insight in the future development of the real cost levels over time. Further research will therefore be required to investigate the options to take such changes to the costs structure into account.

[80] Davidson (2004) argues that it is immoral to weigh the negative external effects of a certain policy differently because the exposed one is living far away, has a different ethical culture, or is much richer than the one who causes the damage. In a similar way he argues that it is also immoral to discriminate future generations by applying high discount rates (that includes a risk margin to guarantee sufficient return on investment for the present generation). Weitzman (1998) provides a convincing argument that distant irreversible negative effects should be discounted at the lowest thinkable rate (e.g. zero).

With respect to the second item I suggest to include the direct effects on the total transport performance and on the total transport cost. The total transport performance can be addressed in *‘tonnes’* and/or *‘tonne kilometres’*. If waterway managers require additional insight in the number and size of the barges sailing through a certain section of the waterways, additional scenarios for the development of the fleet mix can be developed. The estimation of the overall effects on the transport system (i.e. on the overall transport performance and costs levels) requires the effects caused by a shift to/from other modes of transport to be taken into account. It is therefore not possible to limit the analysis to the sole effects on the IWT system. The policy evaluation process requires all modes of transport to be taken into account.

With respect to the third item it should be noted that the evaluation of the main external effects can be based on *‘key figures’*, that relate the external effects to the actual transport performance by mode and type of transport (e.g. external effect per tonne kilometre for a certain type of barge). However the level of detail required for estimating these effects is generally far too high to be forecasted on a very long time horizon up to the year 2100. It is simply not possible to look very far into the future with respect to detailed issues such as: applied safety standards, noise levels, and fuel-, engine-, and propulsion technology. A sensible approach will therefore be required to deal with these effects in the policy evaluation.

I do not consider it sensible to prescribe all the effects that need to be taken into account in an integrated strategic pre-assessment at the network level, but eventually the analysis will have to comply with the effects prescribed by the official guidelines. The external effects that need to be taken into account in the MIRT stage are specifically discussed in the framework document *“Cost benefit analysis for MIRT-studies”* (Ministerie van Infrastructuur en Milieu, 2012, translated title). A practical approach would be to address only the most important direct external effect in the strategic pre-assessment phase, and to leave the remaining effects for the formal MIRT assessment.

Concerning the fourth item I would argue that it is irresponsible to impose irreversible negative external effects onto future generations, without at least taking all the future consequences into consideration. For transport infrastructure policies the irreversible negative very long term effects are mainly related the emission of greenhouse gasses. The question is how to deal with these effects in the assessment. When considering the emission of greenhouse gasses I would argue that one has two options. Either one takes into account the ultra-long lasting effects of the marginal emissions that are caused by the execution of the infrastructure project, or one adds mitigating measures and includes the costs of applying these mitigating measures (i.e. the costs for capturing carbon dioxide) throughout the lifetime of the infrastructure. I consider the latter option the most practical. In that case the length of time taken into consideration can be limited to the lifetime of the infrastructure.

Please note that I do not find it necessary to take the ultra-long lasting effects of a reduction in irreversible negative effects, such as a reduction in greenhouse gasses due to a proposed infrastructure development, into account. The applied criterion is ‘not to impose irreversible negative effects to future generations’ and not ‘to base the present decision on what is best for the future generations’. In case of a reduction of irreversible negative effects, these effects can be taken into account in the same way as the other external effects that are included in the third item (i.e. as a normal benefit or disbenefits for the present generation).

In order to quantify the very long term effect of the emission of greenhouse gasses I suggest to use a high level output indicator such as the total energy footprint measured in '*kwh energy output'*. The highly aggregated nature of the kWh energy output indicator still has a close relation to the emission of greenhouse gasses, but avoids the problem of dealing with aspects that are too detailed to be forecasted on a very long time horizon, such as the types of engines or fuels that will be applied. The kWh energy output indicator can be applied in combination with scenario assumptions on the rate of adopting sustainable energy solutions, to obtain a quantitative estimate of the effect of proposed policies on the emission of carbon dioxide (and possibly also on the emission of other greenhouse gasses) in a certain scenario[81].

6.7 Defining the Valuation System

The evaluation of the strategic 'area options' with a very long term impact (as defined in Section 6.3) requires a clear and unambiguous valuation system that takes into account the various effects of the proposed policy over time. This section address the use of a social cost benefit analysis and the implications of applying a very long time horizon.

6.7.1 Use of a social cost benefit analysis

In most western countries, including the Netherlands, the valuation of government financed projects is based on a social cost benefit analysis (SCBA). Other frequently used methods are the cost-effectiveness analysis (CEA) and the multi-criteria analysis (MCA). The initial guidelines for the Netherlands (i.e. the OEEI methodology) were adopted after the political debate that followed the construction of the Betuwe Route[82] (Mouter et al., 2012, p.3).

It is sensible to question the desirability of SCBAs as *'the preferred evaluation method'*. To answer this question Mouter et al. (2012, p.19) performed a comprehensive study on the use of the Dutch SCBA method among 86 professionals. They concluded that the vast majority of the experts still regards the SCBA as the most appropriate alternative (at least much more appropriate than the CEA and MCA). In line with these findings, and the fact that the SCBA is prescribed for the official MIRT procedure, I also suggest to apply the SCBA for the evaluation of integrated policy options with a very long term impact on the IWT system.

The SCBA is based on the principles of the financial *'cost-benefit analysis'* (CBA), which is a method for evaluating the merits of a particular project or course of action in a systematic and rigorous way. CBAs are generally applied for the evaluation of private investments for which a limited number of effects (i.e. the expected revenues and expenditures) are taken into account in order to define the overall profitability of a project, and in which all the effects are quantified in monetary units (e.g. in Euros). The SCBA is more or less similar to the CBA though it concerns the impact of a certain project on the overall society. The main purpose of the SCBA is to evaluate the desirability of a certain project for *'the entire society'*. It aims to enable a fair comparison and transparent decision process along the various policy options.

[81] Due to greening of the energy system a decoupling of the kWh energy output and the emission of greenhouse gasses will take place. A fully sustainable future transport system that no longer contributes to the carbon dioxide levels in the atmosphere is not unthinkable in the year 2100 (see also Shell International B.V., 2013).

[82] A Dutch Railway megaproject for transport of goods between Rotterdam and the German Ruhr area.

The SCBA contains the following steps:

1. Identify the relevant outcomes of interest throughout the anticipated time horizon of the project for each individual time period taken into consideration, for instance for each individual year;
2. Apply monetary values to the outcomes of interest and calculate the net effect of each policy option in each of the applied scenarios. The outcome of this exercise is a kind of cash flow that indicates the net effect for each individual time period;
3. Apply discounting techniques to convert the ranges of periodic outcomes into a single monetary value that represents the social net present value of the proposed policies in each of the applied scenarios (and derive additional performance indicators for the evaluation of the project, such as the social internal rate of return, social payback time, and social cost benefit ratio).

There is abundant literature on the use of SCBAs – and there exist clear guidelines for the Netherlands (Ministerie van Infrastructuur en Milieu, 2012; Romijn and Renes, 2013). For this reason I do not consider it necessary to discuss the methodology in detail. However, the very long time horizon that is applied in the analysis raises three issues that need to be addressed:

- Concerning the 1st step: The farther one looks ahead, the less detail one can take into account in the projections;
- Concerning the 2nd step: The value system may change over time due to shifting preferences;
- Concerning the 3rd step: Due to the general practice of future discounting the more distant very long term benefits (and disbenefits) are virtually negligible. This implies that policies aiming for robust sustainable very long term benefits are hardly considered of any value today.

The first concern requires the outcomes of interest to be described by relatively aggregated output indicators (as suggested in Section 6.6). Despite being important I will leave the second concern for further research and suggest to apply today's value system throughout the analysis. I consider the third concern the most important, because the practice of future discounting can be all-determining in the evaluation of proposed policies with a very long term impact. I therefore consider this a major issue that needs to be addressed.

6.7.2 The principles and current practice of future discounting

In today's economic reality the value of one money-unit tomorrow is perceived less valuable than the value of one money-unit today. Economists therefore apply future discounting to define the Present Value (PV) of a future cash flow (CF). This section addresses the principles and current practice of future discounting, that is applied in SCBAs for the evaluation of the various outcomes of interest over time.

<u>The difference between nominal and real discount rates</u>

In order to avoid confusion I will first discuss the difference between nominal and real discount rates that are applied in SCBAs, as well as the effects of inflation on the outcome of the SCBA. In finance and economics the nominal value refers to the economic value at current prices (e.g. defined in historical, present, or future Euros), while the real value refers to the value that has been adjusted for changes to the general price level over time (i.e. defined in Euros at constant price levels of a certain base year).

Economists apply discount rates to compare the value of an item at different time periods. In case a value is expressed in nominal terms, use is made of a nominal discount rate (R) that includes inflation (i). In case a value is expressed in real terms (i.e. at constant price levels of a certain base year) use is made of a real discount rate (r), that has been corrected for inflation. There exists a clear relation between the nominal and the real discount rate. This relation is expressed by the following formula:

$$R = (1+r)\cdot(1+i)-1 \qquad \text{(Nominal Discount Rate)}$$

in which:

- R : nominal discount rate;
- r : real discount rate;
- i : rate of inflation.

In case a similar rate of inflation is applied to all the benefits and disbenefits in the SCBA the present value will be similar for the nominal and real approach. For this reason, and because inflation is hard to forecast more than a few years ahead, it is common to apply a real discount rate in SCBAs. In the remainder of this thesis I will therefore simply speak of the *'discount rate'*, while I actually refer to the *'real discount rate'*.

<u>The principles of future discounting</u>

For the evaluation of commercial investment projects it is common to calculate the Net Present Value (NPV) by deducting the Present Value (PV) of the costs from the PV of the revenues. A positive NPV implies that a project is feasible. A similar approach is also applied in SCBAs, although the revenues and costs are then replaced by the moneterised values of the evaluated effects. If the discount rate is kept constant over time the present value of the discounted cash flow (PV(CF)) can be obtained by applying the following formula:

$$PV(CF) = \sum_{t=0}^{t=\infty} \frac{CF_t}{(1+r)^t} \qquad \text{(Discount Formula)}$$

in which:

- PV(CF) : present value of a cash flow;
- CF_t : cash flow at time t;
- r : the applied discount rate;
- t : number of time periods ahead.

These discounting principles imply that, given a sufficient high discount rate, the very long term effects of a certain policy become almost negligible in the evaluation. This is also addressed by Blauwens et al. (2002, p.455), who indicates that: *"Given a discount rate of 4%, the significance of an error of 1 million Euro in the assessment of an effect that will occur in three hundred years' time will be a mere 1 million / 1.04^{300}. That is just EUR 7.76. When it comes to effects in the distant future, one can afford to make considerable errors. The effect on the present value is very small indeed"*. The consequence of applying a fixed discount rate is therefore that the very long term benefits and disbenefits of the project are tended to be neglected in outcome of the SCBA.

The present discount rates applied in Dutch SCBAs

For the preparation of SCBAs the Dutch government prescribes a risk free discount rate of 2.5% plus a project specific risk mark-up (Minister of Finance, 2011). In case it is not possible to define the project specific risk mark-up, which is generally the case, a default risk mark-up of 3% should be applied. The Dutch government therefore prescribes an overall discount rate of 5.5% for most projects. Only for projects that contain important irreversible negative effects the Dutch government allows the project specific risk mark-up to be halved from 3% to 1.5%. For these projects a lower overall discount rate of 4% can be applied.

6.7.3 Reflection on the applied discount rates

For the evaluation of very long term policy effects the use of a single fixed discount rate (as prescribed by the Dutch government) is questionable. A number of experts consulted by Mouter et al. (2012, p.43) pointed out that long term aspects tend to be undervalued in SCBAs. The experts argue that they have considerable problems with the level at which negative external effects are discounted in Dutch SCBAs, because: *"As a consequence of the applied discount rate (dis)benefits over 20 to 30 years are virtually negligible"*. According to the experts this practice is not in line with policies aiming for robust sustainable long term solutions. They argue that, as a result of the high prescribed discount rates, sustainable project alternatives aiming for long term benefits are likely to be scored too low in SCBAs.

Over the last two decades there has been a growing belief that at least the irreversible negative effects should be discounted at much lower rates (see for instance: Weitzman, 1998; Gollier, 2002; and Davidson, 2004). This belief resulted in a fierce debate after the submission of the Stern Review (Stern, 2006), that was released on behalf of the British government. Nordhaus (2007), for instance, opposed the low discount rates suggested by the Stern Review and defended the use of the presently applied discount rates, while Weitzman (2007) argued that the Stern Review may get it right for the wrong reasons[83]. To the best of my knowledge, the international debate on future discounting has not yet reached consensus (see also Minister of Finance, 2009, 2011). One should be aware that different views on the appropriate level of the discount rate exist – and that the discount rate can be all-determining in the evaluation of proposed policies with a very long term impact. Romijn and Renes (2013, p.155) therefore recommend a sensitivity analysis on the prescribed rates, to addresses the presumably large impact of the applied discount rate on the outcome of the SCBA.

A possible suggestion for the rates that can be applied in the sensitivity analysis is provided in the following textbox, that presents my personal views on future discounting, which are developed in line with the post-neo-classical paradigm on economic growth that has been proposed in Chapter 4, and the ethical considerations of Davidson (2004).

[83] Weitzman indicates that there are good reasons why one should apply lower diminishing discount rates (and spend more money to slow down global warming) as proposed by the Stern report, but that the discussion should be much more about how much insurance to buy in order to offset the small chance of a ruinous catastrophe that is difficult to compensate by ordinary savings, than about consumption smoothing over generations.

My personal views on future discounting:
The fact that the international community has not yet reached consensus on the appropriate level of the applied discount rate does not imply that I have not reached a clear personal opinion on the subject. I expressed my personal views in a reflection section that is presented in Appendix C. This textbox provides a summary of these views and concludes with a suggestion for an alternative discount scheme that can be applied for the evaluation of very long term policy effects (e.g. in a sensitivity analysis).

I propose a new discounting scheme that consists of three elements, which are: (1) a risk free discount rate that reflects the risk free investment opportunities from the perspective of both the present and future generations; (2) a project specific discount rate that includes a risk and/or profit mark-up to justify the investment from the perspective of the present generation; and (3) a reduced social discount rate that deals with the irreversible negative very long term effects that are imposed onto future generations.

The risk free discount rate should reflect the risk-free investment opportunities from the perspective of both the present and distant future generations. For the present generation there still exist sufficient risk free investment opportunities to guarantee a positive return on investment. This implies that the initial risk free discount rate can remain at its present level of 2.5% (as prescribed by the Dutch government).

Risk free investment opportunities may not exist for distant future generations. In line with the post-neo-classical paradigm on economic growth, that was proposed in Chapter 4, I consider economic growth as a temporary phenomenon that is related to a very long term (about 400 year lasting) transition process of the industrial and knowledge revolution, in which the state of technology (i.e. TFP), labour productivity, and economic output are assumed to gradually move towards a maximum attainable level (see Chapter 4).

From an investment perspective I argue that, the closer the overall state of technology moves towards its maximum attainable limit, the fewer options there will be for innovation. It therefore becomes increasingly difficult for companies to be distinctive, which implies that there will be fierce competition on price levels, and that the profit margins and returns on investment for the individual companies are gradually forced down. At the same time there will be little investment opportunities due to lack of innovation and absent growth of the economy. This causes a condition in which there is excess capital (hence: investments < savings). In search for profit the excess capital will flow into stocks and bonds, that increasingly become less profitable (i.e. higher price levels for stocks and bonds, that offer similar or lower dividend- and interest payments, and gradually dilute the returns on capital). In absence of economic growth, this situation will go on until it will eventually no longer be possible to gain risk free returns on investment.

A similar conclusion can also be drawn when looking at the issue from a social- instead of an investment perspective. For issues that concern intergenerational wealth transfer it is common to apply a social discount rate, that weighs between the preference of consumption in the present and consumption in the future. These discount rates are derived from the so called Ramsey (1928) equation, that can be written as:

$$r = \delta + \eta \cdot g \qquad \text{(Ramsey Equation)}$$

Where **r** is the social discount rate that represents the preference of consumption today (e.g. by the present generation) compared to consumption in the future (e.g. by distant future generations); **δ** is the pure time preference for consumption today compared to consumption in the future; **g** is the per capita growth rate between the present and future time period; and **η** is the elasticity of marginal consumption (see also Weitzman, 2007).

The risk free discount rate reflects the rate at which the stakes of the present and the future generations are considered equally important. This implies that no pure time preference should be taken into account, and therefore the δ should be set at 0%. As a result, r becomes a direct function of g (for any given risk preference η). If labour productivity growth ultimately ceases to exist in response to the law of diminishing returns on technological progress, as I presume in the post-neo-classical paradigm on economic growth, this implies that the per capita income growth, and hence also the per capita consumption growth (g), will eventually go down to zero. If $g \rightarrow 0$ this implies that $r \rightarrow 0$.

Therefore, from both the investment- and social perspective, I would argue that: *the very long term discount rates should eventually go down to zero.*

For the intermediate period (between now and infinity) a diminishing risk-free discount rate can be assumed. The suggestion to apply diminishing discount rates is not new. It has for instance also been proposed by Gollier (2002) and Stern (2006). In addition the British government has now also adopted a diminishing discount rate for negative external effects (Lowe, 2005, p.8). However, these discount rates are not reduced to zero as follows from adopting my new post-neo-classical economic growth paradigm.

As long as it concerns a policy with net benefits it is sensible to include a risk and/or profit margin on top of the risk free discount rate. In line with the guidelines of the Dutch government it can be suggested to apply a default 3% risk/profit-margin for normal policy effects. However, I find it odd that in case of irreversible negative effects the Dutch government still prescribes a risk/profit-margin of 1.5% (on top of the risk free discount rate of 2.5%). This implies that: *because we are uncertain about the profitability of the project for our own generation, we deem the negative effects of irreversible environmental damage to future generations less important.*

For irreversible negative effects I do not find it appropriate to apply a risk and/or profit margin. In fact, it is my personal opinion that applying the risk free discount rate would already be unfair. Davidson (2004) argues that most policy initiatives aiming at reducing negative external effects (such as the effects of carbon emissions on global climate change) are not related to government investments, but to measures that come at costs of consumptive spending (e.g. taxes on carbon emission). Only a small fraction of the national income is saved and therefore invested (hence savings equal investments in Macroeconomic models). He further argues that it is not in line with moral choices of society and international justice to consider the impact of irreversible negative effects less important just because the one on which the impact is imposed lives at a distance or is much richer. For this reason it would not be reasonable to allow the one causing the effect, to judge the potential damage to the one exposed by a lower weight (or discount rate), due to the fact that he lives in the distant future. Davidson therefore suggests to make a clear political choice and apply a zero discount rate to the consumptive fraction of public spending which, according to Lind (1982), is about 80%.

This implies that only the investment fraction of about 20% should be taken into account when defining the discount rate for irreversible negative effects. I find this a reasonable approach and have therefore adopted the idea to apply the 20% investment fraction to the risk free discount rate in order to obtain a fair discount rate for irreversible negative effects.

On the basis of the above arguments I developed an alternative very long term discounting scheme of which the proposed discount rates are indicated in Table 6-1.

Table 6-1: Proposed Discounting Scheme

Discounting period	Risk free base rate for investments	Project rate including 3.0% risk premium	Rate for irreversible negative effects
0-30 years	2.50%	5.50%	0.50%
31-75 years	1.78%	4.78%	0.36%
76 - 125 years	1.06%	4.06%	0.21%
126 - 200 years	0.49%	3.49%	0.10%
200 - 300 years	0.15%	3.15%	0.03%
300+ years	0.00%	3.00%	0.00%

*Note: The risk free investment rate is based on (1) a value of 2.5% for the first 30 years which is similar to the value required by the Dutch Government, and (2) the assumption that 200 years from now 95% of the Great-Transition S-curve of labour productivity and economic growth will be completed.
** Note: The time periods in the discount scheme are similar to those applied by the British Government (Lowe, 2008). A more advanced alternative would be to apply a different value for each individual year.

The reason for applying a diminishing risk free base rate that gradually goes down to zero on the very long term is free of any ethical considerations, as it directly reflects the consequences of adopting my new post-neo-classical paradigm on economic growth. This does of course not hold for the reason to apply even lower discount rates in case of irreversible negative external effects, that is entirely based on the ethical consideration not to judge the potential damage for the one exposed by a lower weight (or discount rate) due to the fact that he lives in the distant future. However, even if one disagrees with the ethical considerations, the neutral (no ethics involved) conclusion, that the risk free discount rate should gradually go down to zero on the very long term, will still have a major effect on the outcome of the SCBA. If the proposed discount rates are applied as a sensitivity to the present rates, the results are likely to point out clearly that more weight should be given to very long term effects.

6.8 Concluding Summary

This chapter addresses the first methodological sub question (MSQ 1): *"How should Rijkswaterstaat structure its policy framework to allow for the ex-ante evaluation of integrated infrastructure development strategies with a very long term impact on the IWT system?"*. It starts with a description of the proposed policy framework and continues with the discussion of a number of issues that were raised concerning the valuation of very long term policy effects.

6.8.1 The proposed policy framework

The working arrangements between Rijkswaterstaat and the Dutch Ministry of Infrastructure and Environment are structured in such a way that construction and replacement of infrastructure is covered by the MIRT programme, that deals with individual projects and has a time horizon of about 20 years. What lacks is an integrated policy framework that takes the very long lifetime of hydraulic structures into account and considers the necessary replacements as an opportunity to improve the IWT network at a systems level. The development of such an integrated policy approach can be based on the views of Walker (2000) and Lempert et al. (2003) that have been combined by Agusdinata's (2008) into the so called XPIROV policy framework. The XPIROV framework consists of: proposed policies (P); scenarios for external developments (X); a model of the system domain containing internal factors and relationships (I+R); performance indicators defining the relevant outcomes of interest (O); and a value system that applies weights to the various outcomes of interest (V).

I made the XPIROV framework specific for the management of IWT infrastructures (see Figure 6-4). The various items of the framework can be addressed as follows:

Proposed policies (P): Rijkswaterstaat executed a case study for the Dutch part of the River Meuse to investigate the options to develop an integrated infrastructure development strategy. This case study showed how replacement strategies can be developed for a larger integrated area instead of a single hydraulic structure. I addressed these views but have not further investigated this subject in more detail.

External developments (X): Literature review reveals that the following four major external developments are likely to affect the very long term development of the Dutch IWT system: (1) the very long term development of the overall transport demand; (2) the development of new transport infrastructure networks as well as the development of the IWT infrastructure itself; (3) the effect of climate change on the navigability of the waterways; and (4) the possible effect of major changes to the cost structure of transport on the modal share for IWT. These four external developments are discussed in Chapter 7 to 10.

System domain (I+R): The system domain provides the modelling heart of the policy framework. It contains a description of the study area and defines the effects of proposed policy alternatives while taking into account the different scenarios for the various external developments. The system domain contains four modules that deal with: (1) the available transport infrastructure (in particular for IWT); (2) the competitiveness of the various transport modes; (3) the overall freight transport volumes; and (4) the overall performance of the various transport means. The proposed structure for modelling the system domain as well as the options to implement this model are discussed in Chapter 11 and 12.

Outcomes of interest (O): When defining the outcomes of interest a distinction can be made between 'direct' and 'indirect' effects on the one hand and 'internal' and 'external' effects on the other hand. For the pre-assessment of integrated infrastructure development strategies with a very long term impact I suggest to include at least: (1) the direct internal effects, that are related to the use and provision of the infrastructure; (2) the direct negative external effects, that take place during the lifetime of the investment (or throughout the execution of the proposed policy); and (3) the direct irreversible negative external effects, that are passed on to future generations (that no longer benefit from the provided infrastructure). It is my personal opinion that a responsible policy maker should take all direct irreversible negative external effects into account in the evaluation of a proposed policy. I think these effects should not be cut off at any future time horizon. Even if the discounted value of the effects is almost negligible it is still important to realise that these effects continue to occur, in particular when considering the fact that there may be something wrong with the presently applied discount rates (as will be discussed in the next section). The main irreversible very long term negative effects of the transport system can be related to the emission of greenhouse gasses. When considering these emissions one can either take into account the negative ultra-long-lasting effects on the climate system or include the costs of mitigating measures (i.e. the shadow costs for capturing carbon dioxide) during the lifetime of the project. I consider the latter option the most practical.

Valuation system (V): The valuation of policies with a very long term impact can be based on the principles of a social cost benefit analysis (SCBA). In general a SCBA: (1) identifies the relevant outcomes of interest over time; (2) applies monetary values to each of the relevant outcomes of interest; and (3) applies discounting techniques to convert the ranges of periodic outcomes into a single monetary value. There is abundant literature on the use of SCBAs – and for the Netherlands clear guidelines have been developed. For this reason I do not consider it necessary to discuss this subject in detail. However, the very long time horizon under consideration does raise a number of issues that need to be addressed.

6.8.2 Issues with the valuation of the outcomes of interest

Minor issues with the validation of the very long term outcomes of interest are: (1) the notion that the very long time horizon implies that very aggregated high level indicators will be required to describe the outcomes of interest; and (2) the notion that the value system may change over time. Much more important is the issue concerning the general practice of future discounting. As a result of the presently applied fixed discount rates (e.g. 5.5% as prescribed by the Dutch government) the more distant very long term benefits (and disbenefits) become virtually negligible in the evaluation of proposed policies. This implies that policies aiming for robust sustainable very long term benefits are not considered of any value today.

The past two decades there has been a growing belief that at least the irreversible negative effects should be discounted at much lower rates. In this respect reference can be made to amongst others Weitzman (1998), Gollier (2002), Davidson (2004), and Stern (2006). The submission of the Stern Review (Stern, 2006) and prescription of diminishing social discount rates by the British government (Lowe, 2008) sparked a fierce debate that is still going on.

The fact that the international community has not reached a clear consensus on the level of the appropriate discount rate does not imply that I have not reached a clear personal opinion on the subject. In line with the post-neo-classical paradigm on economic growth (see Chapter 4), and the views of Davidson (2004), I have proposed an alternative discounting scheme that can be applied as a sensitivity analysis on the presently prescribed rates (see Table 6-1).

The proposed scheme consists of the following three elements: (1) a risk free discount rate that reflects the risk free investment opportunities from the perspective of both the present and future generations; (2) a project specific discount rate that includes a risk and/or profit mark-up to justify the investment from the perspective of the present generation; and (3) a reduced social discount rate that deals with the irreversible negative very long term effects that are imposed onto future generations.

Unlike the prevailing discount schemes, I expect the risk free discount rate to go down to zero on the very long term (i.e. limit value goes to zero), because in absence of technological and economic growth, the options to gain risk free returns on investment will gradually disappear. If the proposed discount rates are applied as a sensitivity to the present rates, the results are likely to point out that more weight should be given to very long term effects.

6.8.3 Answer to Methodological Sub Question 1

In answer to MSQ 1, I conclude that an integrated policy approach can be developed on the basis of Agusdinata's (2008) XPIROV framework, that is based on the views of Walker (2000) and Lempert at al. (2003). This framework consists of proposed policies (P); scenarios for external developments (X); a model of the system domain containing internal factors and relationships (I+R); performance indicators defining the relevant outcomes of interest (O); and a value system that applies weights to the various outcomes of interest (V). Rijkswaterstaat studied the policy options (P) to develop an integrated very long term infrastructure development strategy for a larger part of the waterway system on the basis of a real case study for the river Meuse. I addressed these views but have not further investigated this subject in detail. The main external developments (X) that act on the IWT system are expected to relate to the development of: (1) the overall transport demand; (2) the transport infrastructure; (3) climate change and morphological changes; and (4) the relative costs of the various transport means. These developments are discussed in Chapter 7 to 10. The system domain (I+R) contains the modelling heart of the policy framework that is discussed in Chapter 11 and 12. For the pre-assessment of integrated infrastructure development strategies with a very long term impact I suggest to include at least the following outcomes of interest (O): the direct internal- and external effects, that are related to the use and provision of the infrastructure; and the direct irreversible negative external effects, that are passed on to future generations. With respect to the latter it is my personal opinion that the effects should not be cut off at any future time horizon. The value system (V) can be based on the principles of a social cost benefit analysis (SCBA), for which clear guidelines are available in the Netherlands. The very long time horizon does however raise a number of issues that need to be addressed. The most important issue is related to the practice of future discounting. In line with the post-neo-classical paradigm on economic growth (see Chapter 4), and the views Davidson (2004), I argue that much lower discount rates should be applied, in particular when it concerns irreversible negative external effects. For that reason I have proposed an alternative discount scheme that can be applied as a sensitivity analysis to the officially prescribed discount rates.

Literature:

Agusdinata, B. (2008) *Exploratory Modeling and Analysis: A promising method to deal with deep uncertainty*, TRAIL Thesis Series Volume T2008/17, Trail Research School, Delft, The Netherlands.

Blauwens, G., P. De Baere, and E. Van de Voorde (2002) *Transport Economics*, De Boeck nv, Antwerp, Belgium.

Davidson, M.D. (2004) *Discontovoet voor klimaatschade behoeft politieke keuze*, Economisch Statistische Berichten (ESB), 89^{e} jaar, no. 4439, p. 290.

De Haan, M. and L. Nagtegaal (2010) *Strategie vervanging natte kunstwerken*, DHV.

Den Heijer, F., M.A. Wolters, J.C.M. van Dorsser, H.E.J. Berger, and A.C.L. Hijdra (2010) *Developing a substitution strategy for hydraulic structures to meet the challenges of a new century*, PIANC MMX Congress, Liverpool, UK.

Eijgenraam, C.J.J., C.C. Koopmans, P.J.G. Tang, and A.C.P. Verster (2000) *Evaluatie van infrastructuurprojecten: Leidraad voor kosten-batenanalyse. Deel 1 Hoofdrapport*. Ministerie van Verkeer en Waterstaat, Ministerie van Economische Zaken.

Elhorst, J.P., A. Heyma, C.C. Koopmans, J. Oosterhaven (2004) *Indirecte Effecten Infrastructuurprojecten, Aanvulling op de leidraad OEI*, Ministerie van Verkeer en Waterstaat / Ministerie van Economische Zaken.

Feiveson, H., Z. Mian, M.V. Ramana, and F. von Hippel (eds.) (2011) *Spent Fuel from Nuclear Power Reactors, An Overview of a New Study*. International Panal on Fissile Materials (IFPM).

Gollier, C. (2002) *Discounting an uncertain future,* Journal of Public Economics, vol. 85, no.2, pp.149-166.

Grübler, A. (1990) *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport,* Physica-Verlag Heidelberg.

Hekkenberg (2012) *Inland Ships for Efficient Transport Chains*, TU-Delft, The Netherlands.

Janssen, L.H.J.M., V.R. Okker, and J. Schuur (2006) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040,* Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau, www.welvaartenleefomgeving.nl/pdf_files/WLO_hoofddocument.pdf

Kreutzberger, E.D. (2008) *Distance and time in intermodal goods transport networks in Europe: A generic approach*. Transportation Research Part A, vol. 42, pp. 973-993.

Lempert, R.J., S.W. Popper, and S.C. Bankes (2003) *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis.* RAND, Santa Monica.

Lind, R,C. (1982) *A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options.* In: R.C. Lind et al. (red) Discounting for Time and Risks in Energy Policy. Resources for the Future. Washington D.C.

Lowe, A.J. (2008) *Intergenerational wealth transfer and social discounting: Suplementary Green Book guidance*. HM Treasury, London, UK.

Marchau, V., W. Walker, and B. van Wee (2007) *Innovative Long-Term Transport Policymaking: From Predict and Act to Monitor and Adapt,* Association for European Transport and contributors.

Minister of Finance (2009) *Waardering van risico's bij publieke investeringsprojecten*, brief naar Tweede Kamer 29352, nr. 4. Den Haag.

Minister of Finance (2011) *Reële risicovrije discontovoet en risico-opslag in maatschap-pelijke kostenbatenanalyses*, brief naar Tweede Kamer, 24 augustus 2011.

Ministerie van Infrastructuur en Milieu (2012) *KBA bij MIRT-verkenning, Kader voor het invullen van OEI-formats.* Dienst Verkeer en Scheepvaart, Rijkswaterstaat, Delft.

Nordhaus, W.D. (2007) *A review of the Stern review on the economics of climate change, Journal of economic literature*, vol. 45, pp. 686-702.

Mouter, N, J.A. Annema, and B. van Wee (2012) *Maatschappelijke kosten- en batenanalyse inhoudelijk geëvalueerd*, TU-Delft, The Netherlands.

Petersen M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, and A. Ulied (2009) *TRANSvisions: Report on Transport Scenarios with a 20 and 40 year Horizon, Final Report*, Funded by DG TREN, Copenhagen, Denmark.

Platz, T.E. (2009) *The Efficient Integration of Inland Shipping into Continental Intermodal Transport Chains: Measures and Decisive Factors,* TRAIL Thesis Series Volume T2009/11, Trail Research School, Delft, The Netherlands.

Romijn, G, and G. Renes (2013) *Algemene leidraad voor maatschappelijke kosten-batenanalyse*, CPB and BPL, Den Haag, The Netherlands.

Shell International B.V. (2013) *New lens scenarios, a shift in perspective for a world in transition*, http://www.shell.com/global/future-energy/scenarios/new-lens-scenarios.html.

Spit, W., E. Devillers, K. Vervoort, and J. Nuesink (2008) Werkwijzer OEI bij MIT-planstudies: Hulpmiddel bij het invullen van de formats. Ministerie van Verkeer en Waterstaat, www.rijkswatersrtaat.nl/dvs/see.

Stern, N. (dir.) (2006) *The Stern Review Report: the Economics of Climate Change*, London, HM Treasury, October 30, 603 p.

Tavasszy, L., I. Davydenko, K. Ruijgrok (2009) *The Extended Generalized Cost Concept and its application in Freight Transport and General Equilibrium Modeling*. Paper prepared for Integration of Spatial Computable General Equilibrium and Transport Modelling, Bilateral Joint Seminar under agreement between NWO and JSPS, 2009 August 19-20 The University of Tokyo, SANJO-Hall.

Turpijn, B., and R. Weekhout (2011) *Klimaat en Binnenvaart*, Rijkswaterstaat.

Van Dorsser, J.C.M., M.A. Wolters, and B. van Wee (2012) *A Very Long Term Forecast of the Port Throughput in the le-Havre – Hamburg range up to 2100*, European Journal of Transport and Infrastructure Research, vol. 12, no. 1, pp. 88-110.

Walker, W.E. (2000) *Policy Analysis: A Systematic Approach to Supporting Policymaking in the Public Sector*, Journal of Multi-Criteria Decision Analysis, vol. 1, no. 3, pp. 11-27.

Weitzman, M.L. (1998) *Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate*, Journal of Environmental Economics and Management, vol. 36, no. 3, pp. 201-208.

Weitzman, M.L. (2007) *A review of the Stern Review on the Economics of Climate Change*, Journal of Economic Literature, vol. 45, pp. 703-724.

7 Development of Freight Transport Demand

"GDP still seems to be closely coupled to freight transport. If transport costs increase, trade volumes decrease. If trade share of output decreases, GDP is likely to follow."
- I. Feige (Transport, Trade and Economic Growth – Coupled or Decoupled?, 2007, p. 108)

7.1 Introduction

This chapter addresses methodological sub question 2a (MSQ 2a): *"How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system"* of which the first driver has been identified as: *"the overall development of the demand for freight transport in the larger region covering the West European IWT system?"*. This chapter, that is partly based on the publication of Van Dorsser et al. (2012), discusses the development of a few very long term probabilistic forecasts for the overall transport demand. It starts with a discussion on the applied methodology and concludes with the obtained forecast results. Because insight in the very long term development of freight transport demand can only be obtained at a high level of aggregation (see also Chapter 3, 5, and 6) the forecast is made for the larger hinterland *'Region'* of the West European IWT system, that is defined as: the Netherlands, Germany, France, Belgium, and Luxembourg.

At the start of this PhD project a method for developing probabilistic very long term transport forecasts with a time span of almost 100 years did not yet exist. I developed a new method that is based on the existence of a very strong causal relation between economic output and transport. This new method contains the following three steps: (1) apply system dynamics modelling to obtain a probabilistic forecast of the total- and working age population in the Region; (2) apply judgement to make probabilistic assumptions on the development of labour participation, annual working hours, and GDP output per worker – and use these assumptions to convert the probabilistic estimates of the working age population into a probabilistic GDP forecast for the Region; and (3) apply the causal GDP-transport relation to obtain a probabilistic transport forecast for the Region.

This method was first applied to develop a very long term probabilistic forecast of the port throughput volumes in the Region, because relatively long time series dating back to 1936 are available for the corresponding Le Havre – Hamburg port range (LHR). For this forecast an in depth discussion of the applied forecast relation and methodology is provided in this chapter. At second instance the methodology was also applied to develop a very long term forecast of the inland transport- and short sea shipping volumes in the Region. For these forecasts only the results will be discussed. The three obtained transport forecasts were finally combined into a single probabilistic forecast for the overall freight transport demand in the Region.

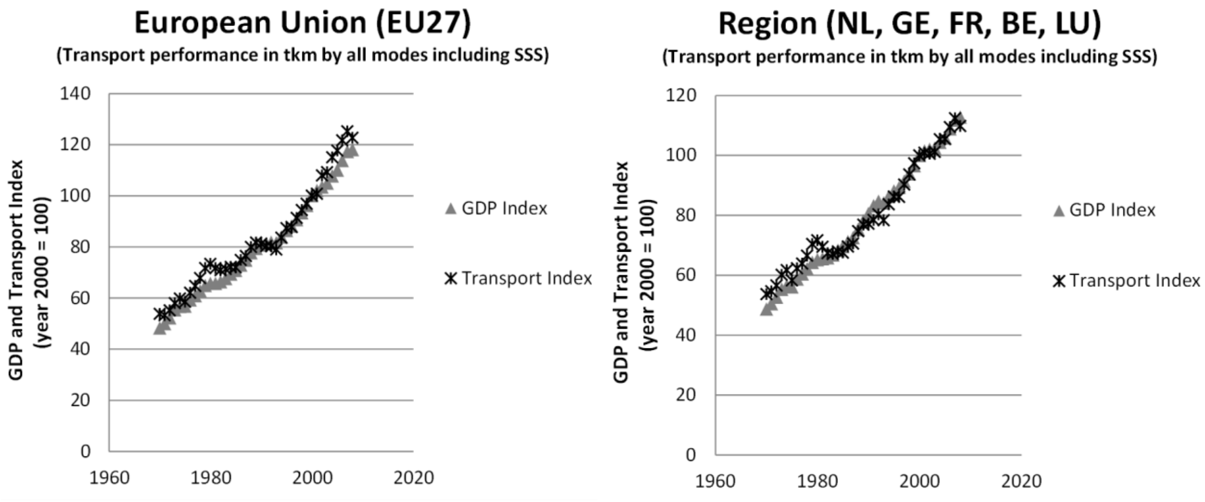
Section 7.2 starts with a discussion on the causal relation between economic output (i.e. GDP) and freight transport; Section 7.3 explains why it is sensible to develop an aggregated forecast on the basis of just one explanatory GDP variable instead of a number of explanatory variables; Section 7.4 provides an in depth discussion on the statistical properties of the regression function, that was applied in the very long term forecast of the port throughput volumes for the LHR; Section 7.5 indicates how the underlying probabilistic population and GDP forecasts were obtained; Section 7.6 addresses the results of the very long term probabilistic forecasts for the port throughput-, inland transport-, and short sea shipping volumes – and combines the results of these three distinct forecasts into a single forecast for the development of the overall transport demand in the Region; and Section 7.7 contains a concluding summary that provides an answer to MSQ 2a. Reference to the calculation files is made in Appendix F.

7.2 The Relation between GDP and Freight Transport

The presented probabilistic forecast method is based on the premise that there exist a strong causal relation between the level of economic output (measured at constant prices of a certain base year) and the level of freight transport (measured in tonnes or tonne kilometres). This section addresses the empirical evidence for the existence of this relation.

7.2.1 Empirical evidence that a strong causal GDP–transport relation exists

Scenario studies (see Chapter 3) and transport literature (see e.g.: Feige, 2007; and Meersman and van de Voorde, 2008) both identify economic output as an important driver for freight transport. Empirical evidence that a strong causal GDP–transport relation exists is obtained by comparing economic output (measured as an index of the GDP at constant prices) with the overall level of transport demand (measured as an index of the overall transport performance). Figure 7-1 shows the results of this analysis for the EU27 member states as well as for a number of countries surrounding the Netherlands, that will be referred to as the 'Region'.



Note: The abbreviation SSS stands for Short Sea Shipping.

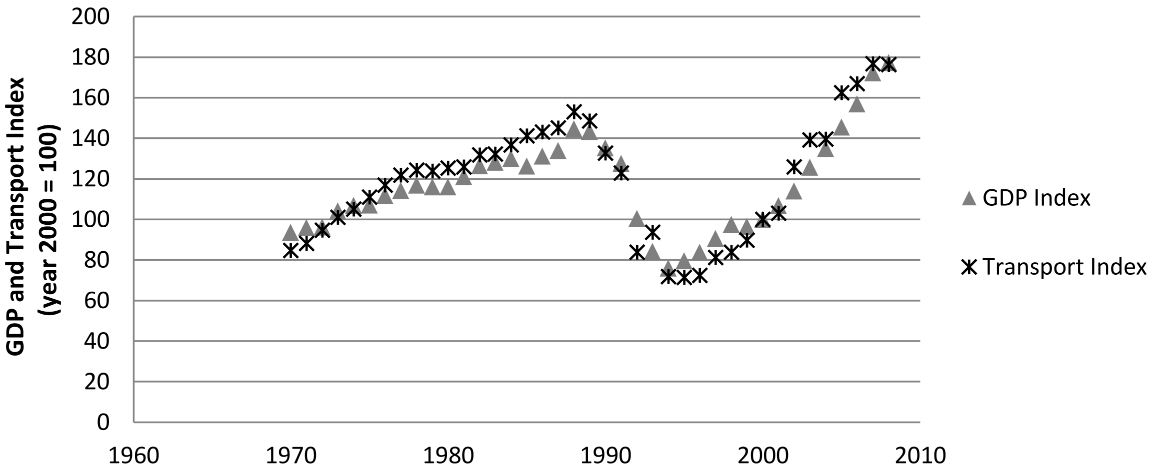
Source: Database discussed in Appendix A.

Figure 7-1: Relation between Economic Output and Freight Transport

Figure 7-1 shows that both variables follow a similar trend. This suggests that there exists a strong causal relation between the level of economic output and the level of freight transport. However, in theory the close correlation between the variables of two trending time series can also be completely coincidental. This implies that a more in-depth investigation of the relation between economic output and transport is required. I have therefore looked for additional evidence that the observed causal relation is not coincidental.

7.2.2 Empirical evidence that the GDP–transport relation is not coincidental

Granger and Newbold (1974, p.111) provide a clear warning on ‘spurious’ (meaningless) regression. They warn that regression of two time series that follow an upward or downward trend can result in a virtual correlation that in reality does not exists. In theory the similar upward trend of the GDP and transport index can be completely coincidental. To ‘prove’ that the similar trend in the development of the GDP and transport indices is not coincidental, I searched for a special case in which the economy has not shown a continuously increasing trend. Such a case can for instance be found in the Baltic States of Estonia, Latvia, and Lithuania; for which the economy has been growing until the dissolution of the USSR in 1989, showed a decline thereafter, and recovered from 1995 onwards.



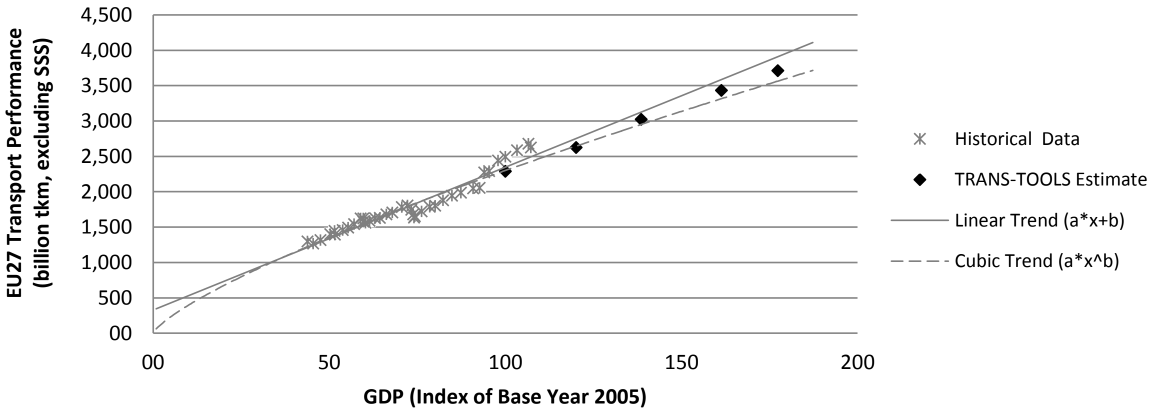
Note: The transport index concerns road-, rail-, pipeline-, and inland waterway transport in tkm.
Source: Database discussed in Appendix A.

Figure 7-2: Economic Output and Freight Transport Index for Lithuania

Figure 7-2 shows that the combined inland freight transport performance (measured in tkm) for road-, rail-, pipeline-, and inland waterway transport closely matched the development of the Lithuanian economy. Similar (less perfect) matches were also found for the other two Baltic States. This implies that, at least for the Baltic States, the relation between economic output (GDP) and transport seems to be real – and if this holds for a single country or region, it is also likely to hold for other countries or other regions. On the basis of this analysis I therefore conclude that GDP–transport relation is not coincidental but real.

7.2.3 The quality of the GDP as a single variable predictor

From the above figures it can be observed that the historical development of the overall transport demand can be almost completely explained by the development of the real GDP (at constant prices of a certain base year). It is interesting to question if this relation will also remain valid in the future. Future GDP and transport developments cannot be known on forehand, but one can compare the outcome of recent transport scenario studies (that are quantified by detailed transport forecast models) with the estimates that could have been obtained by applying a one variable GDP-transport relation. Figure 3-13 already indicated that the aggregated results of the TRANS-TOOLS model for the EU27 are almost similar to the results that could have been obtained from a simple one variable GDP-transport relation.

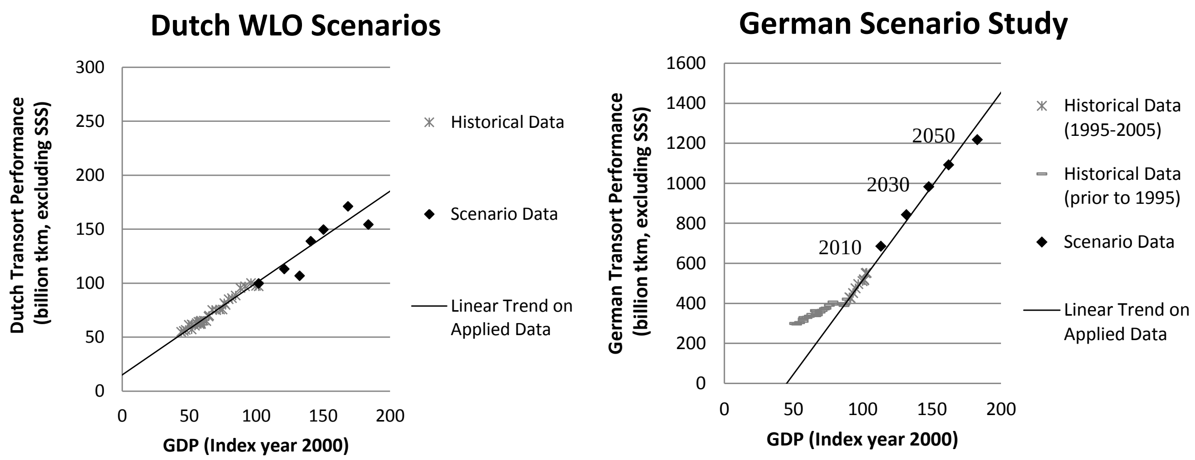


Note: The abbreviation SSS stands for Short Sea Shipping.

Source: Database discussed in Appendix A, TRANS-TOOLS Estimates: Table 3-6.

Figure 3-13 (repeated): Comparison of Historical Trend and TRANS-TOOLS Estimate

The question now remains if this concerns an isolated case or holds in general. To answer this question I have also analysed the quantifications of the Dutch and German transport scenarios that were presented in Chapter 3. The corresponding results are indicated in Figure 7-3.



Note: The abbreviation SSS stands for Short Sea Shipping.

Source: Database discussed in Appendix A, Janssen et al. (2006), Ickert et al. (2007).

Figure 7-3: Comparison of Historical Trend and WLO/German Scenario Estimates

Figure 7-3 (left) indicates that there is also not much difference between the Dutch scenario quantifications, that are based on detailed transport forecast models, and the aggregated estimates, that would have been obtained from a simple regression model with GDP as a single explanatory variable. The situation is slightly more complicated for Germany where the historical relation between economic output and freight transport (for the combined former BRD and DDR) shows a trend breach at the instance of the reunification of Germany in 1990. To deal with this issue Ickert et al. (2007, p.12) based their forecast on data from 1995 to 2005. I would nevertheless be inclined to argue that the German unification triggered a onetime transition period in which the transport performance shifts to a higher level at a given GDP. In that respect it would have been more sensible to apply a forecast model that contains a dummy variable to account for the effect of the reunification and use longer time series. This option would presumably have resulted in much lower transport projections.

However, Figure 7-3 (right) sill indicates that the German scenario is perfectly in line with the projections, that could have been obtained by applying a simple regression model with GDP as the only explanatory variable (provided that this model is also fitted through the data for the same period from 1995 to 2005 that has been used for the scenario quantifications). I therefore conclude that the aggregated outcome of detailed transport models, such as applied for the quantification of the Dutch, German, and EU27 transport scenarios, can also be obtained by applying a very simple one variable causal relation between economic output (measured by GDP) and freight transport (measured in tonnes or tonne kilometre).

7.3 Other Relevant Drivers for the Forecast Model

Historical data indicated the existence of a very strong causal relation between economic output and freight transport. It seems that the GDP–transport relation almost completely explains the development of the overall freight transport demand. This makes the GDP a logical driver for the transport forecast model, but it also raises an important question on the necessity of using other transport drivers in the forecast. *Are other drivers irrelevant?* This section addresses the other relevant transport drivers and explains why some of these drivers may (or even should) be neglected in the very long term transport forecast model.

7.3.1 Other drivers affecting the level of freight transport

Existing transport models are not solely based on the GDP variable. They apply a wide range of drivers. Chapter 3 and Appendix B discussed the main drivers that were applied in four recent transport scenario studies. The Dutch WLO study (Janssen et al., 2006) indicated that freight transport is mainly driven by the size and composition of the GDP, that is considered a function of the size of the working population, the average working hours, and the labour productivity rate; as well as by the size of the international trade volumes. It further noticed that decoupling of economic growth and transport is expected. The German study (Ickert et al., 2007) defined the level of transport on the basis of economic output and international trade volumes; and further applied a correction for the effect of decoupling. The TRIAS study (Schade et al., 2008) considered economic output and trade volumes the most relevant drivers for transport, but also studied the effect of other variables such as: depletion of fossil fuel reserves, new fuel production techniques, infrastructure developments, and policy measures. The TRANSvisions study (Petersen et al., 2009) indicated that the level of transport is driven by: the size of the population, macro-economic developments, trade volumes, globalisation, energy price levels, availability of fuel, and international policies (e.g. the further enlargement of the EU). On the basis of these insights I drafted a simplified causal structure for estimating the overall transport volume, that is shown in Figure 7-4. The indicated structure is intended to show how I think the various drivers affect the transport volumes, without explicitly considering the many possible feedback loops that may also occur in reality. In practice *'international trade volumes'* will for instance also affect the level of *'GDP'*, and thereby the size of the *'labour force'* or even the rate of *'labour productivity'*, but this has not been included. The arrows indicate what I consider the most important causal relations between the primary transport drivers. The presented structure is applicable to estimates of the overall transport volume in tonnes and tonne kilometres, though the strength of the causal relations will be different for each of these two categories.

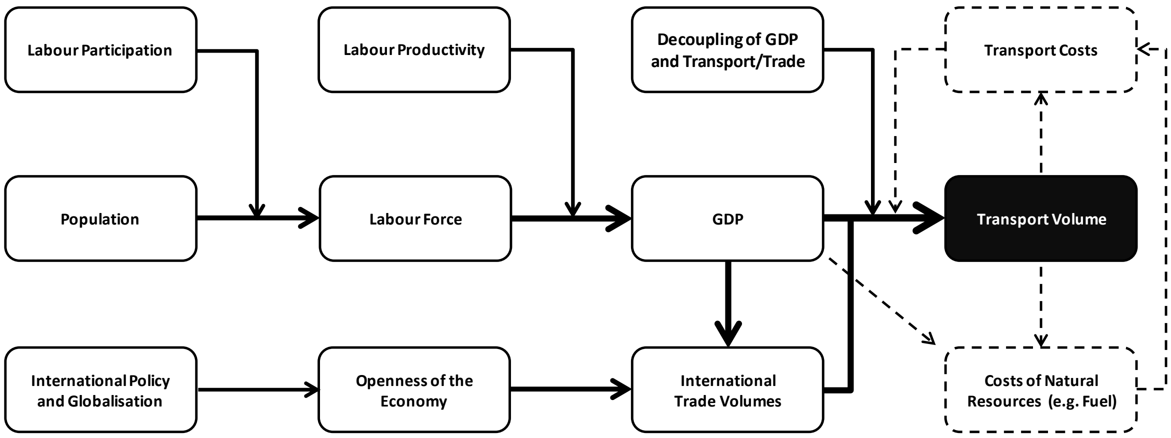


Figure 7-4: Simplified Causal Structure for defining Freight Transport Volumes

I consider economic output (GDP) and international trade volumes as the main drivers for freight transport. The GDP can be regarded as a function of population, labour participation, and labour productivity. International trade volumes depend on the GDP output of the region and the openness of the economy, which is a function of international trade policies and globalisation. On the long term the GDP–transport relation is expected to change as a result of decoupling. This effect is generally taken into account by applying expert judgement.

International trade policies and globalisation affect the openness of the economy and thereby the fraction of the produced goods and services that are exported, as well as the fraction of the national income that is spent on consumption of foreign goods, which both have an effect on the international trade volumes. Though not indicated in the figure, globalisation is also likely to affect the rate of decoupling. This will be addressed in Section 7.3.4.

I already discussed that there exists a strong causal relation between the level of GDP (but also international trade) and the level of transport. It seems that this relationship is quite stable over time and rather insensitive to geopolitical changes, which can be explained by the fact that GDP, trade, and transport tend to move along together. The removal of the internal EU border borders has, for instance, not only increased the level of transport and trade, but also the level of economic output in the region. The other way around, political instabilities that cause international conflicts, trade boycotts, or even war, do not only result in lower transport volumes, but also in a lower economic output for the involved countries. In fact, the Second World War has not affected the long term relation between economic output and port throughput in the LHR (Van Dorsser et al., 2012, p. 99). This implies that international conflicts can be taken into account by applying different GDP scenarios.

The scenario studies that were studied in Chapter 3 indicate that the relation between GDP and transport is likely to change as a result of decoupling. Decoupling is therefore expected to have important implications for the modelling of very long term transport volumes.

High costs of natural resources and fuel in particular can, at least in theory, be expected to reduce the level of economic output, but Schade et al. (2008, p.56) estimated that large variations in fossil fuel prices by a factor 2 will only have a relatively small effect of less than 2% on the European GDP. In addition, Van Dorsser et al. (2012, p.107) indicated that high oil prices tend to correspond with high transport volumes (that are shipped via the seaports in the

Le Havre – Hamburg range). This finding was explained by the inverse causal relation. High global production-, trade-, and transport volumes result in a strong demand for oil and consequently in high oil prices. I therefore conclude that the effect of economic output on the price levels of fuel and other natural resources is much stronger than the inverse effect of fuel and resource prices on the level of economic output. For this reason the arrow is directed from the *'GDP'* variable to the *'costs of natural resources (e.g. fuel)'* variable.

Transport volumes affect the transport price (e.g. via economies of scale). The opposite effect of transport prices on the transport volume is however quite limited. Petersen et al. (2009, p.59) indicated that: *"Transport costs are very sensitive to energy prices, especially to oil. However, traffic flows are less sensitive to transport costs. […] For freight, […] 80% of traffic is not price sensitive. Transport prices may be internalized in goods' prices, but transport flows are not reduced"*. This implies that the effects of changing fuel- and transport prices on the overall level of freight transport may be regarded as a second order feedback loop, and for that reason I have indicated them with dotted lines in Figure 7-4.

7.3.2 Problems with near-linear dependency and multicollinearity

From the above discussion it can be concluded that the overall transport demand is not only affected by economic output, but also by other drivers such as the size of the population and international trade volumes. Taking these variables into account makes sense as: the larger the population, the more food and construction materials will be required; and the higher the amount of international trade, the more goods that have to be shipped. The observation that the estimated level of transport can be almost completely explained by a single GDP variable is at least surprising and counter intuitive. One would expect a model containing a number of explanatory variables (such as population, GDP, and trade volumes) to have a significantly higher explanatory power than a model that contains only one single GDP variable. I have therefore looked for an explanation why this does not seem to be the case and came up with two possible explanations. The first explanation is that the effects of some main drivers have cancelled each other out. The effects of dematerialization may, for instance, have been offset by the effects of globalisation (see Section 7.3.4). However, given the very long term steady relation in the analysed data for the port throughput volumes (that goes back to 1936 in Figure 7-7), it is very unlikely that the transport drivers have continuously cancelled each other out in each individual decade throughout the data series. The second explanation, that is presumably more important, concerns the near-linear dependency of the main transport drivers.

The very high explanatory power of the GDP variable is likely to be caused by the fact that the main transport drivers are near-linear dependant. A regression model that contains near-linear dependant variables is likely to face problems with multicollinearity. *"Multicollinearity is a statistical phenomenon in which two or more predictor variables in a multiple regression model are highly correlated. In this situation the coefficient estimates may change erratically in response to small changes in the model or the data. Multicollinearity does not reduce the predictive power or reliability of the model as a whole, at least within the sample data themselves; it only affects calculations regarding individual predictors. That is, a multiple regression model with correlated predictors can indicate how well the entire bundle of predictors predicts the outcome variable, but it may not give valid results about any individual predictor, or about which predictors are redundant with respect to others"* (Wikipedia, accessed: 2011). If the applied drivers in the transport model turn out to be near-linear dependant, this implies that the model becomes indifferent to parameters that follow a similar historical trend. As a result it will be impossible to estimate the true value of the coefficients for the parameters (or drivers) that are applied in the transport model.

Montgomery and Askin (1981, p.109) warned for the risks of multicollinearity in forecast models: *"Since multicollinearity is synonymous with ill conditioning, its presence implies that one or more of these eigenvalues is near zero. Thus the expected distance from β^ to β may be large. This implies that least squares overestimates the norm of β and results in some regression coefficients that are too large in absolute value. These unstable parameter estimates have potentially damaging consequences in forecasting. Many forecasting models involve extrapolation, particularly extrapolation over time. Good parameter estimates are essential for successful forecasting, particularly when the model's use requires extrapolation into a region of the predictor variable space not adequately covered by sample data points".*

Ill conditioned transport forecast models, that contain near-linear dependant variables with unstable parameter estimates, are still likely to provide reasonable overall model estimates for the period in which the explanatory variables move along in a similar way. However, on the very long term there is no guarantee that the near-linear dependant variables will remain heading in the same direction. When near-linear variables start to follow a different path the overall outcome of the model projections will no longer remain valid. I therefore question the use of multiple (near-linear dependant) variables in very long term transport forecasts.

Figure 7-4 indicates that the main drivers that affect the transport volumes (e.g. population, GDP, and international trade volumes) are highly interrelated. As these drivers feed into each other the use of a linear regression model is not recommended. I consider this a non-linear problem in which there are two explanatory variables that primarily affect the transport volumes, which are *'GDP'* and *'international trade volumes'*. Due to the fact that these two variables are highly correlated any linear regression model that contains both variables is likely to be ill conditioned and sensitive to multicollinearity. From the simplified causal structure I conclude that problems with near-linear dependency can already be expected in a simple linear transport model, that contains more than just one explanatory variable.

7.3.3 The use of GDP as a single variable in the forecast model

Montgomery and Askin (1981, p.109) addressed the issue of multicollinearity in forecasting models based on linear regression. They indicate that *"Perhaps the most obvious approach to dealing with multicollinearity is respecification of the model; in particular, either defining new predictors or eliminating some of the predictors currently in the model. For example, two or more variables involved in a near-linear dependency may be combined into a single new variable. This often preserves the information content in the original predictors while lessening the impact of multicollinearity. Alternatively one or more of the original predictors may be deleted from the model"*. To deal with the problem of multicollinearity I suggest to use only one of the two primary transport drivers in the model and apply a forecast model that is either based on the level of GDP or on the level of international trade volumes.

For aggregated forecasts of the overall freight transport demand it is logical to use the GDP variable, because international trade volumes do not directly relate to domestic transport. At a disaggregated level both variables can be used next to each other. Ickert et al. (2007, p.12) for instance discussed a disaggregated transport model that relates domestic flows to the national GDP and international flows to the international trade volumes. This disaggregated approach is likely to be more accurate, but it also requires more detail than its aggregated counterpart. I therefore regard a model that uses GDP as a single explanatory variable the most appropriate option for the development of an aggregated probabilistic very long term transport forecast up to the year 2100. However, the effects of decoupling and changing transport prices can still affect the applied GDP–transport relation. These need to be addressed accordingly.

7.3.4 The effect of decoupling of economic output and freight transport

Feige (2007, p.108-109) executed an in depth inquiry into the relationships between economic output, trade, and transport. She concluded that the relation between economic output (but also trade) and freight transport is solid on the short term, but that it is uncertain if this relation will also remain valid on the long term when structural changes take place within the economy. The analysed scenario studies (see Chapter 3) also indicate that the functional shape and significance of the applied causal relation between economic output and freight transport is likely to change over time as a result of decoupling. For this reason these studies applied expert judgement to cover the effect of decoupling. This can for instance be observed in the German scenario study where the projections are initially above the linear trend for the period up to 2030 and drop below the linear trend in the period thereafter (see Figure 7-3, right).

The analysed scenarios point out that the effects of decoupling need to be taken into account, but they do not address the considerations on which the adjustments have been based, nor the way that decoupling was taken into account in the forecasts. I think that decoupling should be regarded as a function of the effects of dematerialization and the effects of sustainable developments that counter globalisation. Dematerialisation causes less goods to be produced per unit of GDP output (e.g. due to an increased level of services in the economy) and less materials to be used per unit of produced goods (e.g. due to ongoing efficiency improvements over time). Sustainable developments that aim for a more localised production can be related to possible future trends such as back-shoring (i.e. bringing production back to the European mainland) and more localised production (e.g. by means of 3D printing techniques). A pragmatic solution to deal with the dematerialization and sustainability effects of decoupling in the very long term transport forecast will be discussed in Section 7.4.5.

7.3.5 The effect of changing fuel- and transport prices on transport demand

The transport scenarios analysed in Chapter 3 indicate that the structural effect of high oil prices on the level of GDP and freight transport is almost negligible (Janssen et al., 2006, p.94); and that *"demand for transport services is relatively insensitive to price"* (Petersen et al., 2009, p.43). This implies that it may be possible to disregard the causal relation between transport prices and transport demand in the very long term forecast model.

I have therefore studied the literature on price elasticities for freight transport. According to De Wit and Van Gent (2001) and Geilenkirchen et al. (2010) the present knowledge on freight transport elasticities is limited, but there exists a comprehensive study of Dings et al. (1999) that provides detailed insight in the effects of changing fuel- and transport prices for road transport in the Netherlands. The elasticities reported by this study are listed in Table 7-1.

Table 7-1: Own Elasticities for Road Transport in The Netherlands

Own Elasticities for Road Transport in the Netherlands	Effect of increased Road Fuel Prices	Effect of increased Road Transport Prices
Loss of transport demand due to loss of production (in tonnes)	Not included	Less than -0.1
Loss of transport demand due to a reduction in transport distance (in tonne kilometre)	- 0.03	-0.2 to -0.4
Substitution of road transport to other modes of transport (in tonnes and tonne kilometres)	-0.04	-0.4 to -0.5
Total elasticity (in tonne kilometres)	-0.07	-0.4 to -0.9

Note: The original table does also not include the less than -0.1 figure for loss of production in the totals.

Source: Dings et al. (1999a), numbers taken from table on p.11 and derived from figure on p.17.

On the basis of these elasticities I conclude that loss of transport demand due to loss of production is rather small. Changes to the costs of transport will therefore have only little effect on the overall transport volume in tonnes. However, changes to the costs of transport do affect the location of logistics- and production activities and origin-destination patterns for given production locations, which implies that, at least on the long term, they do affect the transport demand in tonne kilometres. The largest contribution to the elasticity of road transport demand stems from substitution to other modes of transport. Substitution has no effect on the overall level of transport demand.

In order to understand the possible effects of changing fuel- and transport prices on the very long term development of the overall transport demand insight is required in the possible very long term changes to the transport price. I have therefore aimed to obtain a rough indication of the possible effects that can be expected throughout the 21st century.

With respect to the fuel costs I considered a very long term high-end scenario in which fuel costs (at constant year 2010 prices) are expected to triple compared to their present (year 2010 values), and in which a very high tax level on carbon emissions is imposed. As will be discussed in Chapter 10: (1) the actual price for road transport diesel was about € 0.93 per litre in the year 2010; (2) the carbon emissions are 2.7 kg per litre diesel; and the shadow price of carbon emissions is likely to remain below € 0.28 per kg on the long term (based on Maibach et al., 2008, p.77). On the basis of these assumptions one can expect the real diesel price to increase by no more than a factor 3.8[84]. At the reported elasticity of -0.03 this implies a maximum reduction of about 11% in the overall transport volumes in tonne kilometres, but in practice this effect will be even lower as Dings et al. (1999b) report the transport elasticities to become smaller when larger changes to the price levels are concerned.

In a similar way I also investigated the possible effects of a reduction in the overall transport costs. Oosterhaven and Rietveld (2003) indicate that the real costs of sea transport roughly decreased by a factor 4 over the 19th century and by a factor 2 over the first half of the 20th century, after which it remained more or less constant despite the major development of intercontinental container transport. This implies that sea transport followed a very long term product development curve in which the costs slowly evolved towards the lowest attainable final limit value. Similar cost reductions are also reported for international road-, rail-, and IWT transport. The historical- and expected limit values are indicated in Table 7-2.

Table 7-2: Development of Real Transport Costs in Euro Cents per Tonne Kilometre

Transport Mode	1900	1950	1998	Limit Value	Reduction
IWT	15	7.5	6	5.7	5%
Rail	40	18	9	7.0	22%
Road	110	40	20	16.0	20%

Source: Historical data from Oosterhaven and Rietveld (2003, p.36) based on Muconsult (2001); Limit values and further reduction potential based on my own estimates.

The limit values were obtained by fitting logistical S-curves through the historical data. I found that the eventual limit values are expected to be about 5% lower for IWT and about

[84] Calculation: 3 * € 0.93 + 2.7 * € 0.28 = € 3.55 ; € 3.55 / € 0.93 = 3.8.

20% lower for rail- and road transport[85]. If one assumes an overall reduction in transport costs by about 25% due to gradual improvements of the transport system and further applies the upper -0.4 limit for the transport elasticity, one obtains a maximum increase of about 10% in transport demand (in tonne kilometres) due to an ongoing decrease in transport costs.

On the basis of this discussion one can expect higher fuel prices to reduce the overall transport performance (in tonne kilometre) by no more than about 11%, while the effects of ongoing cost reductions to the real price level of transport are likely to increase the overall level of transport demand by no more than about 10%. Apart from the fact that these two effects work in opposite direction, they are also relatively small compared to the effects of changes to the main transport drivers (i.e. economic output and trade volumes), that are expected to result in a growth of the overall level of transport demand by a factor 1 to 3 in the first half of the 21st century (at least for the scenarios discussed in Chapter 3). I therefore conclude that the causal effects of changes in the fuel- and transport prices on the overall level of transport demand can be considered as second order effects, that each at most have an effect of about 10% on the outcome of the projections. For this reason I consider it justified to disregard these effects in aggregated very long term transport forecasts. This simplification significantly reduces the complexity of the very long term forecast model and avoids difficulties with the forecasting of highly uncertain price levels, for which I question the possibility to develop a sound forecast at such a very long time horizon.

Excluding the second order feedback loops of the fuel- and transport prices on the overall level of transport demand enables the use of a relatively simple very long term forecast relation that will be addressed in the next section. Further research will have to define if it is sensible to develop a more elaborated model that includes these two feedback loops.

7.4 The Mathematics of the GDP-Transport Relation

The previous section indicated that aggregated very long term transport projections can be based on a simple one variable causal GDP-transport relation, but it has not yet addressed the mathematical equations that should be applied in the forecast. This section starts with a discussion on the available historical data for the modelling of the port throughput volumes in the LHR; continues with an analyses of the statistical and theoretical performance of three possible forecast equations; and finally proposes to use a combination of two of these equations for the development of a very long term transport forecast up to the year 2100.

7.4.1 Availability of very long term data series

The development of a very long term forecast requires the availability of very long term data series that preferably cover at least one full length of an about 50 years lasting Kondratieff wave (see Chapter 4). This section addresses the available data series for the development of the regional GDP and the total port throughput volumes in the LHR.

With respect to the GDP values that are presented in this thesis it is important to emphasise that they all refer to the real GDP levels at constant prices. The nominal values that include inflation are not considered relevant for the issues that are addressed in this thesis.

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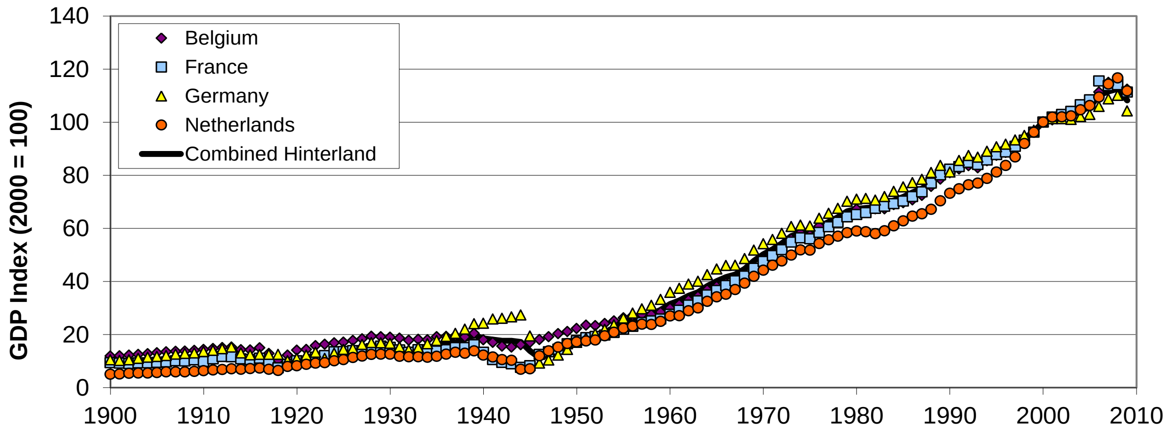
[85] It should be noticed that logistical S-curves are hard to fit and do not provide a very accurate forecast, but the obtained numbers at least provide an indication of what can be expected.

GDP development in the hinterland of the Le Havre – Hamburg range

The LHR does not serve a distinct number of countries exclusively. The actual boundaries are vague and contain overlap with other port areas, such as on the Mediterranean- and Baltic Sea. I therefore applied a pragmatic approach in which the hinterland is roughly linked to a *'Region'* that is defined as: The Netherlands, Germany, France, Belgium, and Luxembourg. This simplification is justified by the fact that integrated economic regions tend to move simultaneously – and that I am not interested in the total port throughput per unit of regional GDP output, but in the way that GDP and port throughput move along together. For the analysis of the transport data in the 'Region' I derived a combined hinterland index of the Regional GDP (at constant year 1990 price levels; with base year 2000 output = 100).



Note: The combined hinterland GDP was derived by summarizing the GDP of NL, GE, FR and BE[86].
Source: GDP index derived from real GDP data of Maddison (accessed: 2010).

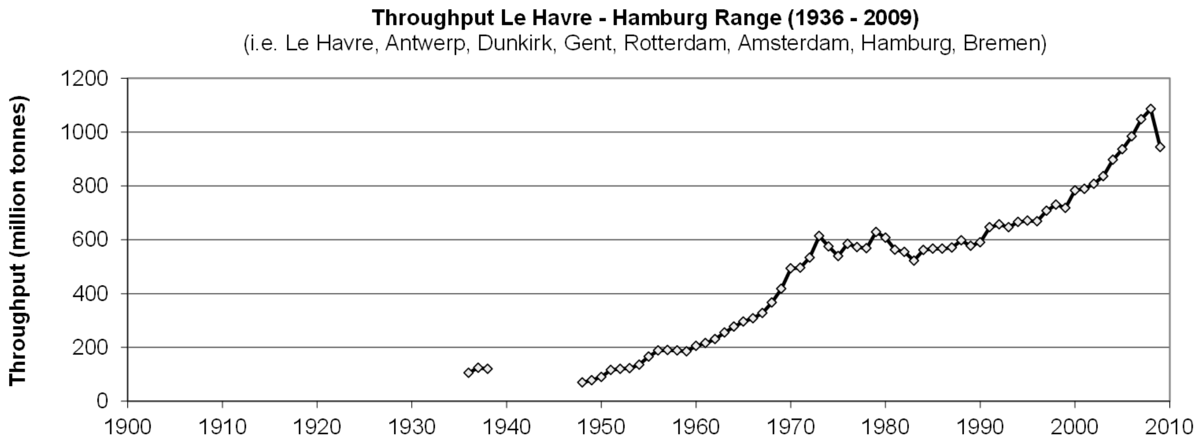
Figure 7-5: Historical Development of the real GDP in the Hinterland of the LHR

Figure 7-5 shows that the growth of the Regional GDP (at constant prices) followed a similar trend for the selected countries. Economic growth has generally been quite stable though a trend breach can be observed at the instance of the Second World War.

Port Throughput data for the Le Havre – Hamburg range

The LHR range contains many seaports of various sizes. The Rotterdam Port Authority includes the ports of Le Havre, Dunkirk, Zeebrugge, Antwerp, Gent, Flushing & Terneuzen, Rotterdam, Amsterdam, Wilhelmshaven, Bremen, and Hamburg in their statistics but provides only a few years of data on their website (www.portofrotterdam.com). Long data series from 1936 onwards (excluding 1939-1947) were obtained from the Antwerp Port Authority for the seaports of Le Havre, Dunkirk, Antwerp, Gent, Rotterdam, Amsterdam, Hamburg, and Bremen. The very long term forecast for the port throughput in the LHR relates to the eight ports included in the statistics of the Port of Antwerp. In 2008 and 2009 these seaports accounted for about 90% of the total throughput in the LHR (based on statistics of Rotterdam Port Authority). A table containing the detailed statistics for these eight seaports is provided in a conference paper of Van Dorsser and Wolters (2010). The overall development of the total port throughput of these eight seaports is indicated in Figure 7-6.

[86] GDP data prior to 1950 was not available for Luxembourg, but the size of this country is small compared to the others. Excluding the GDP of this country has therefore little effect on the index for the combined hinterland.



Source: Port of Antwerp (1936-2007), Port of Rotterdam (2008, 2009).

Figure 7-6: Historical Development of Total Port Throughput in the LHR

The historical trend in the total port throughput volumes of the LHR is more or less similar to the trend in the GDP development for the Region, though the port throughput volumes seem to be much more affected by the very long term Kondratieff waves than the GDP output.

7.4.2 The mathematical relation between GDP and freight transport

Using the long term relation between economic output and transport is not as simple as it may appear from the discussion at the beginning of this chapter. There are a few difficulties that need to be addressed. First of all it is not clear what is meant by *"The relation between GDP and transport demand"*. Even for a simple one variable causal relation there are still many mathematical functions possible. In addition one should be careful with the regression of two trending time series, such as GDP and transport. The first part of this section provides a discussion on the statistical problems that may occur in the analysis of time series and the available tests to identify these problems. The next part scrutinises the GDP–transport relation for the port throughput volumes in the LHR, in order to select a statistically sound regression function that still provides sensible (i.e. theoretically feasible) very long term forecasts.

Problems with the statistical properties of trending time series

Regression of two time series, that follow and upward or downward trend, can result in a virtual correlation that in reality does not exist. Granger and Newbold (1974, p.111) warned that: *"It is very common to see reported in applied econometric literature time series regression equations with an apparently high degree of fit, as measured by the coefficient of multiple correlation R^2 or the corrected coefficient $\bar{R}^2$, but with an extremely low value for the Durbin-Watson statistics. We find it very curious that whereas virtually every textbook on econometric methodology contains explicit warnings of the dangers of autocorrelated errors, this phenomenon crops up so frequently in well-respected applied work"*. In practice many time series are non-stationary and referred to as following a random walk or containing a unit root. If a time series follows a random walk the effects of a temporary shock will not dissipate after several years, but instead remain. The standard methodology for hypothesis testing and goodness of fit is only valid if the regression parameters are stationary, or in a special case where the time series are co-integrated (i.e. the error term is stationary).

To avoid unnecessary misspecification and misinterpretation of the regression model it is important to test for stationarity of the error term. Durbin-Watson provided a test for autocorrelation of which the test statistics lie in the range of 0 to 4. A value of 2 indicates that there is no autocorrelation. High values indicate negative correlation. Low values indicate positive correlation. Low Durbin-Watson statistics are therefore a warning for non-stationary data series. A formal test for random walks is provided by Dickey-Fuller. A low DF-value indicates a high probability of unit roots. For a sample size of 50 data points one can reject the hypothesis of a random walk at the 95% confidence level if the critical value is above 6.73 (and for a sample with 100 data points it can be rejected if the critical value is above 6.49).

Apart from stationarity it also is important to test for normality of the error term. This is necessary because the standard theory for the calculation of prediction intervals[87] is only valid if the error term is normal distributed. Normality can be tested by using the Jarque-Bera (JB) statistics that follows a chi-square distribution with two degrees of freedom. If the JB-statistics are greater than 5.99 the null hypothesis of normality can be rejected at the 95% confidence level[88].

Obtaining a suitable regression function for the relation between GDP and port throughput

In order to obtain a suitable regression function for the relation between GDP and port throughput (or transport) I have investigated the statistical properties of three simple linear regression functions. The selected functions are indicated in Equation 7-1 to 7-3.

$$PT_t = \alpha + \beta \cdot GDP_t + \varepsilon_t \quad \text{(Equation 7-1)}$$
$$\ln(PT_t) = \alpha + \beta \cdot \ln(GDP_t) + \varepsilon_t \quad \text{(Equation 7-2)}$$
$$\Delta PT_t = \alpha + \beta \cdot \Delta GDP_t + \varepsilon_t \quad \text{(Equation 7-3)}$$

with:

α : Intercept value;
β : Linear coefficient;
PT_t : Port Throughput level in year t;
GDP_t : GDP index level in year t;
ΔPT_t : Difference in Port Throughput between year t and year t-1;
ΔGDP_t : Difference in GDP index between year t and year t-1;
ε_t : Error term in year t.

The first two equations contain a *'long term relation'* that directly takes the long term trend into account. The last equation contains a *'short term relation'* that only considers the annual differences and has no long term memory. The statistical properties of the regression analysis are summarized in Table 7-1. Please note that the α value relates to the volume in million tonnes, and that the β coefficient indicates the output in million tonnes per GDP index point.

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87 The standard theory for the calculation of prediction intervals states that the prediction interval can be calculated as: $\hat{y}_p \pm t_{\alpha/2} \cdot s^2 \cdot [1 + 1/n + (x_p - x_{avg})^2 / \{\Sigma(x_i^2) - [(\Sigma (x_i)^2)/n]\}]$ with $\hat{y}_p$: the point estimate; 1-α: the confidence belt, $t_{\alpha/2}$: the t-statistics for α based on t-n degrees of freedom; n: the number of points in the dataset, s: the standard deviation of the sample; x_p: the value of x for which $\hat{y}_p$ is calculated, x_{avg}: the average x value of the dataset; x_i: the individual x values of the i[th] point in the dataset.

88 The discussion of the Durbin-Watson statistics, Dickey-Fuller tests, and Jarque-Bera statistics is based on Pindyck and Rubinfeld (1998, pp. 45-58, 164-166, and 507-513).

Table 7-3: Statistical Properties of the three investigated Linear Regression Functions

GDP-Throughput Relation	Equation 1	Equation 2	Equation 3
Data			
- DF-test GDP/ln(GDP)/ΔGDP	1.85	49.93	10.05
- Unit Root**	Yes	No	No
- DF-test PT/ln(PT)/ΔPT	1.90	10.68	17.59
- Unit Root**	Yes	No	No
Function			
- R^2	0.957*	0.974*	0.516
- Adjusted R^2	0.956*	0.974*	0.508
- Durbin-Watson Statistics	0.23	0.25	2.06
Intercept α	-39.92	1.28	-17.46
- t-Stat	-2.52*	13.11*	- 3.55
Linear Coefficient β	8.76	1.19	20.76
- t-Stat	37.44*	48.88*	8.06
Error Term ε			
- DF-test on Error Term	1.79	2.82	32.16
- Unit Root**	Yes	Yes	No
- JB-Statistics	7.89	5.20	0.28
- Normal Distributed**	No	Yes	Yes

Note (*): meaningless value due to non-stationarity of error series; Note (**): the value "Yes" for unit roots in (or normality of) the error term implies that the hypothesis of unit roots (or normality) could not be rejected at the 95% confidence level.

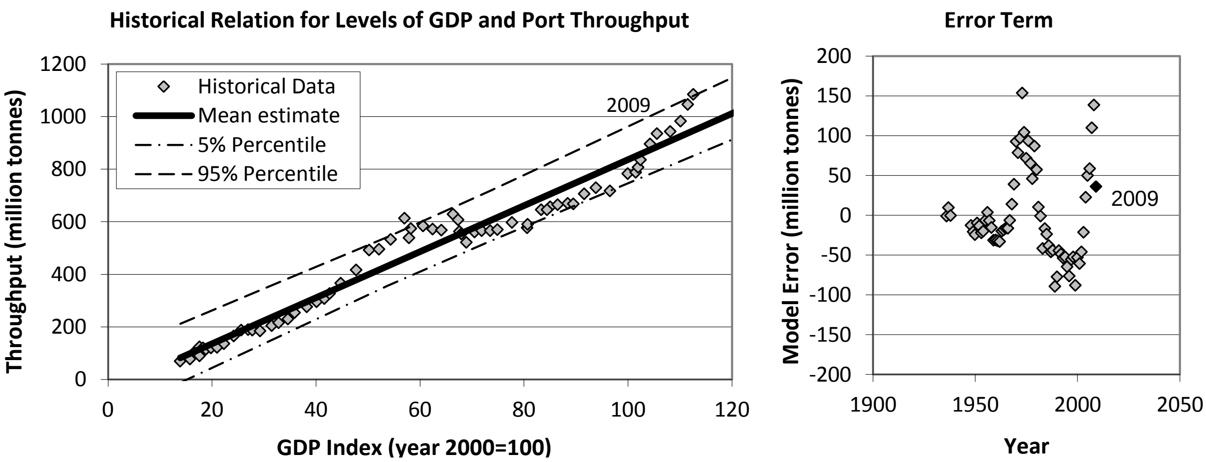


Figure 7-7: Fit of the Regression Function for the 'Levels Equation' (Equation 7-1)

Figure 7-7 shows the fit of the simple linear regression function between the levels of GDP and port throughput. A clear trend can be observed that holds throughout the data series. However, from the regression statistics it should be concluded that one has to be careful with the interpretation of the model. The error term is highly autocorrelated and likely to contain a unit root. Therefore the model is likely to be misspecified in the sense that it is sensitive to trend breaches of common drivers such as globalisation. This implies that the prediction intervals will be too small as a result of the virtually high fit. Finally the error term does not follow a normal distribution and therefore a small additional error in the calculation of the prediction intervals will occur if the standard interval estimation techniques will be applied. However, in case of Equation 7-1 this error is rather small and not considered an issue.

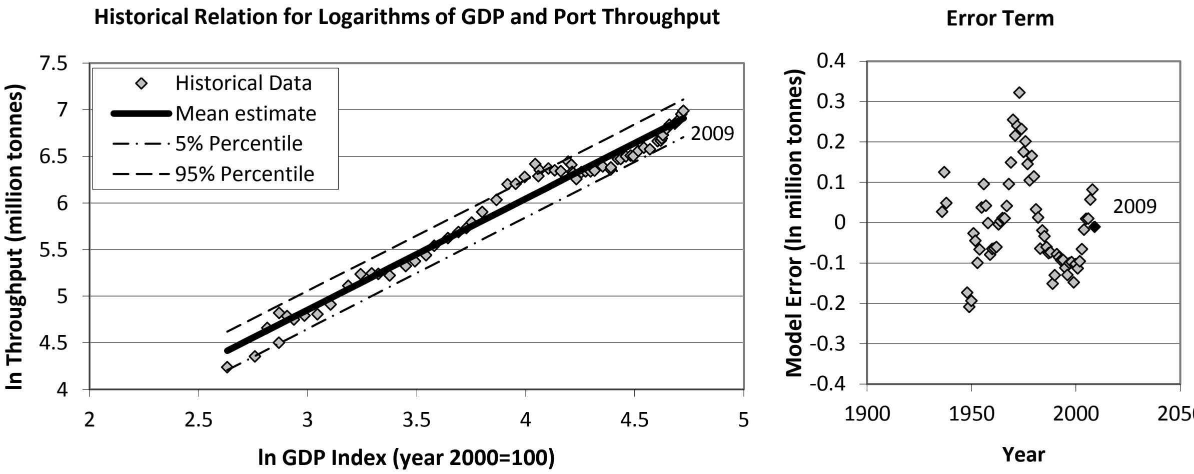


Figure 7-8: Fit of the Regression Function for the 'Log Levels Equation' (Equation 7-2)

Figure 7-8 shows the fit of the log-model. Though the fit of the model looks quite well the error term is still highly autocorrelated. The model is therefore still likely to be misspecified and sensitive to trend breaches of common drivers. This implies that the prediction intervals are too small, compared to the real uncertainty levels. A special property of this model, that applies a logarithm to both sides of the equation, is that the β coefficient equals the elasticity between GDP and port throughput (Van Dorsser et al., 2012, p.95). By applying this equation one assumes the elasticity to remain constant regardless of the output volume.

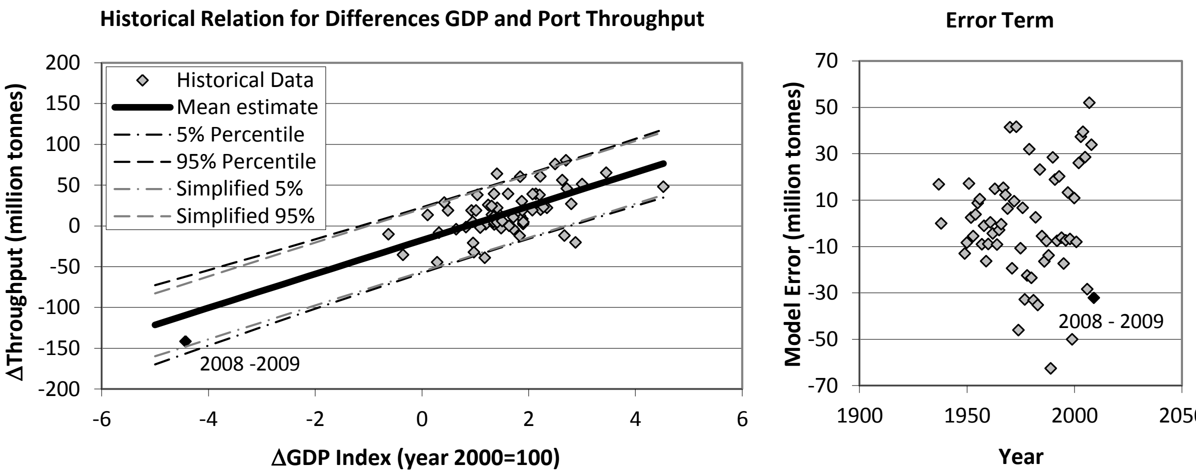


Figure 7-9: Fit of the Regression Function for the 'Differences Equation' (Equation 7-3)

Figure 7-9 relates the annual differences in GDP to the annual differences in port throughput. The basic statistics indicate that this model no longer contains a unit root and has a normal distributed error term. This implies that Equation 7-3 may be a sound candidate. It should however be noted that few observations relate to a decline in GDP. Only the 2008-2009 datapoint relates to a serious decline. It is difficult to judge whether this datapoint should be regarded as valuable information or as an unwelcome outlier. I saw no reason to exclude the datapoint and therefore kept it in the dataset. If the datapoint would have been excluded the absolute value of the α coefficient would have been 40% lower (at value of -10.42); the β coefficient would have been 20% lower (at value of 16.72); and the corresponding bandwidth of the prediction intervals would have been smaller.

Equation 7-3 cannot be used to derive the throughput levels directly from the GDP. To obtain the final forecast the last observation (at t=0) has to serve as a starting point. For each succeeding year the annual change in throughput is derived from the annual change in GDP and added to the value of the previous year. The main problem with this approach is that the calculation requires the growth path of the GDP to be known, which is not the case if the output of a probabilistic GDP forecast is used as input for the transport forecast. A simplified approach that directly relates the throughput value to the GDP is indicated in Equation 7-3B. This equation is however still subject to the less obvious complication that the error term (required in the simulation process) is path dependant. A possible way to solve this problem is to neglect the variance in the slope of the line of the prediction interval (i.e. the curved slope of the intervals). Figure 7-9 shows that this simplification is quite acceptable.

$$PT_{t=n} = PT_{t=0} + n \cdot \alpha + \beta \cdot (GDP_{t=n} - GDP_{t=0}) + \sum_{t=1}^{n} \varepsilon_t \qquad \text{(Equation 7-3B)}$$

with:

- n : Number of years forecasted ahead;
- α : Annual decrease in throughput at constant GDP;
- β : Linear coefficient between throughput and GDP;
- PT_t : Port Throughput in forecast t-years ahead;
- GDP_t : GDP in forecast t-years ahead;
- ε_t : Stochastic error term of forecast in year t.

After obtaining a statistically sound relationship the question raises if the equation also holds from a theoretical point of view. The negative α coefficient indicates that port throughput volume will decrease with a constant annual value as soon as the GDP stabilizes. Theoretical evidence supports the existence of a negative α coefficient. Possible explanations can be found in ongoing production efficiencies and miniaturisation of goods as well as in the increased share of services and virtual goods in the economy, that result in a decoupling of transport and economic output. On the contrary it can also be argued that the existence of a fixed negative α coefficient is fundamentally wrong on the very long term as it implies that the port throughput drops to zero (or even below zero) after a possible future stabilisation of the GDP output. This contradicts the fundamental theory of comparative advantage of David Ricardo (1817), that indicates that there will always be incentives for trade.

To investigate the options to develop a model with an α coefficient that phases out gradually (e.g. by multiplying the α coefficient by a factor between zero and one to the power of the number of years forecasted ahead), I investigated if the decline in α could also be observed from the historical data. For this purpose I studied a multiple regression model with dummy variables for each decade, of which the regression output is indicated in Table 7-4.

Table 7-4: Multiple Regression Model with Dummy Variables

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-17.69	6.86	-2.58	0.01
ΔGDP	21.25	2.42	8.80	0.00
Dummy 1960-1969	1.63	9.33	0.17	0.86
Dummy 1970-1979	-0.76	9.33	-0.08	0.94
Dummy 1980-1989	-17.72	9.24	-1.92	0.06
Dummy 1990-1999	-2.05	9.26	-0.22	0.83
Dummy 2000-2009	12.63	9.23	1.37	0.18

Unfortunately the parameter estimates for this model made no sense and could not support the theory of a declining α coefficient (no trend can be observed in the coefficients of the dummy variables). As a result it is still unclear how to develop a model with significant parameters for the declining α coefficient on the basis of the available historical data.

I therefore had to conclude that I have been unable to develop a sound forecast model with a declining α coefficient. None of the evaluated forecast equations is completely 'sound' from a statistical and theoretical point of view. Equation 7-1 and 7-2 are likely to be misspecified because the error term is likely to contain a unit root. Equation 7-3 passes the statistical tests, but theoretical arguments make clear that this model will also be wrong on the very long term as it overestimates the effects of decoupling. Strictly speaking I should therefore reject all three investigated equations, because none of them fully complies with the statistical and theoretical requirements for the development of a very long term transport forecast.

However, given the importance of the subject and the fact that the causal relation 'proved' to be real for Lithuania (and the other Baltic States) I still find it sensible to consider the use of at least one of these 'bad' equations for the development of an aggregated very long term transport forecast. It is therefore sensible to question how well the various equations are likely to perform as a predictor for the future throughput volumes, and which of them provides the most reliable results. This question can be addressed by means of an ex-post forecast.

7.4.3 Ex-post forecast for the proposed equations

I studied the performance of the proposed equations by means of an ex-post forecast in which I assumed that someone back in 1970 had perfect foresight on the development of the GDP and was asked to develop a forecast of the port throughput in the LHR up to the year 2009 on the basis of post war data (using only the data up to the year 1970 for the estimation of the parameters that are applied in the model). The results of this forecast model as well as the real development of the port throughput since the 1970s are indicated in Figure 7-10.

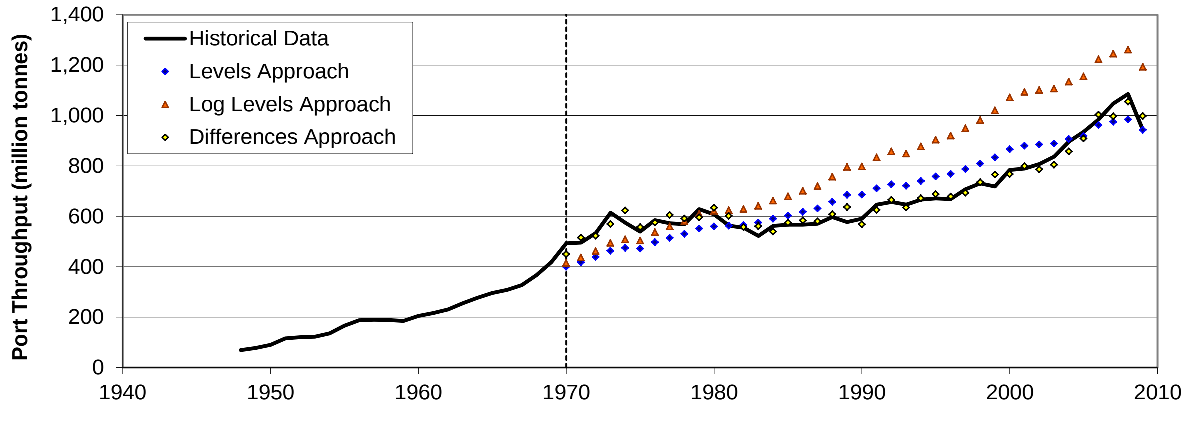


Figure 7-10: Ex-Post Forecast from 1970 to 2009 based on true GDP Development

The results of the ex-post forecast indicate that the differences approach (Equation 7-3) would have performed remarkably well as it shows almost no deviation from the true development of the port throughput volumes. The use of the levels approach (Equation 7-1) would have also performed quite well as it appears to be unbiased towards the long term trend. Only the exponential model that is derived from the log-levels of GDP and port throughput (Equation 7-2) would have resulted in an estimate that significantly deviates from the real historical trend, which in fact implies that the transport elasticity does not remain constant over time.

7.4.4 Suggested use of a combination two forecast equations

Forecasting literature indicates that it is good practice to combine forecasts in order to get more stable results, in particular when it is uncertain which method provides the most accurate forecast (Armstrong, 2001, p.417). Given the 'proof' of the causal relation for Lithuania and the excellent results of the ex-post forecast for Equation 7-1 and Equation 7-3[89], I consider it sensible to use a combination of these two 'bad' forecast equations for the development of a very long term probabilistic transport forecast.

Justification for the use of Equation 7-1 and 7-3

There is no guarantee, but there is strong empirical evidence in support of the use of these two equations. There is over seventy year data showing a strong significant long- and short term causal relation between GDP and port throughput. The long term relation of Equation 7-1 has not shown a trend breach at the instance of the Second World War and has not changed as a result of the shift from an industrial to a services orientated industry nor from to the rise of the four Asian Tigers and China. On the basis of this argumentation it can be concluded that the causal relation between GDP and port throughput is very persistent and likely to withstand new global trends such as a possible shift of production back to Europe or to new industrial nations like India or Brazil. In addition the short term relation of Equation 7-3 (that is referred to as short term because it only takes the annual differences into account and does not have a long term memory) shows an almost perfect fit in the ex-post forecast, that is not likely to be coincidental. I therefore consider it justified to use a combination of Equation 7-1 and 7-3.

Implications of combining the results of Equation 7-1 and 7-3

The long term levels relation of Equation 7-1 is vulnerable to trend breaches that are most likely to have a negative impact on the throughput volumes (e.g. those related to the effects of sustainable developments that reverse globalisation); and in addition Equation 7-1 does also not take the dematerialization effects of decoupling of GDP and transport properly into account. For this reason Equation 7-1 is likely to overestimate the very long term trend. In contrast the short term differences relation of Equation 7-3 is expected to underestimate the very long term trend, because the constant negative α coefficient overestimates the effect of decoupling on the very long term. By combining both equations the overall bias in the forecast is likely to be reduced. The outcome of the combined forecast is therefore considered more reliable than the outcome of one of these two forecasts equations on their own.

The same holds for the width of the prediction intervals. Due to misspecification of the model the prediction intervals of Equation 7-1 are too small (compared to the ideal situation in which the parameters would not be misspecified). This implies that the model assumes common drivers, such as globalisation, to hold on throughout the forecast, while this may in fact not be the case (refer to the main drivers of the 6^{th} Kondratieff wave that have been discussed in Chapter 4). On the other hand the statistical variance of Equation 7-3 completely ignores the existence of common long term drivers, because such drivers cannot be covered by a model that is solely based on annual differences and has no long term memory. The prediction intervals of the short term differences relation are therefore wider than would be strictly necessary if such long term drivers could have been taken into account by the model. In reality the common long term drivers of GDP and transport can be expected to remain active

[89] Please note that the parameter estimates that were used in the ex-post forecast differ from those applied in the very long term forecast because they are based on a shorter data range than the estimates presented in Table 7-3.

for a considerable period of time, but probably not throughout the entire forecast period up to the year 2100. By combining the results of the long term levels and the short term differences approach one obtains a forecast that holds the middle between the assumption that all existing common long term drivers of GDP and transport will remain active throughout the entire forecast period, and the assumption that common long term drivers do not exists. The width of the prediction intervals for the combined forecast will therefore be closer to the width of the prediction intervals of a perfect hypothetical forecast model (that knows how to take the effects of common long term drivers properly into account), than the width of each of the prediction intervals for Equations 7-1 and Equation 7-3 will be on their own.

I therefore conclude that, in contradiction to the very long term forecasts based on Equation 7-1 and 7-3, the median estimate of the combined forecast does not necessarily have to be biased, and the width of the prediction intervals is not necessarily to wide or too small.

7.4.5 The implicit way of dealing with the effects of decoupling

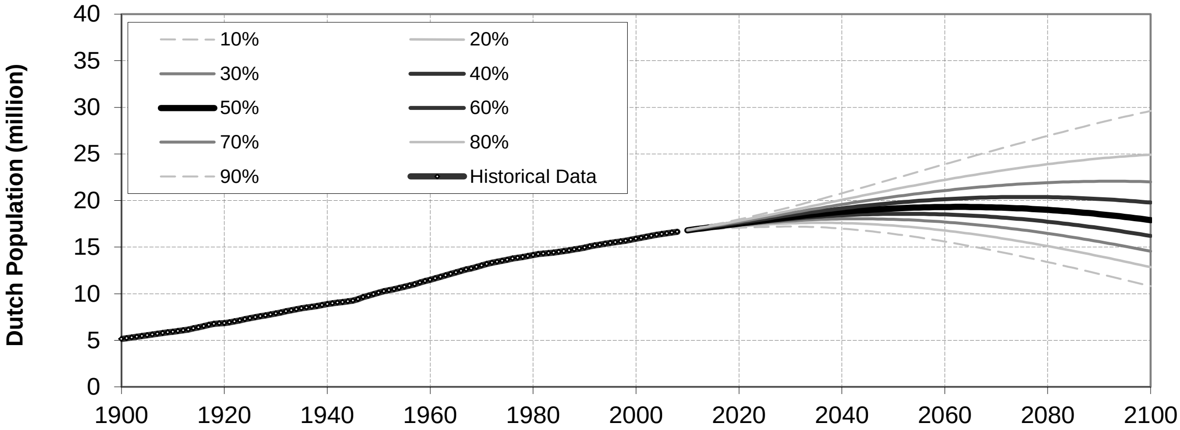
By combining both equations I found an implicit way to deal with the effects of decoupling in the forecast model. Where Equation 7-1 underestimates the effects of dematerialisation, Equation 7-3 overestimates this effect on the very long term; and where Equation 7-1 is vulnerable to trend breaches, that are for instance caused by the discontinuation of common long term drivers such as globalisation, Equation 7-3 does not take the effects of such common drivers into account at all. The effects of decoupling can therefore be expected to be underestimated in Equation 7-1 and overestimated in Equation 7-3. Combining both forecast provides a pragmatic provisional solution to deal with the effects of decoupling in very long term aggregated transport forecasts. The suggested approach is of course not ideal as I would have preferred to take the effects of decoupling explicitly into account in the forecast model, but it still enabled me to develop a probabilistic very long term transport forecast and serves as a starting point for further research on this topic, which is recommend.

7.5 The Probabilistic Population and GDP Forecasts

The development of very long term probabilistic transport forecasts requires input from a probabilistic GDP forecast. However, apart from the fact that all known official very long term economic growth projections seem to be based on the mainstream exponential growth paradigm (that was rejected in Chapter 4), it also appears that no long term probabilistic GDP forecasts have been published yet, let alone very long term GDP forecasts. I was unable to find one single probabilistic long term GDP forecast (not for the World, the United States, nor for Europe) and therefore had to develop my own very long term probabilistic GDP forecast on the basis of a probabilistic forecast of the working age population and some additional assumptions on the development of labour participation, average working hours, and GDP output per hour. To avoid unnecessary complexity I assumed that the Dutch GDP could serve as an approximation for the GDP in the Region. This assumption is supported by historical time series that indicate the Dutch, Belgium, German, and French GDP to have followed an almost identical trend over the past 110 years (see Figure 7-5). I do however recommend the use of a specific GDP forecast for the Region in follow-up studies. The main purpose of the modelling exercise in this chapter is to show that the forecast methodology works.

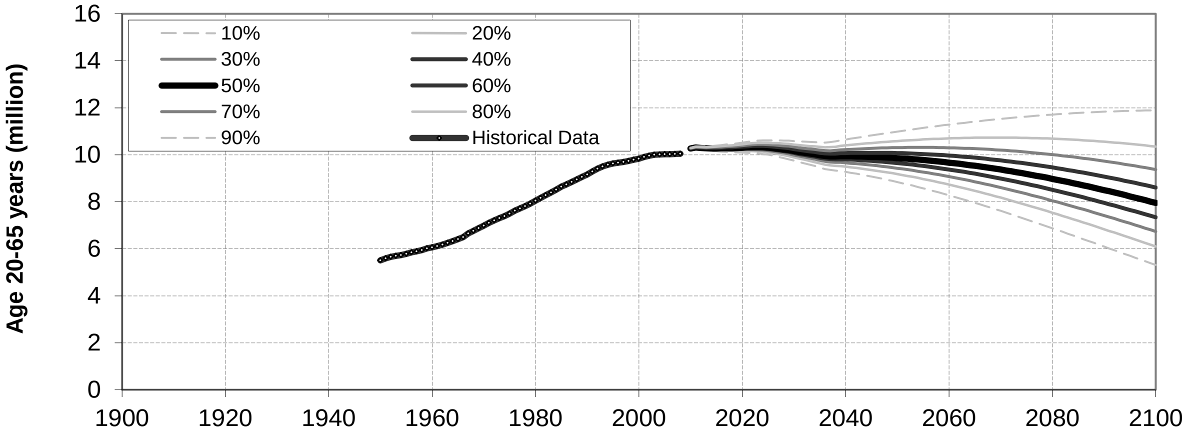
7.5.1 Obtaining a probabilistic population forecast for the Netherlands

I have compiled a probabilistic population forecast out of three different sources, which are: *The probabilistic projections for West Europe of the World Population Program* (IIASA, 2007 update, www.iiasa.ac.at); *The probabilistic projections for the Dutch population up to 2050 of the project Uncertain Population of Europe* (Alho and Nikander, 2004); and *Four* *very long term scenarios for the development of the total population up to 2100* (De Jong, 2008). The obtained population forecast is based on my best interpretation of these sources. It is not directly based on the outcome of a dedicated system dynamics population model, but on assumptions that I made in line with the outcome of such models. For follow-up studies I would recommend to start with a dedicated probabilistic population forecast for the Region (e.g. a forecast similar to the ones provided by IIASA for Western Europe). The obtained forecast results for the Dutch total- and working age population (defined as 20 to 65 years old) are indicated in Figure 7-11 and Figure 7-12.



Source: Historical Data obtained from Maddison (2010) and CBS (2010).

Figure 7-11: Probabilistic Forecast of the Total Dutch Population



Source: Historical Data obtained from Maddison (2010) and CBS (2010).

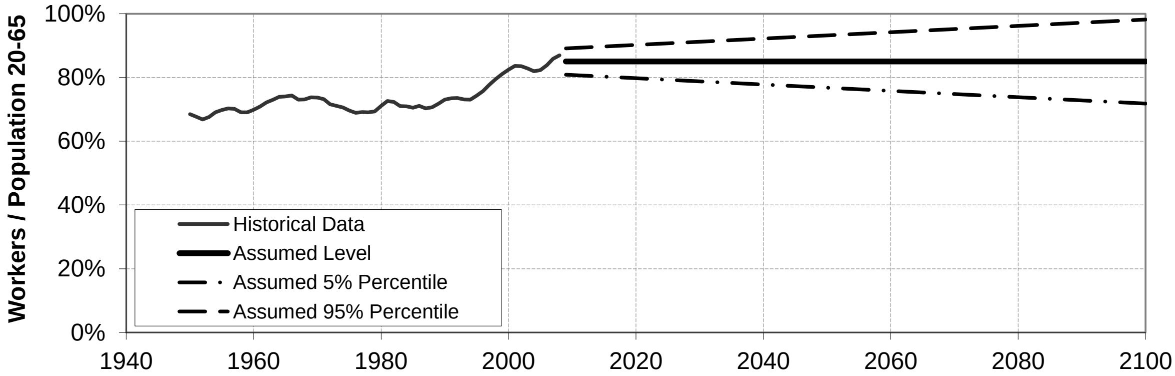
Figure 7-12: Probabilistic Forecast of the Dutch Working Age Population

The percentages in the legend of the figures refer to the percentiles of the prediction intervals. The 10% line for instance indicates that 10% of the probable outcomes lies below the line.

7.5.2 Obtaining a probabilistic GDP forecast for the Netherlands

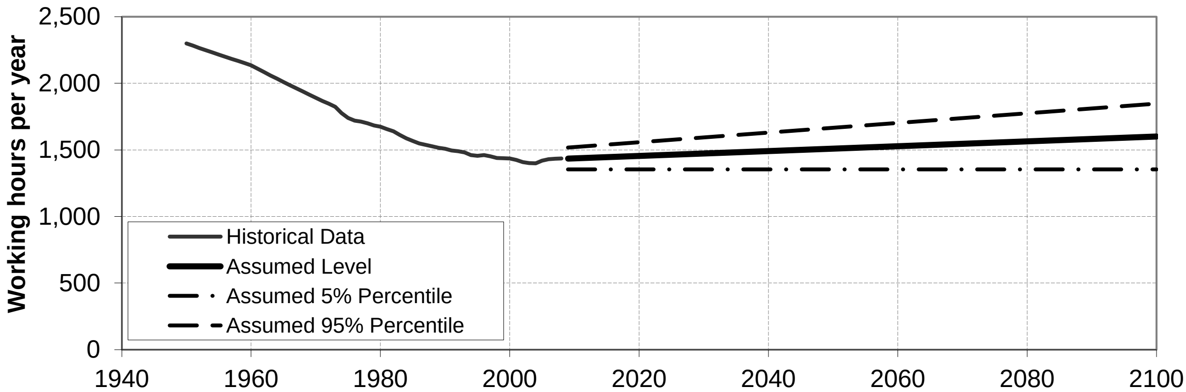
The development of a probabilistic GDP forecast requires insight in the development of labour participation, annual working hours, and GDP output per hour. Such insights would have ideally been based on expert judgement (see also Chapter 5). However, in order to avoid a lengthy discussion on the development of labour productivity, for which I proposed to adopt a different paradigm in Chapter 4; and because the primary aim was to show that it is possible to develop a very long term probabilistic forecast, rather than to come up with an optimal forecast; I decided to analyse the available statistical data and to use my own judgement as a substitute for a more formal approach in which expert judgement is applied.

Labour participation has increased considerably over the past 60 years, but at the same time the annual working hours have plunged. Given the already high level of labour participation I argued (on the basis of data available in the year 2010) that the labour participation rate is likely to remain more or less stable throughout the forecast period; and that there will be some pressure on working hours, due to the decreasing size of the working population and the reduced pace in the growth of labour productivity. For this reason I assumed the median estimate for the labour participation rate to remain constant at a level of 85%; and the related variance to be normal distributed with a standard deviation of 3% in 2009, increasing to 8% in 2100. In addition I assumed the annual number of working hours to increase slightly from 1435 hours in the year 2009 to 1600 hours in the year 2100; and the corresponding variance to follow a normal distribution with a standard deviation of 50 hours in the year 2009 that will increase to 150 hours in the year 2100. The applied assumptions on labour participation and annual working hours are indicated in Figure 7-13 and 7-14.



Source: Historical Data obtained from the (Dutch) Central Bureau of Statistics (www.cbs.nl) and The Conference Board (2009); Forecast based on my personal judgement.

Figure 7-13: Assumed Development of Labour Participation in the Netherlands

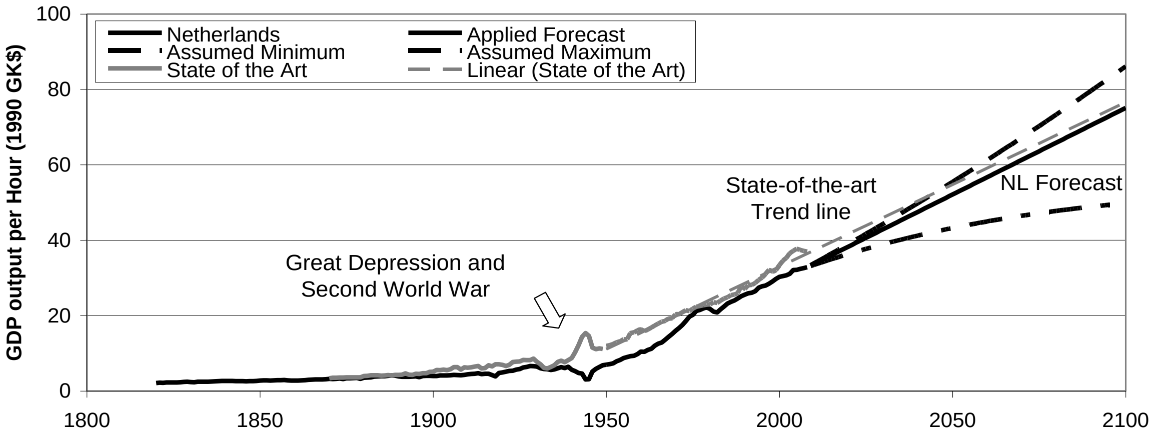


Source: Historical Data obtained from The Conference Board (2009); Forecast based on my personal judgement.

Figure 7-14: Assumed Development of Annual Working Hours per Worker

It is interesting to note that Euwals et al. (2014) recently published an official view on the development of labour participation and working hours up to the year 2060. They assume the labour participation rate of people in the age of 15 to 74 year to increase from 70.8% in the year 2013 to 74.7% in the year 2060; and in addition they expect the average working hours to decrease from 31.1 hours per week in the year 2013 to 30.3 hours per week in the year 2060[90]. I have compared the overall decrease in the total number of hours worked (for all workers combined) from the year 2013 to the year 2060 and found a slight decrease by 0.8% (measured over the entire period) for the median estimate and a comparable decrease by 0.5% for the estimate of Euwals et al. (2014). This implies that the total number of hours worked in the years 2013 and 2060 are expected to be almost similar; and that, despite the fact that I have applied different assumptions on labour participation and working hours, I still assume a very similar rate for the decrease in the total labour volume between 2013 and 2060.

Unlike labour participation and working hours, the development of labour productivity is not bounded by any known physical limits. This implies that differences in the applied view on the growth of labour productivity can potentially have a very large effect on the outcome of economic growth forecasts (see also Chapter 4). I based the GDP forecast on the development of the post Second World War trend (using data from the year 1950 onwards). The historical data and applied labour productivity assumptions are indicated in Figure 7-15.



Source: Historical Data has been obtained from Maddison (accessed: 2010) and The Conference Board (accessed: 2009); Forecast based on my personal judgement.

Figure 7-15: Assumed Development of Average Labour Productivity per Hour

The presented labour productivity data is stated in international 1990 GK$. The use of this monetary unit is not much different from the use of any other real monetary unit such as for instance Euros at constant year 2000 price levels. The 1990 GK$ values could have been converted into year 2000 Euros by applying a single conversion factor, but I did not found this necessary as the linear regression functions applied in the transport forecasts are based on the real GDP index (base year 2000 = 100) instead of the real GDP levels.

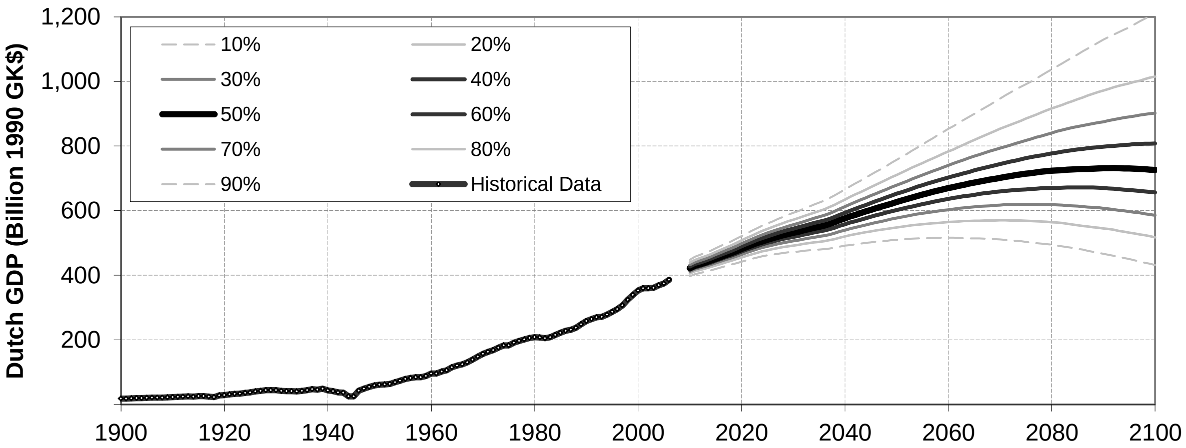
The grey line shows the historical development of the hourly labour productivity rate for the most productive country in the world. This line is referred to as the state-of-the-art trend line. The black line shows the development of labour productivity in the Netherlands. Both lines

[90] It should be noted that this concerns a working week, not an average week. In order to define the total working hours per year one should also know the average number of weeks that is worked, which has not been reported.

indicate a trend breach at the instance of the Second World War. The state-of-the-art trend line shows a strong linear trend since the early 1950s. From the end of the Second World War the Netherlands is performing quite well and slowly creeping towards the state-of-the-art trend line. In line with this observation I assumed that the Dutch GDP output per hour worked can be represented by a triangular distribution function of which the median estimate follows a linear extrapolation of the post war trend. The maximum is defined by a 15% increase imposed on the trend in 2100. This causes an upward shift of the state-of-the-art line. The minimum is defined by a 30% relapse from the long term trend in the year 2100. The downward risk is perceived larger than the upward risk as it is not difficult for a country to fall behind (the analysed data provided many examples of such behaviour) – and because, in line with the post-neo-classical economic growth paradigm, one can also expect diminishing returns on efforts to improve the state-of-the-art technology (see Chapter 4). A shift of the state-of-the-art trend line to a higher level is therefore considered less likely than a relapse.

From a theoretical point of view it would have been more appropriate to describe the labour productivity development by means of a logistical S-curve than by a linear trend, but I do not yet consider it possible to make a sound forecast of the S-curve that describes the very long term logistical trend (see Chapter 4). Since the desired forecast up to the year 2100 covers only a part of the S-curve of the Great Transition (that presumably lasts about 400 years), and because the world is now presumably somewhere in the linear middle section of this S-curve, I consider it more appropriate to base the median estimate on the linear post war trend than to fit it through a logistical (transition) S-curve. However, if one has to look much further ahead, it will become necessary to make assumptions on the shape of the logistical S-curve.

The GDP forecast was finally derived by multiplying the sampled values of the working age population by the sampled values for labour participation, average working hours, and GDP output per hour. The obtained probabilistic GDP forecast is shown in Figure 7-16.



Source: Historical Data obtained from Maddison (2010).

Figure 7-16: Probabilistic Forecast for the development of the Dutch GDP

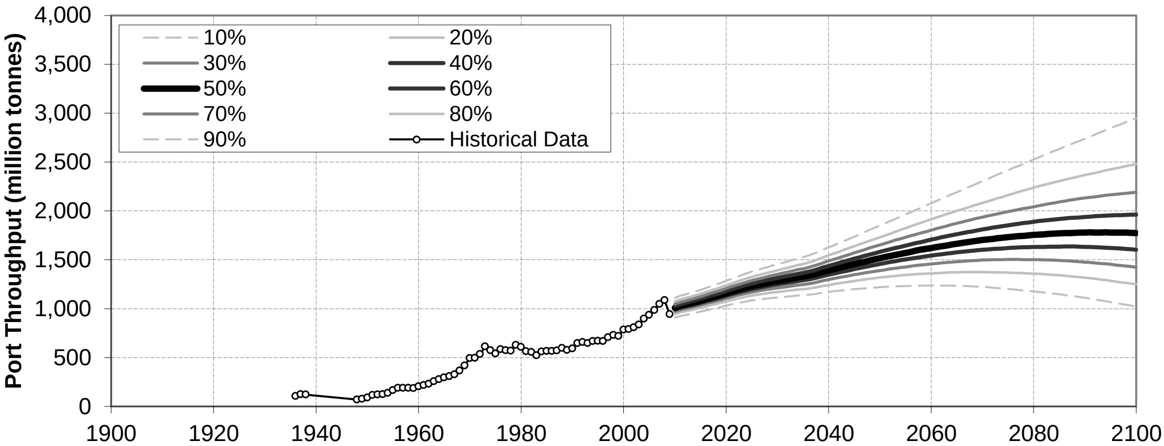
The median value of the GDP forecast indicates that economic growth is expected to slow down over the next two decades. This effect is mainly caused by the retirement of the baby boom generation. Economic growth is once again expected to pick up from about the year 2030 onwards, but further towards the end of the century the anticipated decrease in total population is likely to become an ever more dominant factor, that may eventually result in a reduction of economic growth and possibly even in a stabilising or decreasing GDP output.

7.6 The Final Probabilistic Transport Forecast

The last step is to obtain a final probabilistic transport forecast on the basis of the available GDP forecast and the applied causal GDP-transport relations. This section starts to address how the final probabilistic forecast for the LHR was derived; then presents the results of two similar forecasts for the development of the inland transport- and short sea shipping volumes in the Region (i.e. NL, GE, FR, BE, and LU); and finally shows how these three forecasts were combined into a single forecast for the development of the overall transport demand.

7.6.1 Obtaining a probabilistic forecast for the total port throughput volumes

The final probabilistic forecast of the total port throughput volumes in the LHR is obtained by combining the outcome of the forecasts based on Equation 7-1 and Equation 7-3. The first forecast, that is based on Equation 7-1 (long term levels approach), defines the expected port throughput levels directly on the basis of the GDP levels. For each year 10,000 simulations were made with the Excel add-on @Risk. In each simulation the GDP was drawn from the distribution function of the year under consideration. This value was then used in the stochastic causal relation between GDP and port throughput to obtain an estimate of the total port throughput volumes. Finally the outcome statistics were summarized in order to derive the final prediction intervals. The obtained results are indicated in Figure 7-17.

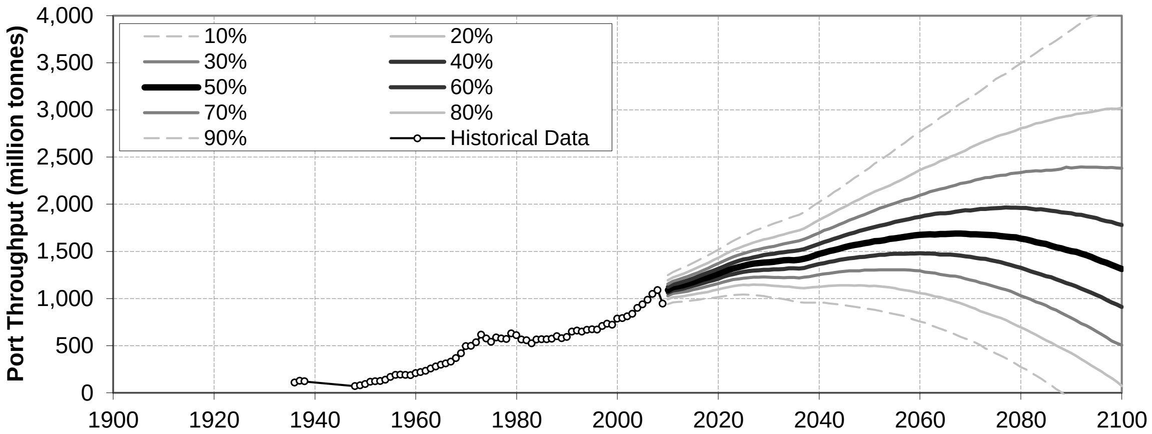


Source: Historical Data from Ports of Antwerp (1936-2007) and Rotterdam (2008, 2009).

Figure 7-17: Probabilistic Forecast based on the Levels Approach of Equation 7-1

The second forecast, that is based on Equation 7-3 (short term differences approach), uses an almost similar methodology as discussed for the levels approach. The only difference is that the forecast starts in a certain base year and that for each following year the differences are calculated and added to the previous year. The obtained results are indicated in Figure 7-18.

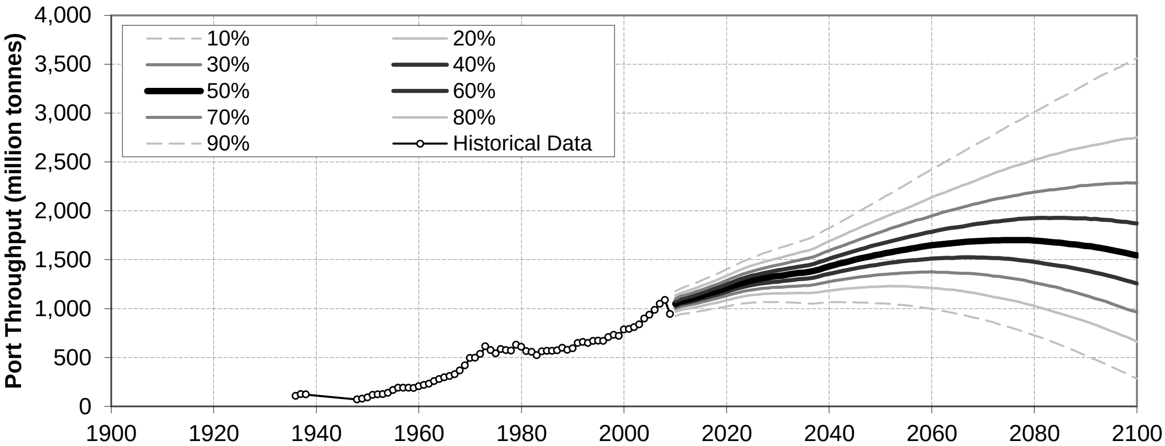
Due to the fact that the GDP estimate does not take into account economic cycles (it is based on future population and labour productivity assumptions), and the fact that the historical fit seemed to be almost perfect in the ex-post forecast, I do not expect the choice of the base year to be very decisive. The use of the year 2009 as base year resulted in a high forecasted GDP growth over 2010, that resulted in a high corresponding throughput growth over the year 2010. The bandwidth of the forecast indicates that the throughput volumes were at the high level of the 80% prediction interval in the year 2008 and dropped just below the 10% prediction interval in the year 2009, due to the recession that followed the financial crisis. It can therefore be concluded that the vertical position of the forecast seems to be reasonable.



Source: Historical Data from Ports of Antwerp (1936-2007) and Rotterdam (2008, 2009).

Figure 7-18: Probabilistic Forecast based on the Differences Approach of Equation 7-3

The final combined forecast was eventually derived by taking the averages of the prediction intervals of the levels- and differences approach. The obtained probabilistic forecast of the total port throughput volumes in the LHR is shown in Figure 7-19.



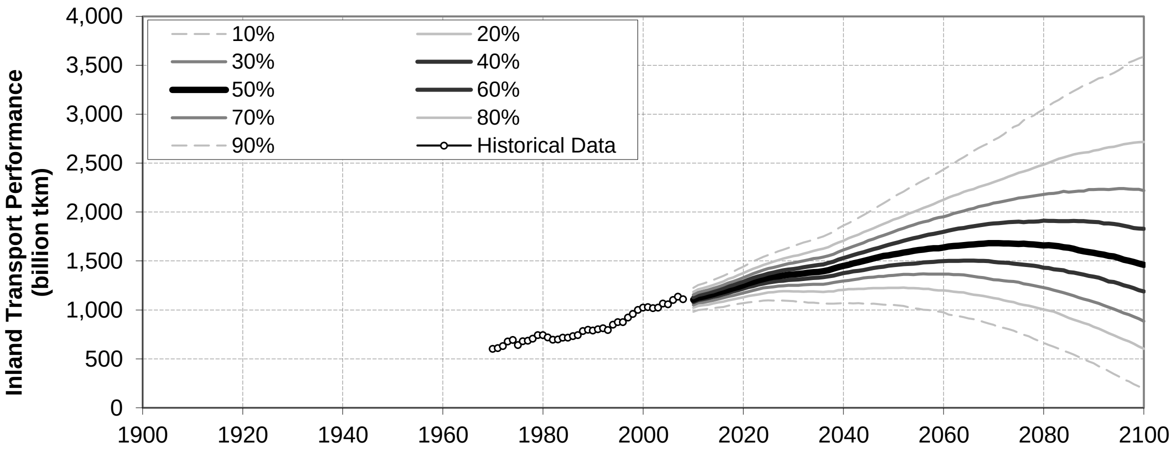
Source: Historical Data from Ports of Antwerp (1936-2007) and Rotterdam (2008, 2009).

Figure 7-19: Final Probabilistic Forecast of Total Port Throughput Volumes in LHR

The median value of the final forecast indicates that the total port throughput in the LHR is likely to increase up to about the year 2075 after which it will slowly stabilize and finally decrease. The reduced pace of growth between 2010 and 2030 is caused by the mass retirement of the baby boom generation. From about 2030 onwards the labour outflow stabilizes and both GDP and port throughput are expected to grow as a result of increased labour productivity. From about 2075 onwards the overall population decrease is expected to result in a stabilisation and possible decline of the GDP and port throughput volumes.

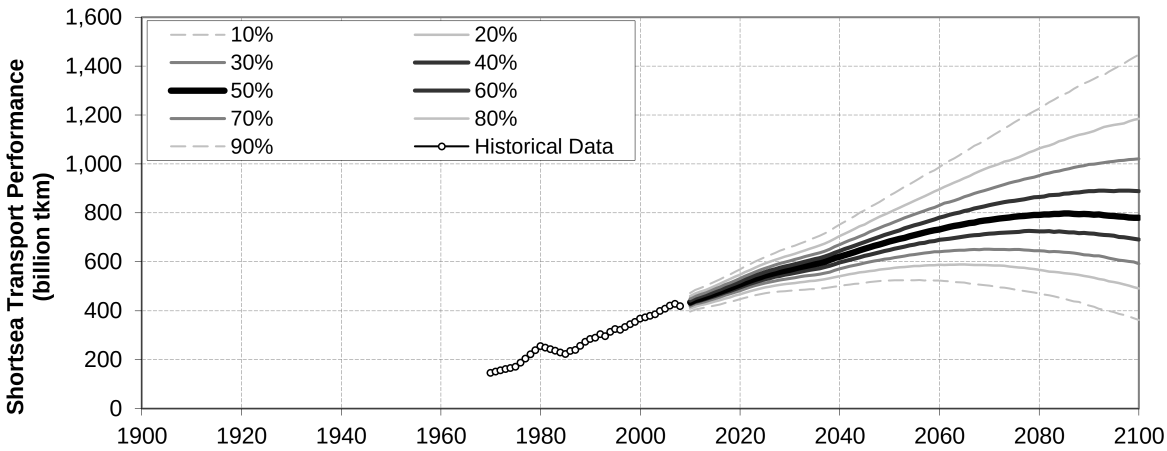
7.6.2 Additional forecasts for the inland transport- and short sea shipping volumes

Chapter 2 discussed that IWT flows can be categorised into port related-, continental-, and river-sea transport flows. Ideally one would like to develop a distinct forecast for each of these individual flows, but this approach is complicated by the fact that the available historical data is not structured according to these three categories, and that one also has to take the competitiveness of the various modes of transport into account (i.e. one has to define the modal split). A possible way to gain insight in the development of the different IWT flows is to develop a corresponding forecast for related subjects for which sufficient data is available. In this respect the port related IWT flows can be related to the development of the total port throughput; the continental IWT flows can be related to the development of the overall transport performance for the combined inland transport modes (i.e. road-, rail-, pipeline- and IWT); and the river-sea transport flows can be related to the development of short-sea shipping. I have therefore developed two additional probabilistic forecasts that address the development of the inland transport- and short sea shipping volumes in the Region. The outcome of these two additional forecasts is presented in Figure 7-20 and Figure 7-21.



Source: Historical Data from database presented in Appendix A.

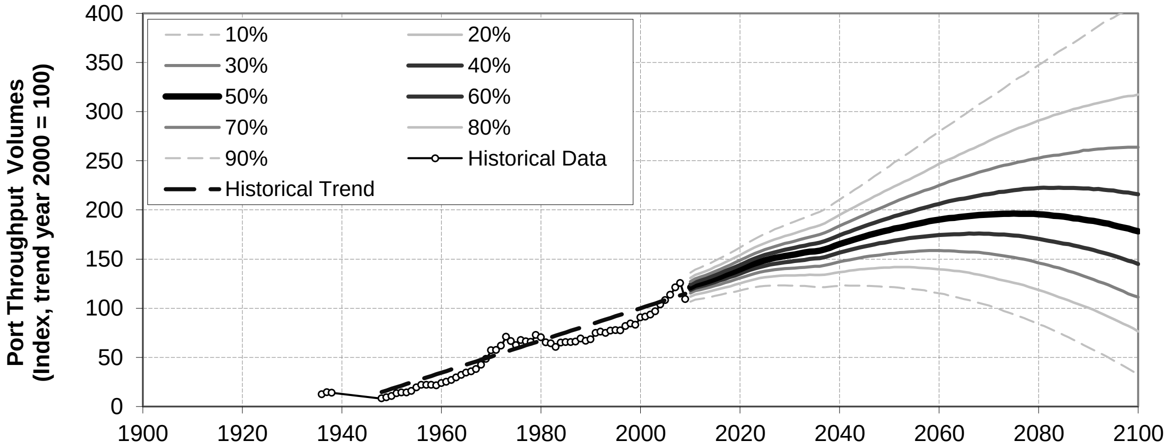
Figure 7-20: Probabilistic Forecast of Regional Inland Transport Volumes



Source: Historical Data from database presented in Appendix A.

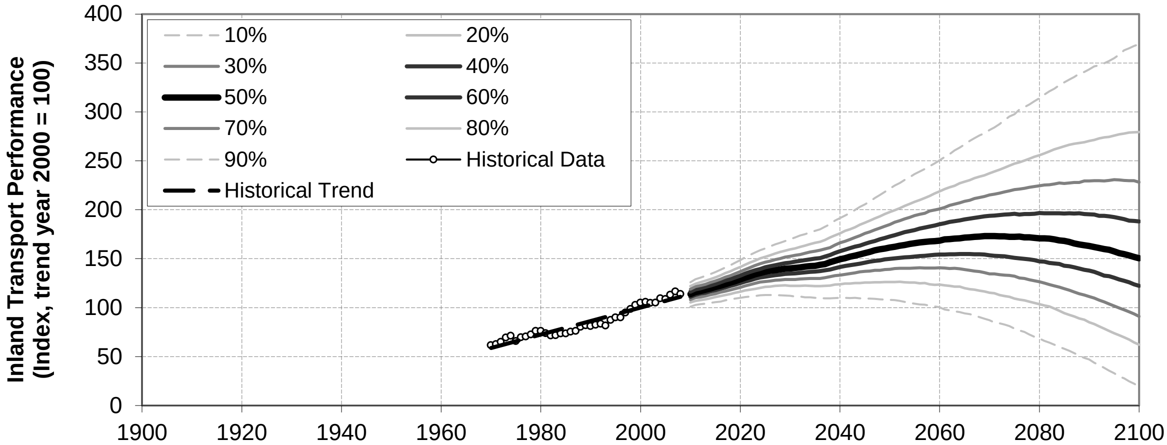
Figure 7-21: Probabilistic Forecast of Regional Short Sea Shipping Volumes

In order to compare the outcome of the three forecasts that have been presented in Figure 7-19 to Figure 7-21 I aimed to present the forecasts as an index of a certain base year, but this approach is somewhat complicated by the fact that the port data seems to be more affected by the long term Kondratieff waves than the inland transport data. For that reason I have first defined the long term trend, that is corrected for long term economic cycles; and then presented the outcome of the forecasts as an index of the base year 2000 value of this trend. The results of this exercise are indicated in Figure 7-22 to Figure 7-24.



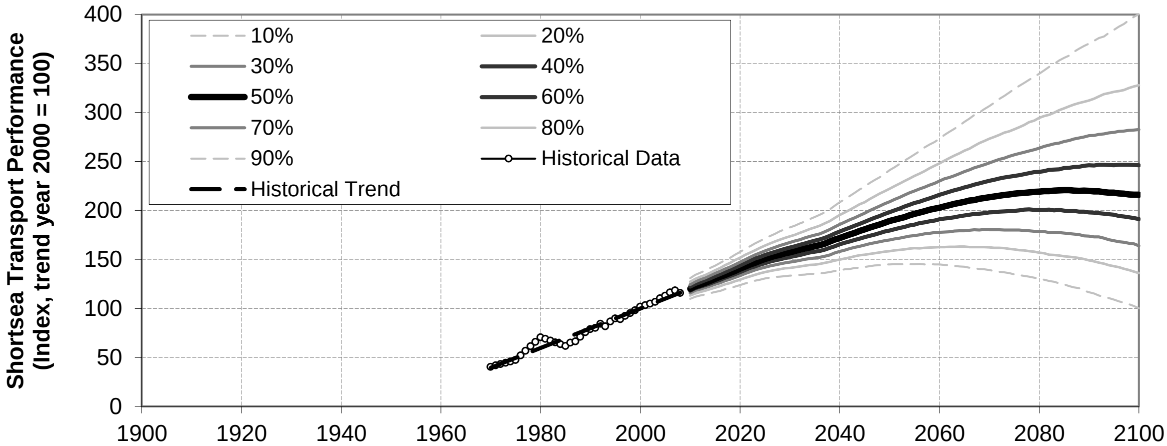
Source: Historical Data from Port Authority of Antwerp and Rotterdam.

Figure 7-22: Probabilistic Forecast of Port Throughput Volumes in the LHR



Source: Historical Data from database presented in Appendix A.

Figure 7-23: Probabilistic Forecast of Regional Inland Transport Volumes



Source: Historical Data from database presented in Appendix A.

Figure 7-24: Probabilistic Forecast of Regional Short Sea Shipping Volumes

From the adjusted figures one can observe that the different forecasts of the port throughput-, inland transport-, and short sea shipping volumes follow an almost similar trend throughout the forecast period up to the year 2100. They all seem to expect the transport volumes to remain growing at a reduced pace. I therefore conclude that the relative growth of transport volumes is quite similar in all three very long term transport forecasts.

7.6.3 Combining the three different forecasts into a single forecast

The relatively small differences between the three obtained probabilistic transport forecast for the total port throughput-, inland transport-, and short sea shipping volumes in the Region raises a question on the sensibility of using three different probabilistic forecasts as input for the modelling of the three different segments of the IWT system. I consider the differences in the obtained probabilistic forecasts too small (compared to the uncertainty levels that are related to the applied forecast methodology) to conclude that the forecasts really differ from each other. More likely, the use of three different forecasts would provide a false sense of accuracy. I have therefore combined all three abovementioned forecasts into one single forecast that reflects the development of the overall transport demand in the Region. This forecast is presented in Figure 7-25.

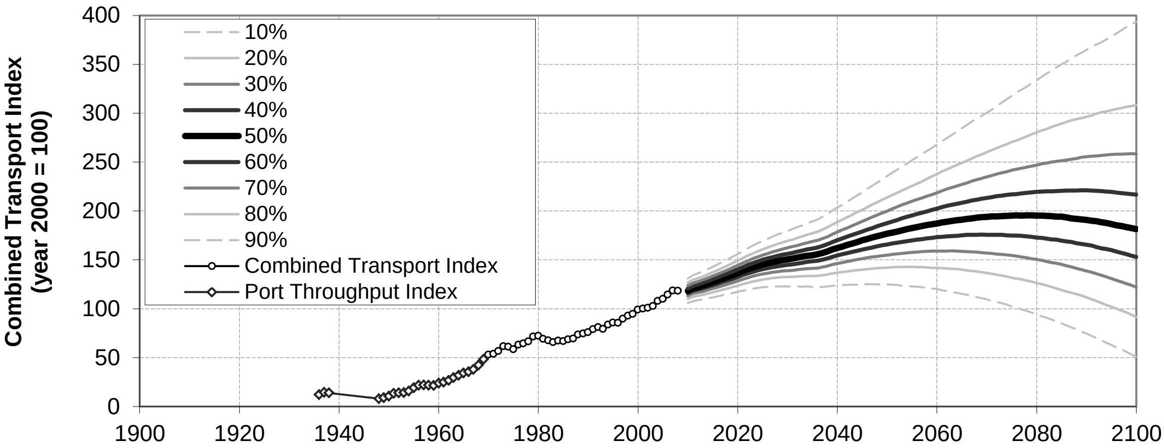


Figure 7-25: Probabilistic Forecast of the Overall Transport Demand in the Region

The output of the forecast is indicated by a combined transport index for which the base year 2000 value equals 100. The median value of this combined forecast for the overall transport demand in the Region shows that transport demand is likely to grow until about the year 2075 where it reaches a volume double the size of the year 2000, and that is likely to stabilise or even decrease thereafter. The low prediction intervals indicate a moderate increase of transport demand over the first half of the century, after which transport demand drops to levels comparable of those at the beginning of the 21st century or even below. The high prediction intervals reflect a continuation of the post war trend. They indicate that transport demand may increase by a factor 3 or even 4 throughout the 21st century.

7.7 Concluding Summary

This chapter addresses methodological sub question 2a (MSQ 2a): *"How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system"* of which the first driver has been identified as: *"the overall development of the demand for freight transport in the larger region covering the West European IWT system?"*. It shows how, in line with the earlier publication of Van Dorsser et al. (2012), a few very long term probabilistic forecasts for the overall transport demand were developed for a larger region, that is referred to as the 'Region' and consists of The Netherlands, Germany, France, Belgium, and Luxembourg. The discussion starts with a section on the applied methodology and concludes with the obtained forecast results.

7.7.1 The proposed forecast methodology

At the start of this PhD project a method for developing probabilistic very long term transport forecasts with a time span of almost 100 years did not yet exist. I have therefore developed a new probabilistic forecast method that is based on the existence of a strong causal relation between economic output and transport. This new method contains the following three steps: (1) apply system dynamics modelling to obtain a probabilistic forecast of the total- and working age population in the Region; (2) apply judgement to make probabilistic assumptions on the development of labour participation, annual working hours, and GDP output per worker – and use these assumptions to convert the probabilistic estimates of the working age population into a probabilistic GDP forecast for the Region; and (3) apply the causal GDP-transport relation to obtain a probabilistic transport forecast for the Region.

7.7.2 The applied GDP-transport relation

Prior to the development of the forecast an investigation was made into the causal relation between economic output (i.e. GDP) and transport. Historical data for the port throughput and inland transport volumes showed that the Regional GDP and transport levels followed a similar upward trend. However, the simultaneous upward movement of two trending time series does not necessarily imply that a real causal relation between these two variables exists. To make sure that the GDP-transport relation is real I studied the special case of Lithuania, for which the economy has been growing until the dissolution of the USSR in 1989, showed a decline thereafter, and recovered from 1995 onwards. The data for Lithuania showed a simultaneous movement of the GDP and transport variables along an up- and downward trend and therefore 'proved' that the causal relation between GDP and transport is real – and if this holds for the single country of Lithuania it is also likely to hold in general.

To investigate the predictive power of the GDP-transport relation the forecasts of three recent transport studies (i.e. the Dutch WLO study, the German federal study, and the EU TRANSvisions study; see also Chapter 3) were compared with the forecasts that could have been obtained by applying a simple one variable GDP-transport relation. Remarkably the projections obtained from the simple one variable GDP-transport relations closely matched the aggregated outcome of the scenario quantifications that were obtained from detailed transport forecast models. This implies that the aggregated results of detailed transport forecast models can also be obtained by applying a very simple one variable causal relation between economic output and freight transport.

The observation that aggregated transport forecasts can also be based on a simple one variable relation is at least surprising, as one would expect a model containing a number of explanatory variables, such as population, GDP, and trade volumes, to have a significantly higher explanatory power than a model with just one GDP variable. I have therefore looked for a clear explanation why this does not seem to be the case and came up with two possible explanations. The first explanation is that the effects of some main drivers, such as dematerialisation and globalisation, have worked in an opposite direction and therefore cancelled each other out, but given the very long term steady relation in the analysed data (of which the port throughput data goes back to the year 1936), it is very unlikely that the transport drivers have continuously cancelled each other out.

The second explanation concerns the near-linear dependency of the main transport drivers. Figure 7-4 shows that the various transport drivers, of which the closely linked ‘GDP’ and ‘international trade’ drivers are considered the most important ones, all seem to be highly interrelated. This emphasises that problems with near-linear dependency (or multicollinearity) can already be expected if more than one variable is applied.

The implication of near-linear dependant variables is that the corresponding multi-variable linear model will not be able to define the true value of its parameter coefficients. As long as the explanatory variables move along in the same direction the aggregated model output will still remain valid, but on the very long term the near-linear variables may start to follow a different path and the aggregated output of the model will then no longer remain valid. In order to deal with the problem of multicollinearity I have suggested to use only one of the two primary transport drivers in the forecast model, which implies that one should apply a forecast model that is either based on the level of GDP or on the level of the international trade volumes. For the development of aggregated very long term transport forecasts I considered the use the GDP variable the most logical option.

The GDP-transport relation is however expected to be affected by changes in the fuel- and the transport prices as well as by the effects of decoupling of economic output and freight transport. I have therefore studied both subjects and found that the effects of changing fuel- and transport prices on the overall level of transport demand should be regarded as a second order effect, that can be disregarded in the very long term transport forecast. Though the effects of decoupling were reported to be taken into account in the analysed transport scenarios of Chapter 3, none of the scenarios addressed the considerations on which the adjustments were based, nor the way that decoupling was taken into account in the forecasts. In my opinion decoupling should be related to the effects of dematerialization (i.e. less material used per unit of GDP output) and the effects of sustainable developments that counter the effects of globalisation. Both effects will somehow need to be taken into account in the very long term transport forecast.

Even for a simple one variable causal relation there still exist many possible mathematical equations. I have therefore studied the use of a linear forecast equation between: (1) the levels of GDP and transport; (2) the log-levels of GDP and transport; and (3) the annual differences in the levels of GDP and transport. The statistical properties indicate that the first two levels equations are likely to be misspecified. This implies that forecasts that are based on one of these two levels equations are likely to be sensitive to trend breaches of common drivers such as globalisation – and that the obtained prediction intervals will be too small as a result of the virtually high fit of the misspecified forecast equation. The third differences equation passed the statistical tests, but this equation has the disadvantage that it overestimates the effects of decoupling and violates the theoretical boundary condition that the transport volumes cannot become negative on the very long term. It should therefore be concluded that none of the analysed forecast equations performs fully satisfactory. However, given the importance of the subject and the fact that the causal relation ‘proved’ to be real for Lithuania I still considered it sensible to use at least one of these ‘bad’ equations for the development of the aggregated very long term transport forecast method.

I have therefore prepared an ex-post forecast to judge the quality of the linear forecast equations and select the best of these three ‘bad’ equations. This ex-post forecast assumed that someone back in the year 1970 had perfect foresight on the development of the GDP and was asked to develop a forecast of the port throughput volumes up to the year 2009 on the basis of post war data. The forecast results showed that the development of the port throughput volumes could have been almost perfectly predicted by the first and third forecast equation. For this reason I have based the very long term forecast on the average of these two equations. By combining both forecasts I have not only reduced the bias in the median value and variance of the forecast, but I also found an implicit way to take the effects of decoupling into account. Due to the fact that the first levels equation does not take the long term effects of decoupling into account, and the fact that the third differences equation overestimates the very long term effects of decoupling, a combination of both equations can be expected to address the effects of decoupling in an implicit way. Combining both equations therefore offers a provisional approach to deal with the effects of decoupling in very long term transport forecasts, but further research on this subject is nevertheless recommended.

7.7.3 The obtained very long term probabilistic GDP forecast

The development of a very long term probabilistic transport forecast requires input from a very long term probabilistic GDP forecast. However, apart from the fact that all known official very long term economic growth projections seem to be based on the mainstream paradigm of ongoing exponential growth (that was rejected in Chapter 4), it also appeared that no probabilistic long term GDP forecasts have been published yet, let alone probabilistic very long term GDP forecasts. I could not find one single probabilistic long term GDP forecast (not for the World, the United States, nor for Europe) and therefore decided to developed my own very long term probabilistic GDP forecast up to the year 2100 on the basis of a probabilistic forecast of the working age population and some additional assumptions on the development of labour participation, average working hours, and GDP output per hour. To avoid unnecessary complexity I assumed that it is possible to use the Dutch GDP index as an approximation for the Regional GDP index. This assumption is supported by very long historical time series that indicate the Dutch-, Belgium-, German-, and French GDP to have followed an almost identical trend over the past 110 years.

The first step in the development of the very long term GDP forecast for the Netherlands up to the year 2100 concerns the development of a very long term probabilistic forecast of the Dutch working age population. Preferably this forecast would have been obtained from the output of a system dynamics population model, but the output of such a model has not been reported for the very long time period up to the year 2100. I have therefore compiled a probabilistic population forecast out of two probabilistic estimates and one scenario study that were available for the development of the Dutch and West European population up to the years 2050 and 2100. In the next step I have made a number of probabilistic assumptions on the development of labour participation, average working hours, and GDP output per hour worked. These assumptions were based on the analysis of historical trends and the use of my personal judgement. The assumptions regarding the development of the average labour productivity rate were prepared in line with the post-neo-classical paradigm on economic growth (see Chapter 4), though it should be noted that the median estimate has been based on the linear post war trend instead of on a logistical S-curve. The use of this linear trend is justified by the fact that the forecast covers only a part of the S-curve of the Great Transition (that presumably lasts about 400 years), and because the world is now presumably somewhere in the linear middle section of this S-curve. The GDP forecast was finally derived by multiplying the sampled values of the working age population by the sampled values for labour participation, average working hours, and GDP output per hour. The obtained probabilistic GDP forecast is indicated in Figure 7-16.

7.7.4 The obtained very long term probabilistic transport forecasts

By applying the GDP-transport relations to the probabilistic GDP forecast I managed to obtain three probabilistic forecasts for the very long term development of: (1) the total port throughput volumes in the Le Havre – Hamburg range; (2) the total inland transport volumes in the Region; and (3) the total short sea shipping volumes in the Region. It was initially my intention to use these three different probabilistic forecasts as input for the modelling of three distinct IWT flows that have been defined in Chapter 2 (i.e. the port related-, continental-, and river sea IWT flows), but at second instance I considered the differences in the forecasts too small (compared to the uncertainty levels that are related to the applied forecast methodology) to conclude that the forecasts significantly differ from each other. I have therefore combined all three abovementioned forecasts into one single forecast that reflects on the development of the overall transport demand in the Region. This forecast is indicated in Figure 7-25.

The median value of the combined forecast for the overall transport demand in the Region shows that transport demand is likely to grow until about the year 2075 where it reaches a volume double the size of the year 2000, and that it is likely to stabilise or even decrease in the period thereafter. The low prediction intervals indicate a moderate increase of transport demand over the first half of the century, after which transport demand drops to levels comparable of those at the beginning of the 21st century or even below. The high prediction intervals indicate a continuation of the post war trend. They show that transport demand may also continue to grow by a factor 3 or even 4 throughout the 21st century.

7.7.5 Answer to Methodological Sub Question 2a

In answer to MSQ 2a, I conclude that insight in the very long term development of the overall transport demand in the Region (defined as: The Netherlands, Germany, France, Belgium, and Luxembourg) can be obtained by developing a probabilistic very long term transport forecast. The applied forecast method is based on the existence of a very strong causal relation between economic output and freight transport. It contains the following three steps: (1) obtain a probabilistic forecast of the total- and working age population (e.g. by applying system dynamics modelling); (2) obtain insight in the future development of labour participation, annual working hours, and GDP output per worker (e.g. by applying expert judgement) – and use these insights to convert the population forecast into a probabilistic GDP forecast; and (3) apply the GDP-transport relation to obtain a probabilistic transport forecast for the Region. The first two steps were necessary because: (1) all known official GDP scenarios are based on the mainstream paradigm that assumes labour productivity to remain growing at an exponential rate throughout the 21st century (as rejected in Chapter 4); and (2) because: to the best of my knowledge, very long term probabilistic GDP forecasts have not been published yet. I therefore had to develop my own GDP forecast prior to the development of the transport forecast. The obtained probabilistic transport forecast shows a continuous growth of the overall transport demand in the first half of the century, after which transport demand may either continue to grow, stabilise or decrease in the second half of the century. The 60% prediction interval shows a growth of the overall transport demand by a factor 1 to 3 over the 21st century. The 80% prediction interval shows a growth by a factor ½ to 4.

Literature:

Alho, J.M., and T. Nikander (2004) *Uncertain Population of Europe Summary Results from a Stochastic Forecast*, Deliverable 12 belonging to Work Package 6 of an EU 5th frame work funded research project Uncertain Population of Europe (UPE), HPSE-CT-2001-00095.

Armstrong, J.S, ed. (2001) *Principles of Forecasting: A Handbook for Researchers and Practioners*, Kluwer Academic Publishers, Boston/Dordrecht/London.

De Jong, A. (2008) *Vier scenario's voor de zeer lange termijn*, Bevolkingstrends, Quarter 4, Centraal Bureau voor de Statistiek.

De Wit and Van Gent (2001) *Economie en Transport*, Lemma B.V., Utrecht.

Dings, J.M.W., B.A. Leurs, M.J. Blom, S.A. Rienstra, E.H. Buckmann, H.W.J. van Haselen and L.M. Bus (1999a) *Prijselasticiteiten in het goederenwegvervoer – Hoofdrapport*, CE Delft, NEI Transport.

Dings, J.M.W., B.A. Leurs, M.J. Blom, S.A. Rienstra, E.H. Buckmann, H.W.J. van Haselen and L.M. Bus (1999b) *Prijselasticiteiten in het goederenwegvervoer – Achtergrond-rapportage*, CE Delft, NEI Transport.

Euwals, R, M. de Graaf-Zijl, A. den Ouden (2014) *Arbeidsaanbod tot 2060*, CPB, Den Haag.

Feige, I. (2007) *Transport, Trade and Economic Growth – Coupled or Decoupled?*, Springer, Berlin, Germany.

Geileinkirchen, G., K. Geurs, and B. van Wee (2010) *Prijsbeleid in verkeer en vervoer*. In: Van Wee, B. en J.A. Annema (eds.), *Verkeer en vervoer in hoofdlijnen. Capita selecta*. Bussum: Coutinho. http://www.coutinho.nl/subsites/verkeer/verkeer-capita-selecta/?PHPSESSID=8699a3ca3dh30pusat2aakp836, accessed: 27 August 2014.

Granger, C.W.J., and P. Newbold (1974) *Spurious Regression in Econometrics*, Journal of Econometrics, vol. 28, no. 1, pp. 3-22.

Ickert, L., U. Matthes, S. Rommerskirchen, E. Weyand, M. Schlesinger, J. Limbers (2007) *Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050*, ProgTrans AG.

Janssen, L.H.J.M., V.R. Okker, and J. Schuur (2006a) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040*, Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau, www.welvaartenleefomgeving.nl/pdf_files/WLO_hoofddocument.pdf

Janssen, L.H.J.M., V.R. Okker, and J. Schuur (2006b) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040; Achtergronddocument*, Centraal Planbureau, Milieu- en Natuurplanbureau en Ruimtelijk Planbureau, www.welvaartenleefomgeving.nl/pdf_files/WLO_achtergronddocument.pdf

Krail M., W. Schade, D. Fiorello, F. Fermi, A. Martino, P. Christidis, B. Schade, J. Purwanto, N. Helfrich, A. Scholz, M. Kraft (2007) *Outlook for Global Transport and Energy Demand*. Deliverable 3 of TRIAS (Sustainable Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Maibach, M., C. Schreyer, D. Sutter, H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten, C. Doll, B. Pawlowska, and M. Bak (2008) *Handbook on estimation of external costs in the transport sector, Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT)*, CE Delft, Delft.

Meersman, H., and E. Van de Voorde (2008) *The Relationship between Economic Activity and Freight Transport*, in Ben-Akiva, M., Meersman, H. and Van de Voorde, E. (ed) Recent Developments in Transport Modelling, Lessons for the Freight Sector, Emerald, UK.

Montgomery, D.C., and R.G. Askin (1981) *Problems of Nonnormality and Multicollinearity for Forecasting Methods Based on Least Squares*, A I I E Transactions, vol. 12, no. 2, pp. 102-105.

Oosterhaven, J. and P. Rietveld (2003) *Transportkosten, Locatie en Economie*, KVS paper, http://www.rug.nl/staff/j.oosterhaven/kvs_paper.pdf.

Petersen, M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, A. Ulied (2009) *Report on Transport Scenarios with a 20 and 40 year Horizon*, Final Report, Funded by DG TREN, Copenhagen, Denmark.

Pindyck, R.S., and D.L. Rubinfeld (1998) *Econometric Models and Economic Forecasts*, Irwin McGraw-Hill, Boston.

Ricardo (1817) *On the Principles of Political Economy and Taxation*. London.

Schade W, D. Fiorello, J. Köhler, M. Krail, A. Martino, B. Schade, T. Wiesenthal (2008) *Final Report of the TRIAS Project: SIA of Strategies Integrating Transport, Technology and Energy Scenarios.* Deliverable 5of TRIAS (Sustainable Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Van Dorsser, J.C.M., and M.A. Wolters (2010) *A Very Long Term Forecast for the development of the Cargo Flows in the le-Havre – Hamburg range*, Port Infrastructure Seminar 2010, TU-Delft, Delft, 22 and 23 June 2010. http://www.citg.tudelft.nl/en/about-faculty/departments/hydraulic-engineering/hydraulic-engineering-section/chairs/chair-ports-and-waterways/port-seminar-2010/papers-and-presentations/.

Van Dorsser, J.C.M., M.A. Wolters, and B. van Wee (2012) *A Very Long Term Forecast of the Port Throughput in the le-Havre – Hamburg range up to 2100*, European Journal of Transport and Infrastructure Research, vol. 12, no. 1, pp. 88-110. http://www.ejtir.tbm.tudelft.nl/issues/2012_01/pdf/2012_01_03.pdf.

Websites:

CBS (accessed: 2010) *Historical Data on Population of Age 20-65*, [www.cbs.nl]

IIASA (accessed: 2009) *IIASA's World Population Program,* [www.iiasa.ac.at/research/pop]

Maddison (accessed: 2010) *Historical Data on Population and GDP*, [www.ggdc.net /Maddison]

Rotterdam Port Authority (accessed: 2010) *Historical Data on Port Throughput in the le-Havre – Hamburg range*, [www.portofrotterdam.com]

The Conference Board (accessed: 2009). *Total Economy Database.xls*, [http://www.conferenceboard.org/economics/database.cfm]

Wikipedia (accessed: 2011) *Discussion on Multicollinearity*, [http://en.wikipedia.org/wiki/Multicollinearity]

8 Development of Transport Infrastructure

"Most of the EU's future transport infrastructure is already in place, or is at least in the planning stage. Road networks, rail networks, airports, ports have been constructed over a long period in history, and this infrastructure will also in the future provide the backbone for transport services."
- Petersen et al. (TRANSvisions final report, 2009, p.48)

8.1 Introduction

This chapter addresses methodological sub question 2b (MSQ 2b): *"How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system"* of which the second driver has been identified as: *"the possible rise of new infrastructures and their implications for the IWT system as well as the anticipated development of the IWT system itself?"*. It starts with a discussion on the emergence of new infrastructure networks; continues with a discussion on the development of intermodal transport networks; and concludes with a discussion on the possible upgrades and expansions of the European IWT network.

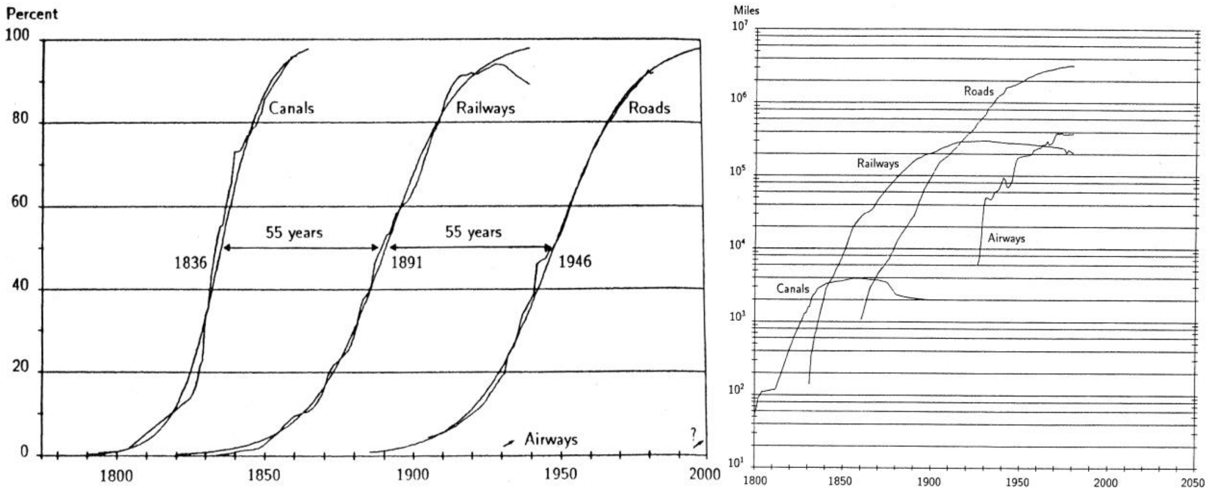
Section 8.2 investigates the possible development of new transport infrastructure networks. It shows that the development of transport infrastructure networks can be related to the pervasive socio-techno-economic drivers of the very long economic Kondratieff waves (see Chapter 4) – and that insight in the possible development of new transport infrastructure networks can be obtained from analysing the emerging drivers of the present Kondratieff wave. On the basis of this analysis I conclude that a new intermodal transport infrastructure network is now emerging. Section 8.3 addresses the intermodal transport revolution that is nowadays taking place on the inland waterways. In analogy with other infrastructure networks the full development of this intermodal transport network is assumed to last about 100 years. Throughout this period from about 1970 to about 2070 the IWT network has gone through and will presumably continue to go through the following four stages: (1) *the development of the first container terminals in the hinterland*, (2) *the mushrooming of inland terminals*, (3) *the development of continental container transport*, and (4) *the development of intermodal pallet distribution networks*. The first two stages are already reaching completion. The world is now, in the second decade of the 21st century, standing at the eve of the third and fourth stage development, of which the perceived effects are discussed in Section 8.4 and 8.5. The renewed interest for intermodal IWT transport may also trigger a revitalisation and further upgrade of the European IWT network. Section 8.6 therefore addresses the possible future expansions of the European IWT network as well as their perceived impacts on the Dutch IWT network. Section 8.7 finally contains a concluding summary that provides an answer to MSQ 2b.

8.2 Evolution of Transport Infrastructure Networks

The past two centuries gave birth to at least four different infrastructure networks (i.e. canals, railways, roads, and airways). It is therefore not unlikely that one or two new infrastructure networks will evolve over the next 100 years. This section addresses the evolution of new transport infrastructure networks and identifies the possible new transport networks that may be developed in the course of the 21st century.

8.2.1 The development of new transport infrastructure networks

Grübler (1990) identified clear patterns in the development of infrastructure networks for the USA, Canada, USSR, France, and Germany. Following an analysis of the development of the canals, railways, and roads system in the USA he concluded that: *"The midpoints between the individual infrastructure growth pulses (i.e., the time of their maximum growth rate) are spaced 55 years, as are their periods of saturation. It is remarkable that the saturation and onset of decline of all three infrastructures coincides with prolonged economic recessions (i.e., in the 1870s, 1930s, and 1980s). At the same time these periods of structural discontinuity see the emergence of new transport systems: surfaced roads around 1870 and air transport in the 1930s"* (p.187). The 55 years period between the midpoints of the individual infrastructure developments is indicated in Figure 8-1 (left).



Source: Grübler (1990, p.186-187).

Figure 8-1: Development of Transport Infrastructure Networks in the USA

Grübler (1990) showed that the 55 years intermediate periods can be related to the very long economic Kondratieff waves and their primary socio-techno-economic drivers (see Chapter 4). He refers to these drivers as *'clusters of pervasive technologies'* and indicates that the full development of these drivers takes place over a period of two subsequent Kondratieff waves.

Table 8-1 lists the various clusters of pervasive technologies that came with the first five Kondratieff waves. A comparison of Figure 8-1 with Table 8-1 shows that the first part of the n^{th} infrastructure S-curve (up to the inflection point) coincides with the emerging technologies of the n^{th} Kondratieff wave while the second part of the n^{th} infrastructure S-curve (beyond the inflection point) coincides with the dominating technologies of the $n+1^{th}$ Kondratieff wave. This interesting observation enabled me to identify likely future infrastructure developments by looking at today's emerging clusters of pervasive technologies.

Table 8-1: Clusters of Pervasive Technologies

Kondratieff Timeframe	**1st Wave 1764-1825**	**2nd Wave 1825-1872**	**3rd Wave 1872-1929**	**4th Wave 1929-1973**	**5th Wave 1973-2020**
Dominating technologies of indicated cycle	Water Power, Sails, Canals, Turnpikes, Iron Casting, Textiles	Coal, Iron, Steam Power, Mechanical Equipment	Railways, Steam Ships, Steel, Heavy Industry, Dyestuff, Telegraph	Electric Power, Oil, Cars, Radio, TV, Durables, Petrochemicals	Gas, Nuclear, Aircraft, Telecom-munication, Information, Photo-Electron
Emerging technologies of next cycle	Mechanical Equipment, Coal, Stationary Steam Power	Steel, City Gas, Indigo, Telegraph, Railways	Electricity, Cars, Trucks, Roads, Oil, Radio, Phone, Petrochemicals	Nuclear, Computers, Gas, Telecom-munication, Aircraft	Biotechnology Artificial Intelligence, Space Industry & Transport
Principal drivers	Manufacturing	Industrial production	Standardization	Ford-Taylorism	Quality Control

Source: Grübler (1990, p.260) adopted the Table from Pry (1988), adjusted timeframe.

Grübler (1990, p.185-186) made another interesting observation with respect to the size of the transport infrastructure networks as he noticed that: *"The length of all four transport infrastructures has increased five orders of magnitude since 1800. Each successive transport infrastructure expanded into a network ten times larger than the previous one. In addition it is interesting to note that, measured by length, new infrastructures overtook existing ones only at the time the latter started saturating. This was the case with canals and railways in the 1840s, and also with railways and surfaced roads prior to the 1920s. Based on this historical pattern, one would expect airways to become a dominant transport infrastructure only after the expansion of the road network is completed".* New infrastructure networks can therefore be expected to become an order of magnitude larger than the ones that preceded them. I will refer to this empirical observation as *'the order of magnitude law'* of Grübler.

The growth by a factor 10 is of course not a strict boundary condition for the development of new transport infrastructure networks, but there is a good reason why it seems to apply to every new infrastructure network development. Transport infrastructure networks have been developed in conjunction with the main drivers of the very long term Kondratieff waves (see Chapter 4). At the end of each Kondratieff wave the corresponding socio-techno-economic paradigm, that has led to the previous upswing phase, reaches the limits of its social acceptability and environmental compatibility. The dominating transport system then also becomes increasingly unable to deal with the challenges that it is confronted with, which are generally related to the capacity of the system. To solve these issues it is not sufficient to provide more of the same infrastructure (e.g. an additional lane on the highway). An order of magnitude improvement of the transport system is required to support the expansion period of the next Kondratieff wave. New transport infrastructure networks are therefore likely to be an order of magnitude larger (or better in some other perspective) than their predecessor.

Figure 8-1 (right) shows the length of the infrastructure networks in the USA on a logarithmic scale. It provides insight in the development of the national canal-, railway- and road-networks, that were established in an age with a predominant national focus. It is uncertain if the length of the airways infrastructure in the USA will finally become an order of magnitude larger than the road network, but air transport is an international affair. When including air transport the comparison should be made on a global scale.

8.2.2 Updated views on Kondratieff waves and clusters of pervasive technologies

The observed relation between Kondratieff waves, clusters of pervasive technologies, and the development of new transport infrastructure networks can be used to obtain important insights in the main drivers of future infrastructure network developments. However, the list of drivers indicated in Table 8-1 is over 25 years old. It provides almost no information on the principal drivers of the 4th and 5th infrastructure networks, that are indicated by the *'airways'* and *'?'* arrows in Figure 8-1 (left). Table 8-2 therefore provides an update of the description of the clusters of pervasive technologies. The presented insights are based on my personal views, that were shaped during the execution of this PhD project. A further improved version of this table can be obtained by conducting expert sessions (as discussed in Chapter 5), but I will leave this for further research and consider my own views sufficient for addressing the expected infrastructure developments in this thesis.

Table 8-2: Clusters of Pervasive Technologies – Updated Version

Kondratieff Timeframe	**4th Wave 1929-1973**	**5th Wave 1973-2020**	**6th Wave 2020-2070**	**7th Wave 2070-2120**
Dominating technologies of indicated cycle	Electric Power, Oil, Cars, Radio, TV, Durables, Petrochemicals, Welding, Pipelines	Global Transport Systems, Mobile Phone, Internet, Social Media, Materials Science, Biotechnology	Recycling, Cradle to Cradle, Renewable Energy, Fully Integrated Systems, Smart grids, Intermodal Transport	New social standards and redistribution of wealth, Local bio-based manufacturing, 3D-printing with recyclable materials
Emerging technologies of next cycle	Bulk Carriers, Containers, Container Vessels, Aircraft, Computers, Electronic Data Interchange, Space Flight, Telecommunication	Recycling, Cradle to Cradle, Renewable Energy, Smart Grids, Integrated Systems, Smart Customised Solutions, Intermodality	Self-Sustainability, Local Production, Bio Based Materials, Decoupling of Economic Output, Wealth and Transport, 3D-Printer	Human Well-Being and Recovery of Ecosystems
Principal drivers	Ford-Taylorism	Globalisation	Sustainability	Quality of life

Source: Grübler (1990, p.260), updated and extended on the basis of my personal views.

In line with the discussion in Chapter 4, I consider the principal drivers of the 5th and 6th Kondratieff wave to be related to *'Globalisation'* and *'Sustainability'*. The globalisation wave developed around a large number of pervasive technologies in the field of transport and communication. Passenger transport made a quantum leap with the development of the airliners. Goods transport boomed after (amongst others) the welding process was introduced to ship building during the Second World War. Welding allowed for the rapid construction of large seagoing vessels. The invention of the container further revolutionised freight transport and allowed for the development of global production facilities. Global production and transport was further supported by the development of the computer and advanced means of communication such as the telephone and electronic data interchange.

The increased means of communication resulted in the development of a fully connected global society by the end of the 5th Kondratieff wave. This global society is however still driven by unsustainable materialistic economic growth based on economies of scale, mass production, exploitation of resources and ecosystems, and finally debt funded consumption and government spending (see also Jackson, 2010). The disruptive (year 2009) crisis at the end of this wave now forces the world to become more sustainable. During the 6th Kondratieff wave the dominant technological development is likely to focus on renewable energy and recycling of materials (see also to the discussion at the end of Section 4.4.5). Governments and private enterprises are forced to increase social responsibility and become more transparent. This enhances sustainable principles such as intermodal transport and cradle-to-cradle design. Problems with the robustness of large integrated systems (such as the banking system) are likely to shift the balance somewhat back (but not completely) from global economies of scale towards more self-sustainability and independent local solutions.

In order to anticipate the dominating technologies of the 7th Kondratieff wave one has to identify the emerging pervasive technologies of the 6th Kondratieff wave. It is still too early to state, with certainty, which of today's new technologies will successfully emerge during the 6th Kondratieff wave, but some possible candidates may already be identified. The emerging pervasive technologies of the 6th Kondratieff wave may for instance be related to self-sustainability and local production with bio-based and/or recycled materials. In addition I can imagine the ongoing efficiency gains stemming from increased labour productivity to enhance social dissatisfaction with unequal wealth distribution, in particular when taking into account the increased transparency levels that raise public awareness on the subject. The next major crisis, that I presume to take place in the second half of this century, may therefore be caused by social unrest stemming from unequal wealth distribution. Finally, by the end of the 21st century the world may start to worry about the substantial ecological damage that was caused during the three preceding centuries of industrial expansion (i.e. the years 1800 to 2100). The focus may then shift to the recovery of ecosystems and improvement of the true *'quality of life'*, but these developments are of course still very uncertain.

On the basis of the updated views presented in Table 8-2 it becomes possible to identify new transport infrastructure networks that can be expected to arise during the 21st century – and may affect the competitive position of IWT in the overall transport system.

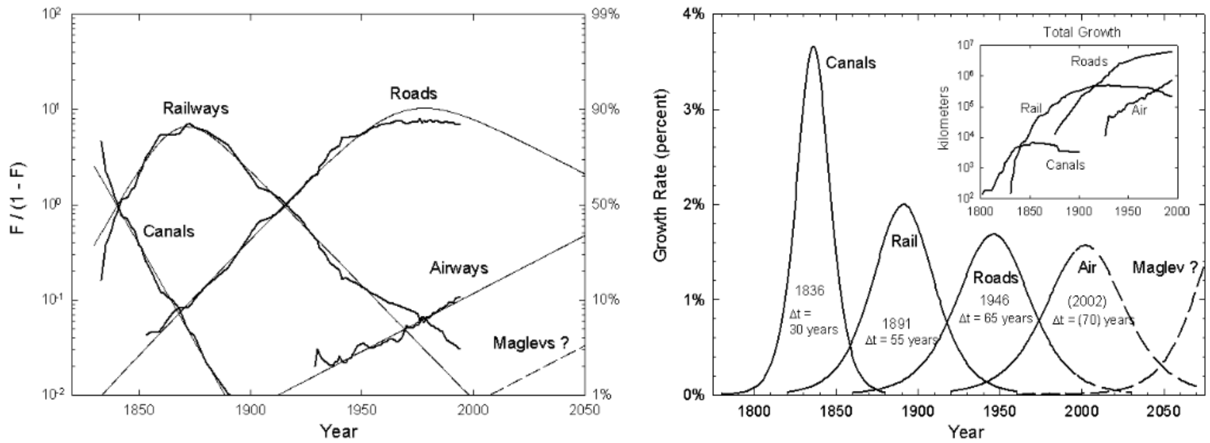
8.2.3 The fourth, fifth, and sixth infrastructure network

The updated views on the development of the 4th ,5th , 6th, and 7th Kondratieff wave allowed me to reconsider the true identity of the 4th (*'airways'*) and 5th (*'?'*) infrastructure network and to start thinking about the developments beyond the question mark. Grübler identified airways as the new predominant infrastructure network for the USA. I argue that the globalisation wave has resulted in the development of two distinct infrastructure networks. Airways provide the means for passengers to move cheaply and quickly all over the globe, but in general only a very small fraction of freight transport is shipped by air. For freight transport it are the motorways of the sea that, in combination with the development of the container and large efficient ships, provide the main transport means. On a global scale these networks are likely to follow Grübler's *'order of magnitude law'*. This implies that both networks are likely to become roughly about ten times larger than the road transport network[91].

Interesting is also to notice that the air and sea transport networks no longer rely on the construction of infrastructure links (transport lanes). They only require the construction of infrastructure nodes (airports and seaports). Taking into account the fact that the 5th network (indicated with a question mark) would, according to Grübler's *'order of magnitude law'*, be

[91] The length of the seaway network is not easy to define as clearly as the other networks, but for sake of the discussion in this section it can for instance be thought of as the sum of the individual distances between the ports that are connected on a regular basis by at least one seagoing vessel.

another ten times larger than the air transport network, it is very unlikely that such a network will be developed in a similar space intense way as its ancestors (canals, railways, and roads). New types of space intensive infrastructures, such as underground transport systems, should therefore be regarded as local transport solutions. Let's now reconsider the meaning of the question mark in Figure 8-1. Some scientists like Geerlings (1998) and Ausubel et al. (1998) discussed the possibility that Maglevs (high speed monorails) become the new transport infrastructure network for the 21st century. Their views are indicated in Figure 8-2.



Source: Ausubel et al. (1998), obtained from http://phe.rockefeller.edu/green_mobility/.

Figure 8-2: Updated Figure on development of Infrastructure Networks for the USA

When considering Maglevs as the new major infrastructure network two important questions should be raised. The first question relates to the size of the infrastructure network. According to Grübler's *'order of magnitude law'* each new infrastructure network is about ten times larger than its predecessor. If I would apply this 'law' in its strictest sense I could argue that it is impossible for a new physical infrastructure system to provide a network that is about 100 times larger than the existing road network. In reality this factor 100 is of course not a strict requirement, but the solution offered by the new transport network should offer an order of magnitude improvement compared to the present system. Considering the fact that the air- and seaway networks already avoided the construction of physical infrastructure lanes, I do not consider it very likely that a new order of magnitude improvement of the transport system can be provided by space intensive Maglevs (that require the construction of monorail infrastructures). I would regard high speed monorail solutions as an upgrade of the existing rail transport system rather than a new transport infrastructure network.

The second question relates to the phasing of the Maglev system. On the basis of the 55 years intermediate periods, which are related to the Kondratieff waves, the new system should be expected to reach its maximum growth rate around the year 2057, or even earlier when considering a shorter Kondratieff wave of about 45 years (see Chapter 4). Figure 8-2 (right) shows that the maximum growth rate will probably be reached around the year 2100 (some 40 to 50 years too late). Given the fact that the airways (and seaways) have presumably reached their maximum growth rate around the year 2000[92], and the fact that a new system generally

[92] This can be expected on the basis of the historical pattern, but I lack data to verify this assumption.

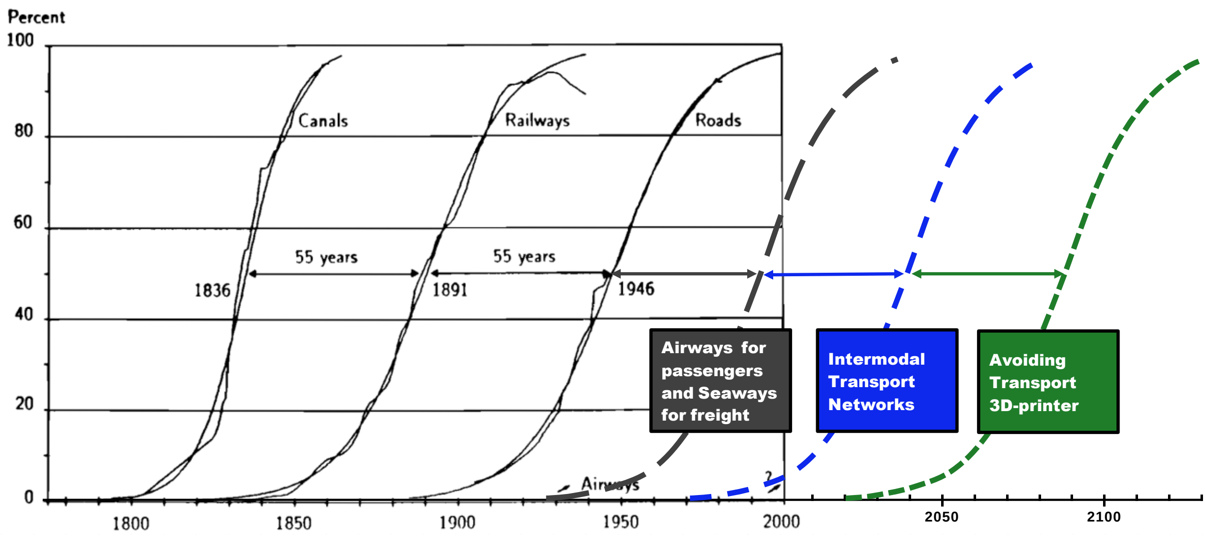
arises before the inflection point of the previous S-curve, evidence of a new system should already be in place. Question: '*Has a complete new infrastructure network been overlooked?'*.

I think the answer to this question is yes! Nowadays a new transport infrastructure network is developing around the principles of intermodality, that can be applied to both passenger and freight transport. The development of the intermodal freight transport network started with the introduction of the first container line in 1956. The timing of this development is much more in line with the timing that I would expect from the historical pattern – and similar to the sea- and air transport networks, the intermodal transport network does also not require the construction of physical transport lanes. It are the different transport options that increase by a tenfold this time. The use of more than one mode of transport is also observed in passenger transport, as travellers are nowadays stimulated to use the best suitable combination of transport means, which is referred to as synchro-modality.

Having discussed the true meaning of the *'?'* it is now time to look even farther ahead. Is it possible to say something about the developments beyond the question mark? The answer is probably yes! The general trend over the past 200 years has been related to a general improvement in connectivity and this trend will probably continue for yet another 100 years. By the end of the 21st century everyone and everything on earth is likely to be connected. One may then enter a stage of intergalactic traveling and space colonisation, but this is still science fiction and may not even be possible. Smart intermodal transport networks could therefore very well represent one of the last physical transport network developments. The only thing that I can possibly think of thereafter is *'teleportation'* (refer to *"Beam me up Scotty"* as applied in science fiction series like Star Trek).

I question the physical possibility of teleportation, but to some extend it is possible to identify techniques that may have a similar effect. Modern communication techniques are increasingly used to stimulate travellers *'not to move at all'*. They provide possibilities for work and leisure at home! In line with the developments in passenger transport a similar trend can also be expected for freight transport. First of all there is the effect of dematerialisation. Instead of sending music disks all over the world they can now be downloaded digitally from the internet. In a similar way electronic books can be ordered from the internet without any physical movements involved. Digital services are literary *'beamed up'* over the internet. In the future this may also hold for physical goods that are printed by a 3D-printer. Of course the *'cartridges'* will still need to be transported, but it may become possible to produce them locally (e.g. by using bio-based production and/or advanced recycling techniques). Finally the energy system may completely change into smart grids requiring less physical transport of fossil fuels. The final transport infrastructure network development is therefore likely to be related to *'avoiding transport'* or *'not transporting at all'*.

Figure 8-3 provides a plausible scenario for the overall development of the earth-based transport infrastructure networks, that will be adopted as a conceptual framework for the development of the very long term shipping scenarios in Chapter 13 and 14. It should however be emphasised that the presented timeframe is no more than an assumption. The precise timing of technological S-curves cannot be forecasted with any reasonable accuracy unless they have well passed their inflection point, which is not yet the case. The primary relevance of this scenario is therefore that it shows the expected sequence of the anticipated new infrastructure network developments and that it provides a rough indication of the timing of these developments on the basis of an assumed continuation of the historical patterns in the corresponding very long term Kondratieff waves.



Source: Grübler (1990, p.187), updated and extended on the basis of my personal views.

Figure 8-3: Overall Development of Transport Infrastructure Networks

The presumed development of the overall transport system has a number of implications for the modelling of the IWT system. The first implication is that no new transport infrastructure networks have to be taken into account in the development of very long term transport scenarios; and that the modal share of IWT can therefore still be based on the expected development of the existing transport modes. The second implication is that intermodal transport can be considered as a dominant driver of the next 6th Kondratieff wave, which implies that the development of intermodal transport can be expected to go on for at least another about 50 years. Intermodal transport is therefore likely to have an ongoing very long term effect on the development and composition of the IWT flows. The third implication, that stems from the avoiding transport trend, is that the effects of decoupling are likely to continue to hold on throughout the entire 21st century, which further justifies the use of the differences equation in the very long term forecasts presented in Chapter 7.

8.2.4 Improved quality of the existing transport infrastructure networks

The fact that most of the existing transport infrastructure networks have reached a certain stage of maturity, in which the length of the network can no longer be expected to increase, does not imply that these networks will no longer evolve. The difference with the historical development is that, instead of an increase in length of the network, one can now expect an improvement in the quality of the network. In some cases, such as for the inland waterways, this may come quite unexpected. Consider for instance the following quote by Grübler (1990, p.235): *"Only the lowest value goods (basic commodities, and bulk raw materials and agricultural products) remain as the last competitive domain for traditional (low speed) transport modes. This was, and continues to be, the principal market niche for inland river navigation in all countries, and is progressively also becoming the case for railways"*. Clearly the above argument is no longer valid. The introduction of intermodal container rail- and barge services has triggered a complete revival of the rail- and IWT system. Container transport by rail- and barge are now booming due to the possible economies of scale that can be obtained on these networks. Rail- and barge transport are also regarded cleaner and safer than road transport. In addition the inland waterways still have sufficient free capacity which is often not the case for road infrastructure. Each type of infrastructure has its own strength. The notion that networks should be regarded as complementary to each other is now adopted by the European Union and referred to as co-modality (see Chapter 2).

8.3 The Intermodal Inland Waterway Transport Network

The previous section showed that the 5th infrastructure S-curve is now developing around the concept of intermodality. This section starts with the definition of intermodal transport; continues with a retrospective on the introduction of the first container shipping lines and the development of intermodal transport services on the inland waterways; and finally presents four presumed stages in the development of intermodal IWT network of which the first two are now (in the second decade of the 21st century) reaching completion.

8.3.1 The definitions of intermodal transport

There are several definitions of multimodal, intermodal, and combined transport. The United Nations (2001, p.16-18) provided a harmonized set of definitions agreed on by the European Union (EU), the European Conference of Ministers of Transport (ECMT), and the Economic Commission for Europe of the United Nations (UNECE). The applied definitions are:

- Multimodal transport: carriage of goods by two or more modes of transport;
- Intermodal transport: the movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes;
- Combined transport: intermodal transport where the major part of the European journey is by rail, inland waterways or sea and any initial and/or final legs carried out by road are as short as possible.

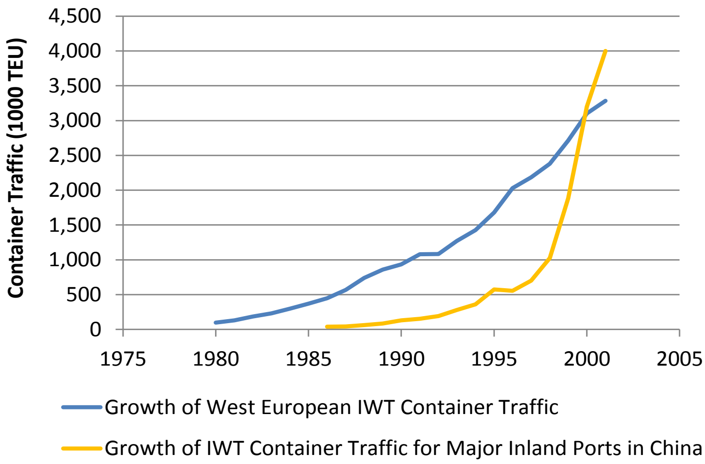
The terms co-modality and synchro-modality were introduced more recently. Co-modality refers to the efficient use of different modes on their own and in combination (EC, 2006, p.6). Synchro-modality (Tavasszy et al., 2010) aims at making optimal use of a combination of transport modes based on real time information regarding the available transport capacity. I will mainly refer to the first two definitions and apply *'multimodal'* in case the goods are transported in more than one loading unit (e.g. bulk shipments) and *'intermodal'* in case the cargo remains in a single loading unit (e.g. inside a container).

8.3.2 The introduction of the first container services

The intermodal transport revolution started with the development of the container and a supporting chassis by Malcom MacLean in the 1950s. The original size of the containers (35' x 8' x 8') was optimised according to the allowed truck dimensions on the USA highways, which varied across the individual states. On 26 April 1956 MacLean started his first container line on board of a converted tanker. *"His next ship had on-board container gantries as well as cells in the holds, where containers could be stacked on top of the other and could nest safely in bad weather. Others seized upon the idea. The first Pacific crossing, though still domestic, took place in 1958, from San Francisco to Hawaii, the year when the authorised container length was increased to 40 feet. The first international multimodal move was initiated in 1960, between the United States and Venezuela. However, the agreed date of the full-scale revolution is April 1966, with the arrival in Rotterdam of the first full cellular containership across the Atlantic, bringing Europe closer to the United States by weeks. By providing such secure long-distance transportation chains, containerization aided by facilitation created what is known today as Multimodal Transport"* (UN, 2004, p.5-6).

8.3.3 The development of intermodal inland waterway transport

Brolsma (2010, p.30, translated) indicated that: *"the first trans-Atlantic containers that arrived in Rotterdam were shipped by truck. Containers were expensive and needed to be transported quickly to the final destination. Only in special cases containers were shipped as deck cargo on board of an inland vessel. It took quite a while for containers to become* *common, but at a certain stage transport costs gained importance relative to speed. In 1974 the first liner container service was introduced on the river Rhine"*. From 1974 onwards liner container services developed quickly on the main routes between Rotterdam, Antwerp and the Ruhr Area (see Figure 8-4, left). A decade later container transport also started to develop on the Chinese rivers at an even much higher pace (see Figure 8-4, left). The discussion in this section is limited to the West European situation, but it should at least be recognised that the development of intermodal inland waterway container transport is a worldwide phenomenon.



Source: United Nations (2004, p.9 and p.27), www.bureauvoorlichtingbinnenvaart.nl/maps/.

Figure 8-4: Development of Intermodal Container Transport on the Inland Waterways

It took quite a while before inland terminals were developed at shorter distances to the seaports. In the Netherlands the first dedicated IWT container terminal was opened in 1987 in Nijmegen. By 2002 the number of dedicated IWT container terminals had increased to 16 of which 4 terminals also served rail and 2 terminals also handled seagoing vessels. In addition there were also 3 dedicated inland road/rail terminals operational (AVV, 2003). By 2007 the number of intermodal inland container terminals had increased to 18 barge terminals, 6 rail terminals, and 5 tri-modal (road/rail/barge) terminals (Matze, 2010, p.54). In 2011 the EICB (www.informatie.binnenvaart.nl) provided a map that indicates 35 operational, 6 planned, and 16 potential future inland container barge terminals, but in reality the number of terminals was even higher as multiple inland terminals at a single location, such as in the city of Rotterdam, were only counted once. Visser et al. (2012, p.77-79) finally listed 31 inland terminals, 29 intermodal terminals in seaports (at 12 different port municipalities), and 15 locations where new terminals are planned. The development of IWT container terminals started slightly later in Belgium. Macharis et al. (2011, p.64) indicated that the first Belgium intermodal container barge terminal became operational in Avelgem in 1991. It took until 1996 before the second intermodal barge terminal was opened in Meerhout. By the year 2007 the Belgium transport system counted 19 intermodal terminals of which 13 are connected to the inland waterways. A similar impressive growth of inland terminals has also taken place in Germany. By 2010 Germany counted 148 terminals (Visser et al., 2012, p.35). An updated overview of West European intermodal terminals can be obtained from www.inlandlinks.eu. Figure 8-4 (right) indicates the main intermodal inland terminals in the larger Rhine delta. Nowadays intermodal inland container terminals can be found at distances of less than 20 km from each other providing access to the waterways almost everywhere. There is clearly a revolution going on with respect to intermodal freight transport.

The intermodal transport revolution is also recognised in academic literature. Bontekoning et al. (2004) investigated 92 academic papers on the subject of intermodal freight transport over the period 1977 to 2001. Up to 1989 the annual number of papers did not exceed two papers per year. Thereafter a strong increase could be observed. By 2001 the number had increased to 28 papers. On the basis of their research they concluded that: *"a new transportation research application field is emerging; and that, while still in a pre-paradigmatic phase, it is now time to move on to a more mature independent research field. An independent research field can be justified because intermodal transport is a complex system that has characteristics which distinguishes it from other transport systems".* I agree that a new field is emerging, but it is not only just a new field of research. It marks the development of new major transport infrastructure network.

8.3.4 Staged development of intermodal inland waterway transport

In analogy with the development of the existing transport networks (canals, railways, roads, airways, and seaways) it can be expected that the full pervasive development of the intermodal IWT network will also last about a century. Throughout this period the system is likely to pass through a number of stages. In order to provide a clear discussion framework I will presume four stages of some 25 years each. The first stage, that roughly took place between 1970 and 1995, relates to the development of container terminals at distant locations in the hinterland (i.e. the development of inland terminals further upstream in Germany). During the second stage, that roughly lasts from 1995 to 2020, inland container terminals mushroom throughout the hinterland. New terminals are not only developed close to each other, but also close to the seaport. At the end of the second stage a dense network of inland terminals exists throughout the navigable hinterland. The third stage, that roughly lasts from 2020 to 2045, marks the development of intermodal continental container transport links between the various terminals in the hinterland (that were established in the second stage). Transport services may then no longer remain solely directed to the import/export flows to/from the seaports. At this stage companies may start to recognise the merits of multimodal transport and shift to the waterfront. The development of waterborne business locations may then finally, during the fourth stage, that roughly lasts from 2045 to 2070, allow for the development of door-to-door pallet distribution networks such as perceived by Districvaart (see also Connect, 2003). The first two stages have already been discussed in the previous sections. The challenges with respect to the development of an intermodal continental IWT container network (in the third stage) as well as an intermodal continental IWT pallet distribution network (in the fourth stage) will be discussed in the next two sections.

8.4 Development of Continental Container Transport

The third stage development of the intermodal IWT network consists of the creation of continental container services between the various inland terminals, that were developed in the first two stages of the intermodal transport network. As will be discussed in Chapter 12 the development of continental container barge transport may have a substantial effect on the transport volumes that are shipped by IWT. However, from a transport economic point of view the development of intermodal continental container services is still a major challenge. The successful development of intermodal continental IWT will, to a large extent, depend on the options to shape the right (cost effective) environment for IWT. This section addresses the challenges that are related to the development of continental container barge transport and serves as input for the very long term shipping scenarios that are developed in Chapter 13.

8.4.1 Challenges for the development of continental container transport

The main challenge for intermodal continental transport is to compete with unimodal road transport, which is not an easy task. Intermodal transport involves many handlings such as indicated by the following indicative process description: *truck loads empty container at container depot A, truck drives towards company, truck loads at company, truck drives towards terminal, container is loaded into terminal stack, container is transported towards quay, container is loaded onto container barge, container barge sails towards destination terminal, container is loaded from barge onto quay, container is placed in stack, container is loaded on truck, container is shipped by truck towards final destination, container is unloaded at destination (or changed for empty), empty container returns to container depot B*. Costs are involved for each of these handlings, as well as for the rent and possibly also the relocation of the container; while in order to remain competitive the overall intermodal transport costs should remain lower than, or at least equal to, the costs of direct trucking.

Platz (2009, p.373) identified a number of decisive factors for the efficient integration of inland shipping into continental intermodal transport chains, which are: *"(1) bundling in space, (2) bundling in quantity, (3) backup transportation, (4) guaranteed lead times, (5) easy intermodal load transfer, (6) complete transport-related service packages ("all-in"), and (7) loading unit providing the capacity of a standard semi-trailer"*. I will argue that the first five decisive factors are also applicable to the port related import/export flows, that were developed in the first two stages of the intermodal IWT network. The main difference is however that bundling in space, quantity, and time is more complicated for the smaller and more diverse continental transport flows, than for the combined import/export flows to/from the seaports. The sixth item refers to the difficulty of organising continental transport. Attempts to set up independent companies for the organisation of intermodal transport have not yet been very successful due to the complex nature, low levels of transparency, and small margins in the transport sector; but this may now change with the recent start-up of synchro-modal transport companies such as Wayz (founded in 2011). The seventh item relates to the fact that, in order to be competitive, the capacity of the continental loading unit should match the capacity of a standard semi-trailer. However, the dimensions of a standard deepsea container do not match the requirements for continental container transport[93]. For several decades there has been a search for a universal intermodal loading unit that can be applied in continental container transport. Nowadays this unit has been found in the 45 foot, pallet wide, high cube container, that has similar inner dimensions as a standard semi-trailer and will be referred to as the continental 45 foot container. The continental 45 foot container has now become the new European standard for continental short-sea-shipping and rail transport[94], but it is still hardly used for transport of continental freight via the inland waterways.

Continental container barge transport faces a number of additional drawbacks compared to port related container barge transport. First of all, it involves the costs of an extra terminal

[93] The standard 40 foot container is too small to allow for loading of two euro-pallets next to each other. In addition it is shorter and lower than the size of a standard semi-trailer. Therefore the loading capacity of the standard 40 foot container is considerable less than that of a semi-trailer.

[94] Platz (2009, p.314-316) provides a comprehensive description on the development of the intermodal 45 foot container in short sea shipping. From UNIT45.COM, a leading producer of continental 45 foot containers, it was understood that the 45 foot container has now also become a standard in European intermodal rail transport.

handling (assuming similar tariffs for handling of barges and trucks at the deepsea terminal); secondly, it requires an additional pre-haulage trip, of which the per km costs are higher than the per km costs of long haulage trips; thirdly, the road transport costs of trucking a 45 foot container are almost similar to the cost of trucking a 40 foot container, but shipping a 45 foot container requires 12.5% additional length in the hold of a container barge compared to a 40 foot container and therefore the transport costs are also at least 12.5% higher[95]; fourthly, the transport volumes are considerably smaller and therefore they require smaller and relatively more expensive barges and/or less frequent services; and fifthly, the current inland waterway transport infrastructure is not fully compatible with the size of the continental 45 foot container (see Chapter 2). The successful development of intermodal continental container barge transport is amongst others related to the political will to take measures to improve the competitiveness of continental intermodal container barge transport. Of major importance are: (1) *the implementation of spatial policies aiming at preservation and redevelopment of waterfront industrial sites*; (2) *investments in upgrades of the IWT network that make the IWT system compatible with the efficient transport of continental 45 foot containers*; and (3) *policy measures aiming at the internalisation of external transport costs*. The first two measures, that can be related to the specific development of the IWT infrastructure network, are discussed in the remainder of this section. The effects of each of these three measures on the competitiveness of continental container barge transport are further discussed in Chapter 10.

8.4.2 Spatial policies aiming at the development of waterfront industrial sites

The development of waterfront industrial sites is probably the most important policy measure that can be taken to reduce the costs of pre- and end-haulage as well as the terminal handling costs. If companies are located at the waterfront or close to a common user inland container terminal, this automatically reduces the pre- and end-haulage costs to the bare minimum. In addition, the development of industrial and/or logistical activities around common user barge container terminals also stimulates the bundling of cargo. This increases the terminal volumes and reduces the terminal handling costs. For companies that are located at the waterfront (but have insufficient cargo volumes to invest in a dedicated crane) sophisticated container crane barges may provide an alternative solution. This solution is indicated in Figure 8-5.

Source: Mercurius Shipping Group (pictures taken in 2005, left; and 2008, right).

Figure 8-5: Container handling with a dedicated Container Crane Barge

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[95] In practice the tariffs for shipping a 45 foot container are often even based on 3 TEU (i.e. 50% higher rates).

Spatial planning policies should be regarded as one of the main drivers for the development of intermodal continental container flows by barge, but spatial planning requires a long breath. The historical shift of companies from the waterside to the landside took about half a century, and therefore a possible shift back towards the waterfront will also take considerable time. In this respect it is important to realise that the many real-estate developments taking place at existing waterfront locations may restrict the future development of waterfront industrial sites. I therefore consider it of major importance to secure sufficient waterfront area for future IWT developments, that may take place a few decades from now.

8.4.3 Upgrading the available inland waterway dimensions

The chain is as strong as its weakest link. The development of continental container transport requires all links in the chain to be able to provide cost effective services. This also holds for the main link on the inland waterways. The present infrastructure dimensions are not very compatible with the transport of continental 45 foot containers[96]. This makes the efficient shipping of continental 45 foot containers quite difficult. To point out the inefficiencies of the existing IWT infrastructure network, I have analysed the maximum loading capacity of the largest inland barges that can sail on the various waterway classes, for the condition that all continental 45 foot containers are empty and maximum ballast is taken in the side wing tanks of the barges (to reduce the air draft). The results are indicated in Table 8-3.

Table 8-3: Evaluation of Loading Efficiency for Continental 45 Foot Containers

Item \ Waterway	Class I	Class II	Class III	Class IV	Class V
Maximum dimensions					
- Length	38.5 m	55.0 m	80.0 m	85.0 m	110.0 m
- Width	5.05 m	6.60 m	8.20 m	9.60 m*	11.45 m*
- Height	4.00 m	5.00 m	5.00 m	7.00 m	9.10 m
Hold dimensions					
- Length**	23.0 m	39.0 m	56.0 m	61.0 m	86.0 m
- Width***	3.70 m	5.25 m	6.85 m	8.25 m	10.10 m
Theoretical capacity					
- 45 foot cont. in length	1.66 box	2.81 box	4.04 box	4.40 box	6.20 box
- 45 foot cont. in width	1.42 box	2.01 box	2.62 box	3.16 box	3.87 box
- 45 foot cont. in height	1 layer	2 layers	2 layers	3 layers	4 layers
Total Capacity	2.36 box	11.30 box	21.17 box	41.71 box	95.98 box
Guaranteed capacity					
- 45 foot cont. in length	1	2	4	4	6
- 45 foot cont. in width	1	2	2	3	3
- 45 foot cont. in height	1	1	1	2	3
Actual capacity	1	4	8	24	54
Loading efficiency	*42%*	*35%*	*38%*	*58%*	*56%*

Note: * Based on new standards; ** Based on existing barges; * Based on width minus 1.35 meter.**

[96] Various types of continental 45 foot containers exists. In general the length is 13.72 meter and the height is 2.90 meter. For standard containers the width goes down to 2.50 meters, but for special containers such as reefers or containers with curtains a wider frame of 2.56 meters (or even 2.60 meters) is applied. In addition there exists a range of shorter (e.g. 20, 24, or 30 foot), but also wider bulk containers of up to 2.60 meters wide. These containers may also be important for the development of intermodal continental container transport.

The length of the holds is not a fixed figure, but depends on the streamlining of the barge and the size of the living accommodation. The estimates are based on the dimension of real vessels with a reasonable streamline and a reasonably compact living accommodation. The width of the holds is based on the minimum required width of the gangways (600 mm) and some additional width for plating (75 mm) on each side. Taking this into account the maximum available width of the holds is similar to the width of the vessel minus 1.35 meter. The theoretical capacity is defined on the basis of a 45 foot container (13.72 m x 2.56 m) taking into account an additional spacing of 0.05 meter in width and 0.15 meter in length. No additional space requirement is assumed at the sides of the holds. The stacking height is based on the rule of thumb that, in general, containers can be loaded as high as they can be stacked wide[97]. No correction is applied for lack of ship stability when loading full containers.

The results of Table 8-3 clearly indicate that the present IWT system is not very compatible with the requirements for efficient intermodal continental container transport. The present system results in loading efficiencies of less than 40% on the smaller waterways (Class II and III) and about 55% to 60% on the larger waterways. Given the high levels of competition with unimodal road transport these poor loading efficiencies may, to some extent, preclude the development of intermodal continental container barge services. The full scale development of continental intermodal barge transport therefore requires an upgrade of the IWT system. This implies that the future development of continental container transport on the inland waterways will, amongst others, depend on the political will to invest in an upgrade of the waterway infrastructure. In addition it will of course also require entrepreneurs to invest in new cost effective barges, but I do not expect this to be a limiting factor. I therefore consider the political will to invest in an upgrade of the Dutch and/or European IWT network as the second main driver for the development of continental intermodal IWT.

8.5 Development of a Continental Distribution Network

Suppose that, during the third stage development of the intermodal transport network, there will be sufficient political will to upgrade the IWT system in order to make it compatible with the requirements for cost effective transport of continental 45 foot containers; and that spatial developments will also result in a substantial shift of logistical companies to the waterfront. Under such favourable conditions for IWT there is a fair chance that new intermodal pallet distribution networks will evolve during the fourth stage of the intermodal transport network, that roughly lasts from the years 2045 to 2070. This section investigates the likelihood that advanced pallet distribution networks will be developed in the slipstream of the successful development of continental container barge transport. The obtained insights are intended to serve as input for the more optimistic shipping scenarios in Chapter 13 and 14.

8.5.1 The development of continental pallet distribution by barge

Within the broader scope of the *'Distrivaart'* project Groothedde (2005) investigated the possibility to develop a new intermodal pallet distribution network on the Dutch inland waterways[98]. The basic concept behind this network is that the overall transport costs for the

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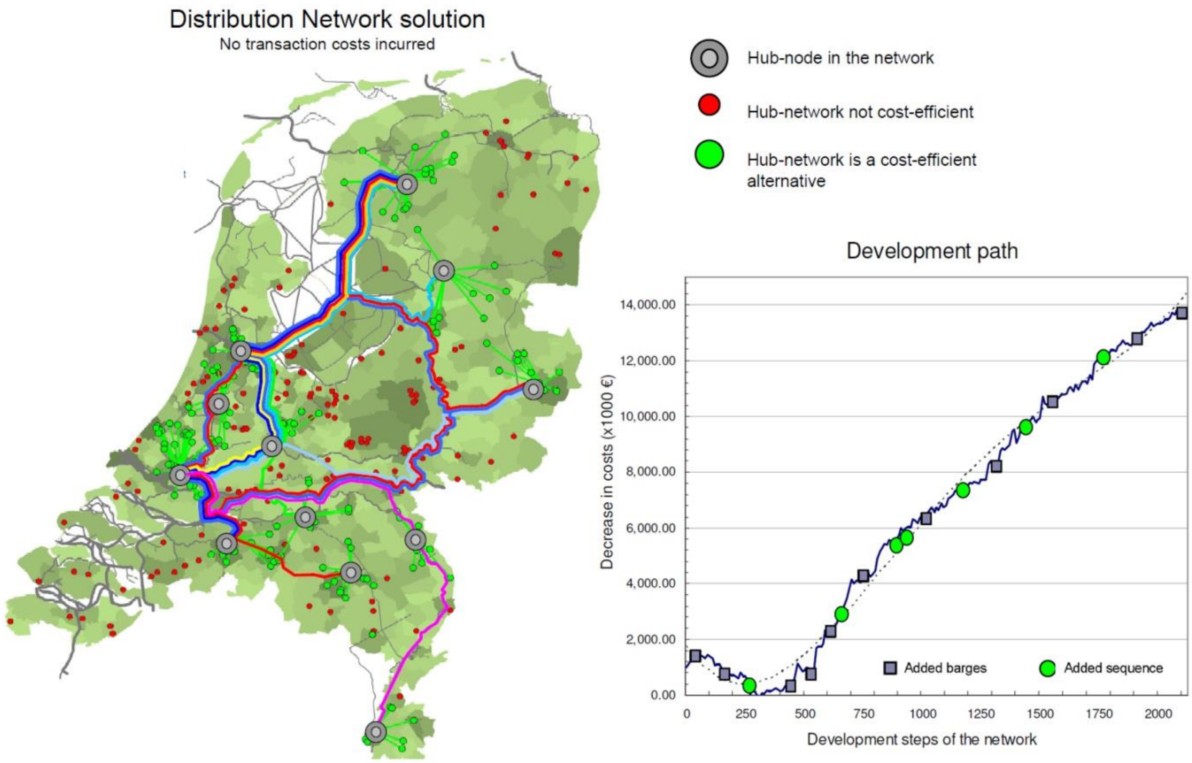
[97] This is only a rule of thumb. Loading of heavy containers on the top layer is often restricted by the stability of the vessel. For empty containers the stability is often sufficient to allow for an additional layer of containers.

[98] Note that such pallet distribution networks should also be regarded as intermodal transport. The difference is however that the intermodal loading unit is now the pallet instead of the container.

distribution of pallets can be reduced by combining individual pallet flows into a large distribution network. Groothedde (2005) therefore started with a large database of pallet flows and investigated the possible options to develop a full scale pallet distribution network in which the flows of various parties are combined into a single transport network. Figure 8-6 (left) indicates the obtained final structure of a possible pallet distribution network in which no transaction costs are incurred (i.e. costs levels are based on transport costs excluding margins for planning, overhead, profit, etc.). The various liner services (or sequences) that connect the hub-nodes in the network are indicated with a different colour. The final origins and/or destinations that can be served in a cost effective way are marked green. The ones that cannot be served in a cost effective way are marked red.



Note: the upper right legend refers to the map indicated in the left.
Source: Groothedde (2005, p. 175 and 182), adjusted layout.

Figure 8-6: Intermodal Pallet Distribution Network and Development Path

Figure 8-6 (right) shows the potential overall transport cost reduction for the entire network solution. It indicates that there will be little savings throughout the start-up phase of the network. In fact the costs will first increase (i.e. the savings are reduced in the figure) until the network becomes large enough to generate economies of scale. This is indicated by the J-stick like development path. Larger savings are obtained in a later stage of the network when the system becomes available to the smaller less than truck load (LTL) shipments for which the direct road transport costs are generally higher than for full truck load (FTL) shipments.

In addition to the research project of Groothedde (2005) a commercial pilot was executed with a dedicated pallet barge called the *'River Hopper'*. The first phase of this pilot took place between September 2002 and June 2003 (Connect, 2003). At that time the pallets were handled with forklifts and a single sequence per week was completed. During the second phase of the pilot the barge was equipped with a fully automated pallet handling system. The commercial pilot was however cancelled by the end of the year 2004, because the utilisation of the barge was structurally too low. The reason for the low barge utilisation was amongst others that the first point-to-point connection could not yet compete with the cost levels of unimodal road transport (Van Dorsser, 2004). In response to the cancellation of the commercial pilot Groothedde (2005, p.181) concluded that *"the Distrivaart concept, as proposed was never actually tested because only a single barge was deployed, thus never really achieving the necessary economies of scale".*

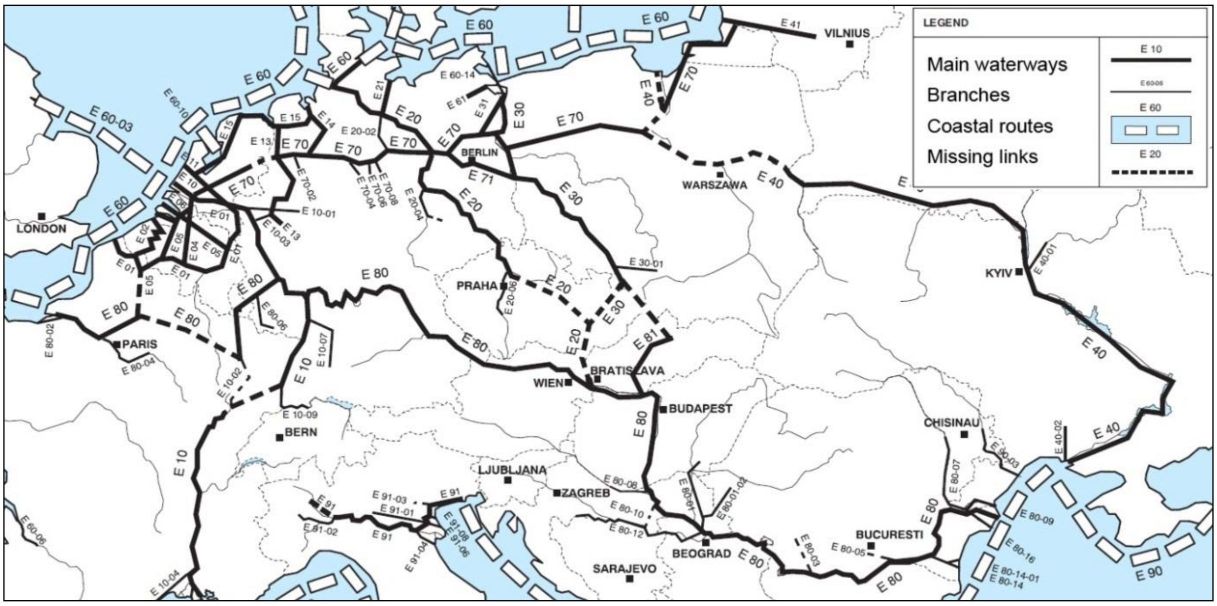
Groothedde (2005, p.182) further concluded that: *"the scenario closest to the commercial pilot, is very difficult to 'start up' (see* Figure 8-6*). In the beginning of the development path of this network the benefits are very low and it is not until the capacity in barges is extended and the number of sequences is increased that the cost benefits may become substantial. Especially, if we take into account the very competitive rates that the trucking carriers are able to offer. It is not until the network consists of four hubs and five barges that the cost decrease in an upwards direction and the economies of scale are achieved"*. This implies that there seems to exists a great potential for the transport of smaller (pallet sized) shipments on the Dutch waterways, but that this potential cannot be realised, because the system is unable to compete during the start-up phase of the network.

Van Dorsser (2004, p.viii) studied the possibility to compete with a single barge on a single point-point connection and concluded that *"multimodal pallet distribution is only possible at large distances (point-to-point connections of at least 250 km), if large ships are used (at least twice the size of the River Hopper) or in case of no before and or after transportation"*.

By combining the work of Groothedde (2005) and Van Dorsser (2004) it can be concluded that new intermodal pallet distribution services may become feasible during the fourth stage development of the intermodal IWT network, under the condition that the IWT infrastructure is upgraded and companies shift to the waterfront during the third stage development of the intermodal IWT network. The shift of companies towards the waterfront may at a certain stage enable the development of very simple point-to-point pallet transport services between various waterborne business locations. Unlike the Distrivaart project the transport of pallets to and from these waterborne locations may then finally become financially feasible, because the pre- and end-haulage costs are reduced considerable, and therefore the financial feasibility conditions of Van Dorsser (2004) are finally met. As time passes by and more point-to-point relations evolve the system may slowly turn into a network that, at a certain stage, starts to offer the cost savings that were once perceived by Groothedde (2005). These cost savings may then eventually spark the further development of the pallet distribution network – enhancing even more companies to shift to the waterfront. It is therefore sensible to anticipate the possible development of advanced pallet distribution networks in the second half of the 21st century. If this happens one may, to a certain extent, also expect a revitalisation of the smaller inland waterways for the distribution of pallets by barge.

8.6 Development of European Inland Waterway Infrastructure

The further integration and upgrade of the European waterways is still uncertain, but the number of possible waterway expansions is limited. Most of the possible expansions for the inland waterways are included in the E-Waterway Network of the UNECE (2006, 2011). The structure of this network is indicated in Figure 8-7.



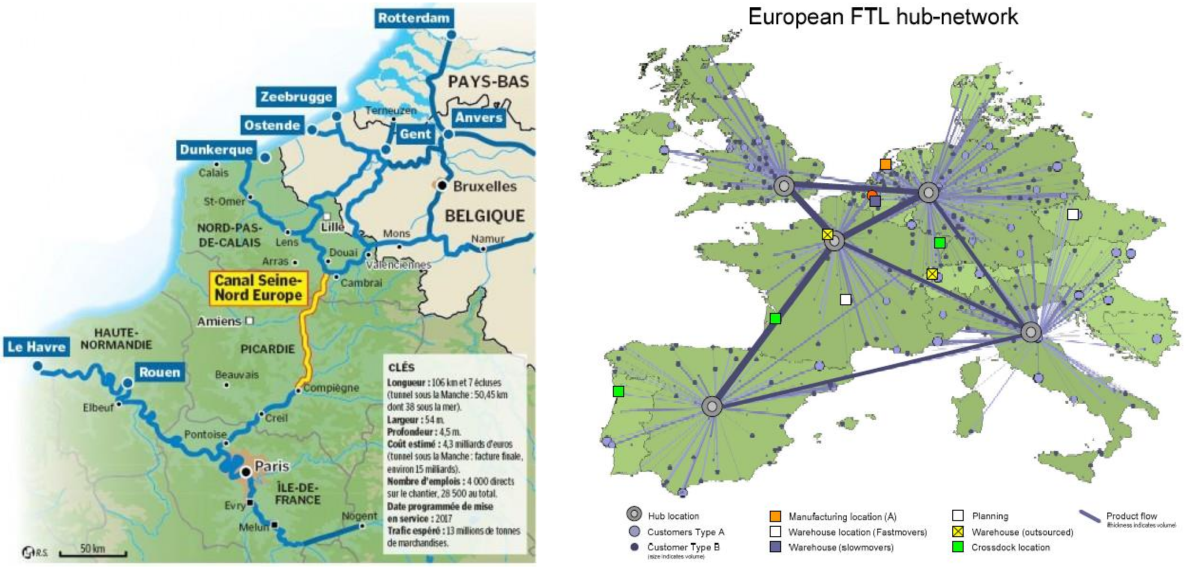
Source: UNECE (2006, p.87), adjusted layout and reduced content.

Figure 8-7: E-Waterway Network proposed by the ECE

However, according to (Brolsma, 2010, translated, p.20) *"There are quite a lot of bottlenecks and missing links in the E-Waterways Network. Many old plans that have been developed for national or strategic (read: military) reasons, seem to lead a tough life and old sentiments have resurfaced due to the rather theoretical approach of the Group of Experts that developed the E-Waterway Network. In that respect the approach of the EU, a list of bottlenecks, is more realistic. The bottleneck closest to realisation is the connection between the Seine- and Scheldt: the Canal Seine – Nord Europe. The two most important European bottlenecks are currently the connection Maagdenburg-Berlin (narrow width) and the connection Straubing-Vilshofen on the German part of the Danube (shallow draft)".* The list of bottlenecks provided by the EU is based on projects that have been put forward by national governments. An alternative list of main bottlenecks and missing links in the European IWT network is proposed by Inland Navigation Europe (INE), the branch organisation for inland shipping in Europe (INE, no date).

Since 1990 the European Commission aims to develop a trans-European transport network (TEN-T). *"The trans-European transport network (TEN-T) plays a crucial role in securing the free movement of passengers and goods in the European Union. It includes all modes of transport and carries about half of all freight and passenger movements. One of the key objectives of creating a multimodal network is to ensure that the most appropriate transport mode may be chosen for each stage of a journey"* (EC, 2005, p.7).

The intended development of the TEN-T network (initially to be completed by 2020) involved 30 priority projects related to the construction of *'missing links'* and upgrades of the existing road-, railway-, inland waterway-, and short-sea infrastructure. Two of the priority projects were related to the development of the inland waterways. These projects included an upgrade of the Rhine – Danube connection as well as the construction of a new connection between the Seine and Scheldt (see Figure 8-8, left). However, the planned upgrade of the Rhine – Danube connection is still subject to political debate in Germany (De Scheepvaartkrant, 2012) and the final go-ahead decision for the construction of the new Canal Seine – Nord Europe has been postponed in France (Schuttevaer, 2012; Reuters, 2013).



Source: www.frogsmoke.com (left), Groothedde (2005, p. 146, right).

Figure 8-8: Canal Seine – Nord Europe (left), European FTL Transport Network (right)

MEMO/11/706 of the European Commission (2011, p.2) sets out the revised EU policy for the development of the TEN-T network on the basis of a smaller more tightly defined transport network that *"consists of two layers: a core network to be completed by 2030 and a comprehensive network feeding into this, to be completed by 2050. The comprehensive network, will ensure full coverage of the EU and accessibility of all regions. The core network will prioritize the most important links and nodes of the TEN-T, to be fully functional until 2030. Both layers include all transport modes: road, rail, air, inland waterways and maritime transport, as well as intermodal platforms"*. The revised structure is more comprehensive than the previous one and includes a larger number of projects. A selection of the most relevant pre-identified IWT projects (in the corrected version of the TEN-T network revision of 19 December 2011) is provided in Table 8-4:

Table 8-4: Proposed IWT Infrastructure Upgrades in the Revised Core Network

Pre-identified section	Description/Dates
West-German Canals, Mittelland Canal, Hannover – Magdeburg – Berlin	Upgrading
Milano – Mantova – Venice – Trieste	Studies, upgrading, works
Hamburg – Dresden – Prague – Pardubice	Elbe upgrading
Basel – Rotterdam/Amsterdam/Antwerp	Upgrading
Le Havre – Paris	Upgrading
Meuse	Upgrading
Albert Canal	Upgrading
Canal Seine – Nord Europe	Design completed, competitive dialogue launched, overall completion by 2018*
Waterways in Wallonia	Studies, upgrading
Canal Saône – Moselle/Rhine	Preliminary studies ongoing
Rhône	Upgrading
Main – Main-Danube-Canal – Danube	Studies and works on several sections and bottlenecks, inland waterway ports, hinterland connections
Dunkirk – Lille	Studies ongoing

Note*: The construction of this canal is postponed and therefore the year 2018 is no longer realistic.

Source: http://ec.europa.eu/ transport/themes/infrastructure/revision-t_en.htm.

The missing links reported by INE (no date) include: (1) the Canal Seine - Nord Europe, that is still waiting for the final go-ahead decision; (2) the Twente – Mittelland connection, for which some actual plans exist but sufficient political support is still lacking; (3) a desired connection between the Elbe, Oder, and the Danube for which the Czech Republic has serious plans, but for which funds are still lacking; (4) an upgraded Saône – Moselle (or Rhine) connection, for which preliminary studies are now being prepared; and (5) a suggested connection between Liège and Koln, for which I am not aware of any preliminary studies.

On the medium to long term only the first missing link (Canal Seine – Nord Europe) has a fair chance to be developed, but other missing links may follow later this century. The Canal Seine – Nord Europe is expected to bring clear economic benefits. The Seine-Scheldt Committee (presentation of 4 May 2006) forecasted the transport volumes on the Seine – Scheldt corridor to increase from 4.2 to 16.7 million tonnes (MT) due to the construction of the canal (in the year 2020, which is no longer feasible). The forecast comprises of 5.7 MT construction materials, 4.8 MT agro-products, 1.4 MT metals, 1.2 MT oil/coal, 0.7 MT fertilizers, 0.5 MT chemicals, 0.6 MT cars/other, and 1.8 MT containers (ISO). From the relatively small container volumes and the notion *'(ISO)'* it can be concluded that continental freight is not included in the forecast. Figure 8-8 (right) indicates that there is a good potential for IWT of continental freight between the Ruhr area and Paris. This potential will be further investigated in Chapter 10.

Not all the developments of the European IWT network are likely to have a similar effect on the Dutch IWT system. Table 8-5 provides a list of what I consider the most relevant developments for the Dutch inland waterways.

Table 8-5: Effect of European IWT developments on the Dutch IWT Network

No.	Development	Impact	Expected effects on the Dutch Inland Waterways
1.	Construction of Canal Seine – Nord Europe	+++	- Significant increase in transport of bulk materials between the ARA port region and Le-Havre/Paris. - Development of inter port container traffic between Le-Havre, Antwerp and the Rotterdam Port Area. - Possible development of continental container transport between Ruhr area, ARA region, and Le-Havre/Paris region. - Significant effect on fleet capacity (release overcapacity on Rhine).
2.	Upgrade Mittelland canal and further connection to Berlin (bridge clearance)	++	- Enhanced options for transport of containerised cargoes from Rotterdam/Antwerp towards the northern part of Germany. - Possible development of continental container flows on this route. - Possibility for container transport to Hamburg via upgraded Elbe.
3.	Construction of Twente – Mittelland canal	++	- Dry bulk vessels towards North Germany are routed via the Gelderse IJssel instead of via the Rhine. - Enhanced options for container transport towards North Germany and Berlin (only in combination with an upgraded Mittelland canal).
4.	Construction of Rhine-Meuse Canal	++	- Decrease of bulk and container transport via Scheldt and Rhine due to availability of alternative connection to the Ruhr Area via Liège.
5.	Zeebrugge - Ghent	+	- Increase of transport on the main route via the Scheldt and Rhine to Germany (particularly for Containers and Ro-Ro vessels).
6.	Saône – Moselle or Rhône – Rhine connection	+	- Minor effect on balance of shipments via Rotterdam and Marseilles. - Some effect on fleet capacity (release overcapacity on Rhine). This effect increases if capacity of the locks on the Rhône is improved.
7.	Solving bottlenecks in the Danube	+	- Minor effect on the balance of shipments via Rotterdam and Constanta. - Minor effect on fleet capacity unless the river Danube is deepened over the entire stretch (release overcapacity on Rhine)

The table presents my personal views on the effects of European IWT developments on the Dutch IWT system. It may be further improved by consulting a number of experts, but I consider the presented views sufficient for the discussion in this thesis. With respect to the listed items the following remarks can be made:

1. The new Canal Seine – Nord Europe is expected to increase the annual IWT volumes on this corridor by about 12.5 million tonnes. This will have a considerable effect on capacity of the locks between Antwerp and Rotterdam. Another effect is that the upgraded waterway connection will offer new employ for a considerable number of barges in the larger Rhine fleet. This reduces the present overcapacity. The smaller barges currently sailing on this route will however face enhanced competition and may be forced to look for new employ on the smaller West European waterways.
2. An upgrade of the available bridge height on the North German canals, that connect the Ruhr area towards Hamburg and Berlin, will improve the feasibility of container transport on this route. This enhances the development of container transport from the ARA ports towards Hamburg and Berlin. In addition it also improves the conditions for intermodal continental container transport on the North German waterways.
3. The development of the Twente – Mittelland canal will divert a part of the bulk freight (that is now shipped via the Rhine) towards the Gelderse IJssel. If the bridge heights on the North German waterways are also increased this will further enhance the development of container transport towards North Germany via the Gelderse IJssel.
4. The development of a new canal between the Rhine and the Meuse (near Liège) will reduce the pressure on the Dutch IWT system (mainly the Rhine and Rhine-Scheldt connection) because it provides an alternative route from Antwerp towards the Ruhr area. I am however not aware of any actual feasibility studies for this connection.
5. An upgrade of the connection between Zeebrugge and Gent makes it possible for the port of Zeebrugge to develop a reasonable IWT hinterland connection. At the moment the port of Zeebrugge is mainly active in container and ro-ro (roll on roll off) traffic.
6. A new canal between the Rhône and the Moselle (or the upper Rhine) allows for the development of an IWT connection between Marseille and Rotterdam. In theory this enhances competition between the ports of Rotterdam and Marseilles, but in practice this new Rhine – Rhône connection will only have limited effect on the Dutch IWT volumes as: (1) the majority of the cargo from Rotterdam is shipped towards the Ruhr area, that is located close to the Dutch border and outside the range of competition for Marseilles; and (2) the majority of the cargo from Marseilles is shipped towards Lyon, that is close to Marseilles and outside the range of competition for Rotterdam. A new Rhine – Rhône connection may however support the development of continental transport between the Ruhr area and Lyon. In addition it may also allow for the exchange of barge capacity between these two river basins.
7. The upgrade of the Rhine – Danube connection allows for the transport of cargoes farther upstream the river. This upgrade is however not expected to have much effect on the Dutch IWT transport volumes as: (1) for bulk shipments sea transport from the Black Sea to Rotterdam is perceived more cost effective; (2) the transport volumes towards the east European countries are quite limited; and (3) the draft on the Danube is more restricted than on the Rhine making IWT less competitive.

The possible upgrades of many other Class I waterway connections in France are not included as the effect of these upgrades on the Dutch IWT volumes are likely to be rather small. Upgrades of the smaller East European waterways are also not included for the same reason.

8.7 Concluding Summary

This chapter addresses methodological sub question 2b (MSQ 2b): *"How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system"* of which the second driver has been identified as: *"the possible rise of new infrastructures and their implications for the IWT system as well as the anticipated development of the IWT system itself?"*. It starts with a discussion on the emergence of new infrastructure networks; continues with a discussion on the development of intermodal transport networks; and concludes with a discussion on the possible upgrades and expansions of the West European IWT network.

8.7.1 The emergence of new infrastructures

Grübler (1990) studied the evolution of major transport infrastructure networks (i.e. canals, railways, roads, and airways) and concluded that the development of these networks is closely related to the development of the very long term Kondratieff waves. Each subsequent Kondratieff wave relates to the development of a new transport infrastructure network that is an order of magnitude larger than its predecessor. The full development of a new transport infrastructure network generally takes place over a period of two successive Kondratieff waves (i.e. covering a period of about 100 years). The 1^{st}, 2^{nd}, and 3^{rd} Kondratieff waves gave birth to the development of the canal-, rail-, and road networks which became mature during the 2^{nd}, 3^{rd}, and 4^{th} Kondratieff wave. The notion that a new transport infrastructure network is already being developed by the time the prevailing network becomes mature, as well as the notion that the nature of the next infrastructure network can be identified by investigating the pervasive technologies that emerge during the present Kondratieff wave, implies that insight in the development of the succeeding networks can be obtained by analysing the principal drivers and pervasive technologies of the present and future Kondratieff waves.

I developed an updated view of the principal drivers and pervasive emerging and dominating technologies of the 4^{th}, 5^{th}, 6^{th}, and 7^{th} Kondratieff wave for which literature revealed that the 5^{th} and 6^{th} Kondratieff wave are likely to be driven by the broad concepts of 'Globalisation' and 'Sustainability'. I would argue that the 4^{th} Kondratieff wave gave birth to two major infrastructure networks, that are now being developed throughout the period from about 1930 to 2030. These networks relate to the airways for passenger transport and the seaways for freight transport. In addition I conclude that a new sustainable intermodal transport network is now being developed throughout the 5^{th} and 6^{th} Kondratieff wave, in a period that I roughly presume to last from about 1970 to 2070. This intermodal transport infrastructure network can very well represent one of the last physical transport infrastructure network developments as I expect the last earth-based transport infrastructure development to be related to 'avoiding transport', for instance by applying 3D-Printing techniques in combination with 'reusable ink'. This final development will presumably take place during the 6^{th} and 7^{th} Kondratieff wave in a period that is presumed to last from about 2020 to 2120.

The presumed development of the overall transport system has a number of implications for the modelling of the IWT system. The first implication is that no new transport infrastructure networks have to be taken into account in the development of very long term transport scenarios – and that the modal share of IWT can therefore still be based on the expected development of the existing transport modes. The second implication is that intermodal transport should be considered a dominant technology of the next 6^{th} Kondratieff wave, which implies that the development of the intermodal transport network can be expected to go on for at least another about 50 years. Intermodal transport is therefore likely to have an ongoing very long term effect on the development and composition of the IWT flows. The third implication, that stems from the avoiding transport trend, is that the effects of decoupling are likely to continue to hold on throughout the entire 21st century. This further justifies the use of the differences equation on a time scale up to the year 2100 in the very long term forecasts of Chapter 7.

8.7.2 The development of the intermodal transport network

The development of the intermodal transport network is likely to go through a number of stages that each will have their own effect on the IWT system. In order to get some grip on the timing of the various stages I roughly presume the overall development of the intermodal IWT network to go through four subsequent stages of some 25 years each. The first stage (about 1970 to 1995) relates to the development of container terminals at distant locations in the hinterland. In the second stage (about 1995 to 2020) inland container terminals mushroom throughout the hinterland. By the end of the second stage a dense terminal network exists. This network enables the development of intermodal continental container transport in the third stage (about 2020 to 2045). If companies start to appreciate the merits of intermodal waterborne transport during the third stage and shift their logistical activities towards the waterfront, this may finally spark the development of intermodal pallet distribution networks in the fourth stage development (about 2045 to 2070). The full development of intermodal continental waterborne container and pallet distribution networks is however still a major challenge as these flows face difficulties to compete with unimodal road transport.

The successful development of intermodal continental IWT flows amongst others depend on the political will to take measures that reduce as much as possible pre- and end-haulage, terminal handling, and inland shipping costs. Of major importance are: (1) the implementation of spatial policies aiming at preservation and redevelopment of waterfront industrial sites; and (2) investments in an upgrade of the IWT network to make the IWT system compatible with the efficient transport of continental 45 foot containers. In addition the internalisation of external transport costs is also likely to enhance the use of intermodal IWT.

8.7.3 Upgrades and expansions of the West European IWT network

The large scale development of sustainable intermodal container barge services has already sparked a renewed interest in IWT. This renewed interest may at a certain stage enhance new investments in European IWT infrastructure. On the medium to long term one may expect the possible construction of a new Canal Seine – Nord Europe (if still executed), the possible upgrade of the Rhine-Danube connection (if sufficient political support can be gained) as well as the possible upgrade of some parts of the German waterways that connect the Ruhr area and the port of Hamburg to Berlin. On the very long term further upgrades and expansions of the European IWT infrastructure may follow. These developments can for instance include the construction of the Twente-Mittelland canal, a new Saône-Moselle (or Rhine) connection, and/or a new Elbe-Oder-Danube connection. Each of these investments will have a different effect on the development of the Dutch IWT volumes. The present momentum for developing new IWT infrastructure is still rather low, but one should realise that the shift from the 5th to the 6th Kondratieff wave is likely to affect the future mind-set of our society. This may put new IWT infrastructure investments higher on the political agenda in the future.

8.7.4 Concluding remark

The reason for being specific on the various stages and presumed timing of the infrastructure developments that are discussed in this chapter is that this serves as input for the development of the very long term shipping scenarios in Chapter 13 and 14. It by no means implies that I am able state with any certainty what will exactly happen on the inland waterways.

8.7.5 Answer to Methodological Sub Question 2b

In answer to MSQ 2b, I conclude that the development of transport infrastructure networks is closely related to the main socio-techno-economic drivers of the very long Kondratieff waves. Each subsequent Kondratieff wave has resulted in the development of at least one major transport infrastructure network. The development of new transport infrastructure networks generally lasts about two Kondratieff waves (or about 100 years). The canal-, railway-, and road networks emerged in the 1st, 2nd, and 3rd Kondratieff wave and became dominant in the 2nd, 3rd, and 4th wave. Air passenger transport and global sea-freight evolved during the 4th wave and became a major driver of the 5th 'Globalisation' wave. The invention of the container sparked the development of an intermodal transport network during the 5th Kondratieff wave. Intermodal transport is likely to further evolve during the 6th 'Sustainability' wave – not only for intercontinental transport, but also for continental transport. I roughly presume the development of intermodal IWT to go through four subsequent stages of each about 25 years: The first stage (1970-1995) relates to the development of the first inland container terminals in the distant hinterland; the second stage (1995-2020) concerns the creation of a dense network of inland container terminals throughout the entire hinterland; the third stage (2020-2045) relates to the development of intermodal continental container transport; and the fourth stage (2045-2070) may give birth to the development of intermodal pallet distribution networks. The renewed interest in intermodal IWT as well as the European ambitions to cut greenhouse gas emissions by enhancing a modal shift towards more environmentally friendly modes of transport, may trigger new investments in the IWT system, such as the planned construction of the Canal Seine – Nord Europe (if still executed) or an upgrade of the Rhine-Danube connection; but the execution and timing of major IWT infrastructure developments is still very uncertain and will to a large extent depend on the mental shift that comes with the socio-techno-economic paradigm of the 6th Kondratieff wave.

Literature:

Ausubel, J.H., C. Marchetti, and P. Meyer (1998) *Toward green mobility: the evolution of transport,* European Review, vol. 6, no. 2, 137-156.

AVV (2003) *Inventarisatie Terminals en Regionale overslagcentra in Nederland*, Ministerie van Verkeer en Waterstaat, Adviesdienst Verkeer en Vervoer, Rotterdam.

Bontekoning, Y.M., Macharis C., and Trip J.J. (2004) *Is a new applied transportation research field emerging? – A review of intermodal rail-truck freight transport literature,* Transportation Research, Part A: Policy and Practice, 38, 1-34.

Brolsma, J.U. (2010) *Beknopte geschiedenis van binnenvaart en vaarwegen – de ontwikkeling van natte infrastructuur in Nederland*, Rijkswaterstaat, The Netherlands.

Connect (2003) *Deelrapportages Distrivaart,* compact disk containing full documentation on the various aspects of the Distrivaart project, Connect, Delft.

De Scheepvaartkrant (2012) *Bondsdag staat voor keuze van uitbouwvariant Donau*, 19 december 2012.

EC (2005) *TRANS-EUROPEAN TRANSPORT NETWORK, TEN-T priority axes and projects 2005*, European Commission, Energy and Transport DG.

EC (2006) *Keep Europe moving, Sustainable mobility for our continent, Mid-term review of the European Commission's 2001 transport White Paper*, Directorate-General for Energy and Transport, European Commission.

EC (2011) Connecting Europe: The new EU core transport network, MEMO/11/706, European Commission.

Geerlings, H. (1998) *The rise and fall of new technologies: maglev as technological substitution?*, Transport Planning and Technology, vol. 21, pp. 263-286.

Groothedde, B. (2005) *Collaborative logistics and transportation networks, a modelling approach to hub network design*, Trail Research School, Delft.

Grübler, A. (1990) *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport,* Physica-Verlag Heidelberg.

INE (no date) *Water Transport, Trans-European Waterways*, Inland Navigation Europe, Brussels, www.inlandnavigation.org.

Jackson, T. (2010) *Welvaart zonder groei, economie voor een eindige planeet*, Uitgeverij Jan van Arkel, Utrecht.

Macharis, C., T. van Lier, E. Pekin, A. Verbeke (2011) *Intermodaal Binnenvaartvervoer, Economische en ecologische aspecten van het intermodaal binnenvaartvervoer in Vlaanderen*, Uitgeverij VUBPRESS, Brussels, Belgium.

Matze, A. (2010) *Structurele veranderingen in achterlandtransportketens van de containerbinnenvaart*, Erasmus University Rotterdam.

Petersen, M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, and A. Ulied (2009) *TRANSvisions: Report on Transport Scenarios with a 20 and 40 year Horizon, Final Report*, Funded by DG TREN, Copenhagen, Denmark.

Platz, T.E. (2009) *The Efficient Integration of Inland Shipping into Continental Intermodal Transport Chains: Measures and Decisive Factors*, TRAIL Thesis Series Volume T2009/11, Trail Research School, Delft, The Netherlands.

Pry, R.H. (1988) *The Changing Nature of Industrial Management*. Draft, IIASA, Laxenburg, Austria, March 1988 (reference obtained from Grübler, 1990).

Reuters (2013, 11 December) *Seine canal project could be 3 bln euros cheaper –report*, http://uk.reuters.com/article/2013/12/11/france-canal-idUKL6N0JQ3O520131211.

Schuttevaer (2012) *Seine-Nord in handen van commissie*, Parijs, 26 oktober 2012.

Tavasszy, L.A., L.M. van der Lugt, G.R. Janssen, and E. Hagdorn – Van der Meijden (2010) *Verkenning Synchromodaal Transportsysteem*, TNO, Delft.

United Nations (2001) *Terminology on Combined Transport*, New York and Geneva.

United Nations (2004) *Manual on modernization of inland water transport for integration within a multimodal transport system*, Economic and Social Commission for Asia and the Pacific, ST/ESCAP/2285.

UNECE (2006) *Inventory of Main Standards and Parameters of the E Waterway Network*, Economic Commission for Europe, United Nations, New York and Geneva.

UNECE (2011) *White paper on Efficient and Sustainable Inland Water Transport in Europe*, Inland Transport Committee, Working Party on Inland Water Transport.

Van Dorsser, J.C.M. (2004) *Economische Haalbaarheid van Palletvaart*, Erasmus Universiteit Rotterdam / Vos Logistics Organizing, Rotterdam / Nijmegen.

Visser, J., J. Francke, H. Gordijn (2012) *Multimodale achterlandknooppunten in Nederland, Een studie naar containeroverslagterminals in het achterland van Nederlandse Zeehavens - herziene versie juli 2012*, KIM, Ministerie van Infrastructuur en Millieu.

Presentations:

Crombrugge, W. van, F. Gauthey, N. Bour (4 May 2006) *Presentation to the TEN Committee,* Seine-Scheldt Committee.

Websites:

BVB (accessed: 2011) *Inland Terminals*, [www.bureauvoorlich tingbinnenvaart.nl/maps/]

EICB (accessed: 2011) *Inland Terminals*, [www.informatie.binnenvaart.nl]

European Commission (accessed: 2013) *Revision of TEN-T guidelines*, [http://ec.europa.eu/transport/themes/infrastructure/revision-t_en.htm]

Frogsmoke (accessed: 2011) *Canal Seine – Nord Europe*, [www.frogsmoke.com]

Inlandlinks (accessed: 2013) *Overview of intermodal terminals,* [http://www.inlandlinks.eu/nl]

The Rochefeller University (accessed: 2013) *Transport Infrastructure Networks*, [http://phe.rockefeller.edu/green_mobility/]

UNIT45 (accessed: 2011) *Properties of 45 foot containers*, [www.unit45.com]

Wayz (accessed: 2014) *Synchromodal Transport Provider*, [www.wayz.nu]

9 Effect of Climate Change on IWT

"In 1540, people spoke of the great solar year. It was very hot and very dry in Europe for months. In Basel 10 days rain fell in 10 months' time. The Rhine at Cologne contained virtually no water and was unnavigable."
- Buisman (Thousand years of weather, wind, and water in the Netherlands – Part 3, 2003, translated)

9.1 Introduction

This chapter addresses methodological sub question 2c (MSQ 2c): *"How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system"* of which the third driver has been identified as: *"the adverse very long term effects of climate change and morphological changes on the performance of the IWT system?"*. According to the 4th assessment report of the International Panel on Climate Change (IPCC) all global climate models agree on an increase in mean global temperature by 1.1 to 6.4 degrees Celsius over the 21st century (IPCC, 2007)[99]. Temperature rise causes sea level rise as well as major changes to the weather system, such as changed precipitation patterns and an increased number of extreme events. These changes are likely to affect the transport system and the IWT system in particular (Koetse and Rietveld, 2009).

In addition to climate change the quality of the IWT system is also affected by large- and small scale changes to the morphology of the river. Large scale changes can be related to the vertical movement of the entire river bottom (i.e. the effect of subsidence and uplift). Some areas show considerable vertical movement while others contain *'hard spots'* for which the bottom is stable and no subsidence or uplift takes place. This unequal movement of the river bottom creates barriers, that have a negative impact on the available draft for inland shipping. Small scale changes to the river morphology concern the effects of erosion and sedimentation, which are affected by the variation in water discharge volumes as well as by the prevailing and future waterway policies that affect the shape of the river. Turpijn and Weekhout (2011, p.48) warn that a nautical bottleneck between Lobith and Emmerich can already be expected before the year 2020 if insufficient action is taken to mitigate the adverse morphological effects that presently take place. Such effects will become even worse in combination with extreme low water levels, that are caused by the effects of climate change.

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[99] Temperature rise measured in °C for period 2090-2099 relative to period 1980-1999; A new 5th IPPC assessment report was published in 2013, for which the scenarios are not very different from the 4th assessment report. The available studies for the effects on the inland waterways are still based on the 4th assessment report.

Considerable research has been conducted on the effects of climate change ever since the publication of the first IPCC assessment report in 1990. Research on the effects of climate change for inland shipping started around the year 1995. The overall research methodology for estimating the effects on the IWT system generally covers three steps. The first step deals with the conversion of global climate scenarios into regional climate scenarios (e.g. the West European climate system); the second step relates to the hydraulic- and preferably also morphological modelling of the concerned river systems (e.g. by defining the discharge volumes and water levels along the river Rhine); and the last step finally deals with the effects of climate change on inland shipping as well as with the possible options for mitigation and adaptation. This general methodology does however still confines itself to the effects of very low- and high discharge levels, while climate change may also impose other restrictions to inland shipping, such as caused by sea level rise, adverse storm conditions, and extreme cold weather. Table 9-1 lists the identified adverse effects of climate change on inland shipping.

Table 9-1: Adverse Effects of Extreme Weather Conditions

Extreme weather condition	Adverse effects on IWT
A: Very low precipitation levels in combination with high evaporation levels resulting in exceptionally low river discharge volumes and water levels.	A1: Unnavigable rivers: water levels become too low for barge operations to be continued on certain river sections. A2: Reduced barge capacity: lower available draft results in reduced cargo weight that can be shipped by the barge. A3: Navigational restrictions: low water levels result in a smaller navigational width and depth of the waterway. This constrains the allowed number of dumb barges in push convoys.
B: Very high precipitation levels resulting in exceptionally high river discharge volumes and water levels.	B1: Safety measures against flooding: several policy measures including speed limits, reduced maximum number of dumb barges in push convoys, and eventually total blockage of the waterway. B2: Safety measures against unsafe navigation caused by high current velocities (such as for instance near the Loreley rock that is located in the middle section of the Rhine where the river makes a sharp and dangerous bend; see Figure 2-5): several policy measures including speed limits, reduced maximum number of dumb barges in push convoys, and eventually total blockage of the waterway. B3: Height restrictions: high water levels result in a lower available air draft underneath bridges. This reduces the number of container layers that can be loaded on board of a container barge.
C: Very strong winds that restrict barge operations and raises sea water level if they are directed onshore.	C1: Manoeuvring: strong winds may result in large wind forces on the barges. This imposes restrictions on the number of containers that can be loaded, in particular when loading empty containers. C2: Stability: strong winds result in high waves and large heeling moments that may impose restrictions on the number of containers that can be loaded for stability reasons. C3: Loading and unloading: strong winds may result in a shutdown of (container) terminal operations. Container handling is often terminated at wind speeds over about 15 m/s. C4: Closing of sea port areas: strong (onshore) winds result in higher sea levels (in front of the Dutch coast). This may result in closing of port areas such as a closure of the Maeslant Barrier in Rotterdam. C5: Closing of inland ports in the lower delta: as above, but now affecting accessibility of smaller inland ports.
D: Extreme cold weather conditions related to ice and snow.	D1: Freezing of waterways: in case of frozen waterways shipping will no longer be possible without a sufficient strong ice breaker. D2: Snow on terminals: in case of considerable snowfall terminals may be closed for several hours to clear the area from snow.

Source: Own composition that takes into account the literature referred to in this chapter.

Taking the abovementioned issues into consideration it becomes clear that a full assessment of the very long term navigability of the inland waterways includes the effects of: (1) increased variance in river discharge volumes due to climate change; (2) morphological changes to the riverbed due to: changes in river discharge volumes, subsidence or uplift, and prevailing river management; (3) sea level rise; (4) changes in the prevailing wind conditions (e.g. storm conditions); and (5) changes in cold weather conditions (e.g. ice and snow). A schematic structure for dealing with the effects of climate change and morphological changes on the IWT system is indicated in Figure 9-1.

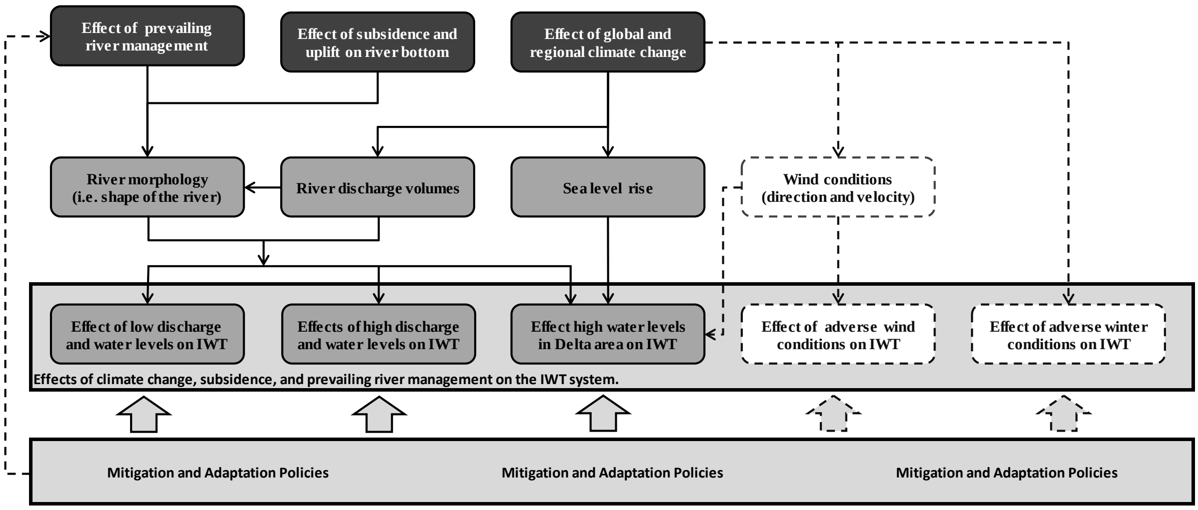


Figure 9-1: Effect of Climate Change and Morphological Changes on the IWT System

The effect of climate change on the performance of the West European IWT system has been assessed by a number of studies including: Timmermans (1995), Nomden (1996, 1997), Van Geenhuizen et al. (1996), Harris (1997), Deursen (1998), Middelkoop (1999), AVV (2000), RIZA (2005), Bosschieter (2005), Jonkeren (2009), Demirel (2011), Turpijn and Weekhout (2011), and Riquelme Solar (2012). There is general agreement along these studies that the most severe impacts on inland shipping are related to the occurrence of extreme low water levels. In addition the effects of extreme high water levels are also often mentioned, but less research has been conducted on this subject until now. The other topics received virtually no attention which raises the question if they can be neglected.

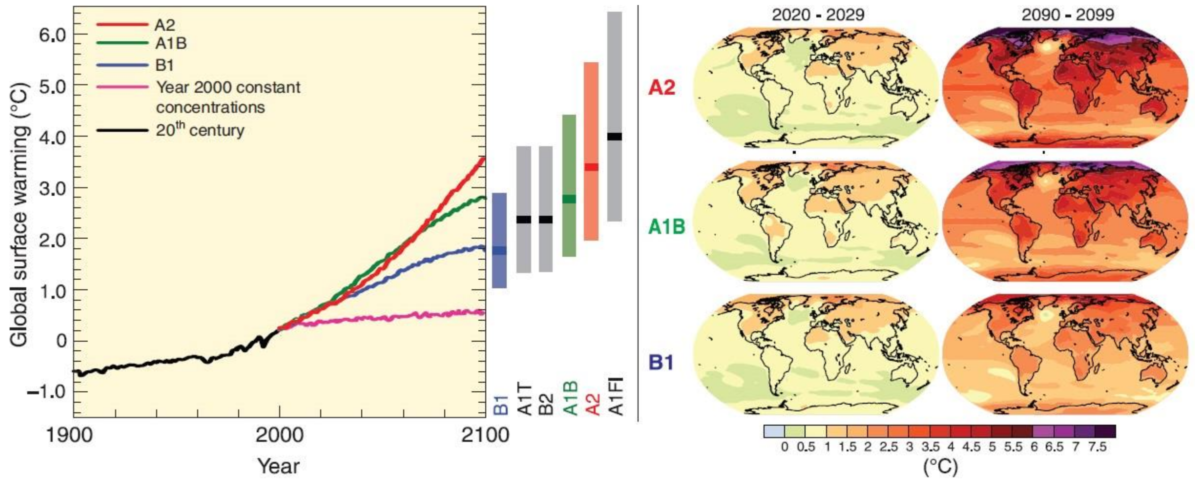
This chapter aims to reveal the state-of-the-art knowledge on the effects of changing climate conditions for inland shipping. The various sections address: (1) *the effects of climate change*, (2) *the effect of morphological changes in combination with climate change*, and (3) *the possible options to mitigate the effects and/or to adapt to the new situation*. Section 9.2 starts with a discussion of the presently applied global and regional climate scenarios; Section 9.3 continues with the perceived effects of these climate scenarios on the regional river discharge and water level projections; Section 9.4 addresses the effect of low water discharge on the performance of inland shipping; Section 9.5 incorporates the morphological effects in the analysis. Section 9.6 addresses the effects of high water discharge on the IWT system; Section 9.7 deals with other effects of climate change, that are related to sea level rise, extreme wind conditions, and extreme winter weather; Section 9.8 starts with a discussion on the price (or cost) elasticity for IWT and applies this elasticity to estimate the low water impacts of climate change on the overall IWT volumes; Section 9.9 identifies possible adaptation strategies, that can be applied in response to the changing climate conditions for IWT; and Section 9.10 contains a concluding summary that provides an answer to MSQ 2c.

9.2 Climate Change Scenarios

The effects of climate change are generally addressed by scenarios. This section discusses the global SRES climate scenarios of the IPCC as well as the Dutch climate scenarios.

9.2.1 Global emission scenarios and regional climate projections

The global climate scenarios of the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) are based on the IPCC (2000) *"Special Report: Emission Scenarios"* (SRES). The SRES scenarios are intended to define the effect of greenhouse gas emissions on the global climate system. A summary of the effects on global temperature rise as perceived by the various SRES scenarios is provided in Figure 9-2.



Source: IPCC (2007, p.46).

Figure 9-2: Effect of SRES-Scenario Projections on Global Surface Warming

"*The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The SRES scenarios do not include additional climate policies above current ones. The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change"* (IPCC, 2007, p.44).

The IPCC deliberately choose to investigate not only the difference in the main values of the scenario projections, but also the uncertainty levels related to the quantification of the scenarios, that are indicated by the bars in Figure 9-2 (left). To cover a wide range of possible ramifications they requested six modelling teams to quantify the storylines of the four scenario families. This exercise resulted in a total of 40 different SRES projections for the six abovementioned story lines (IPCC, 2000). The emission projections were further used as input to a number of different General Circulation Models (GCMs). The results of the GCM runs, that were conducted in the framework of the 4th assessment report (AR4), were made accessible for further research. They serve as input to Regional Climate Models (RCMs), that estimate the effects of climate change in a certain region, such as Western Europe or the Netherlands. This large ensemble of emission based climate scenarios was, for instance, also used as input for the development of the Dutch national KNMI'06 climate scenarios, that will be discussed in the next subsection.

9.2.2 The Dutch climate scenarios

The Dutch have a relatively long tradition with the development of climate scenarios (Van den Hurk et al., 2006). National research on the effects of climate change started almost directly after the publication of the first assessment report (IPCC, 1990) with a project funded by the National Research Programme on Climate Change in 1991. This project provided valuable insights in the relation between the mean daily precipitation volumes and the mean temperature on wet days (Buishand and Klein Tank, 1996).

The previous generation WB21 scenarios

The high water levels of 1993 and 1995 triggered the Dutch water managers to prepare for the challenges related to the rising sea levels and higher maximum river discharges. A more formal set of climate scenarios was developed in the project *'Water Management in the 21st century' (WB21)* by Kors et al. (2000) and Können (2001). These scenarios initially contained a low, central, and high scenario. In a later stage two additional scenarios were added. The first additional scenario that was based on Klein Tank and Können (1997) assumed that global temperature rise would be accompanied by a strong decline of the Atlantic thermohaline circulation, that results in a relative strong cooling of Northwest Europe. The second additional scenario was based on early evidence from climate models that higher temperatures could also lead to changed circulation patterns resulting in very dry weather conditions during the summer. This scenario was eventually turned into a *'extreme drought'* scenario by Beersma and Buishand (2002) that contributed to a National Drought Study (RIZA, 2005). An overview of the main properties of all five WB21 scenarios is provided by Van den Hurk et al. (2006) for the year 2050. An extension of the low, central, and high WB21 scenarios up to the year 2100 is provided by De Wit et al. (2007).

The present generation KNMI'06 scenarios

New insights stemming from improved climate models lead to the development of a new set of climate scenarios. The initial publication by Van den Hurk et al. (2006) presented the KNMI'06 scenarios up to the year 2050. An extended version of the scenarios up to the year 2100 was published shortly thereafter on the internet (www.knmi.nl; see also De Wit et al., 2007). An interesting feature of the KNMI'06 scenarios is that they depart from global temperature rise instead of greenhouse gas emissions. This was done deliberately because the spread in the outcome of the scenario models for the distinct emission scenarios (i.e. A1T, A1B, A1FI, A2, B1, and B2) is equally important as the spread in the mean scenario values – and because the KNMI'06 scenarios are not intended to reflect on the effects of greenhouse gasses, but on the potential challenges for the Dutch living environment. The four KNMI'06 scenarios (G, W, G+, W+) are developed around two driving forces being: (1) the degree of global temperature rise, and (2) the anticipated changes of the atmospheric circulation patterns in our region. The applied letters G and W stand for moderate (G) and high (W) temperature rise. Strong changes to the atmospheric circulation (and precipitation) patterns are indicated with a *'+'*. The main properties of the KNMI'06 scenarios are indicated in Table 9-2.

Table 9-2: Details of the KNMI'06 Scenarios

Scenario	2050 G	2100 G	2050 W	2100 W	2050 G+	2100 G+	2050 W+	2100 W+
Global temperature rise	+1°C	+2°C	+2°C	+4°C	+1°C	+2°C	+2°C	+4°C
Change in air circulation patterns	no	no	no	no	yes	yes	yes	yes
Winter								
average temperature	+0.9°C	+1.8°C	+1.8°C	+3.6°C	+1.1°C	+2.3°C	+2.3°C	+4.6°C
coldest winter day per year	+1.0°C	+2.1°C	+2.1°C	+4.2°C	+1.5°C	+2.9°C	+2.9°C	+5.8°C
average precipitation amount	0.04	0.07	0.07	0.14	0.07	0.14	0.14	0.28
number of wet days (≥0,1 mm)	0	0	0	0	0.01	0.02	0.02	0.04
10-day precipitation sum exceeded once in 10 years	0.04	0.08	0.08	0.16	0.06	0.12	0.12	0.24
maximum average daily wind speed per year	0	-0.01	-0.01	-0.02	0.02	0.04	0.04	0.08
Summer								
average temperature	+0.9°C	+1.7°C	+1.7°C	+3.4°C	+1.4°C	+2.8°C	+2.8°C	+5.6°C
warmest summer day per year	+1.0°C	+2.1°C	+2.1°C	+4.2°C	+1.9°C	+3.8°C	+3.8°C	+7.6°C
average precipitation amount	0.03	0.06	0.06	0.12	-0.1	-0.19	-0.19	-0.38
number of wet days (≥0,1 mm)	-0.02	-0.03	-0.03	-0.06	-0.1	-0.19	-0.19	-0.38
daily precipitation sum exceeded once in 10 years	0.13	0.27	0.27	0.54	0.05	0.1	0.1	0.2
potential evaporation	0.03	0.07	0.07	0.14	0.08	0.15	0.15	0.3
Sea level								
absolute increase	15-25 cm	35-60 cm	20-35 cm	40-85 cm	15-25 cm	35-60 cm	20-35 cm	40-85 cm

Note: the KNMI'06 climate change scenarios are relative to the base year 1990.

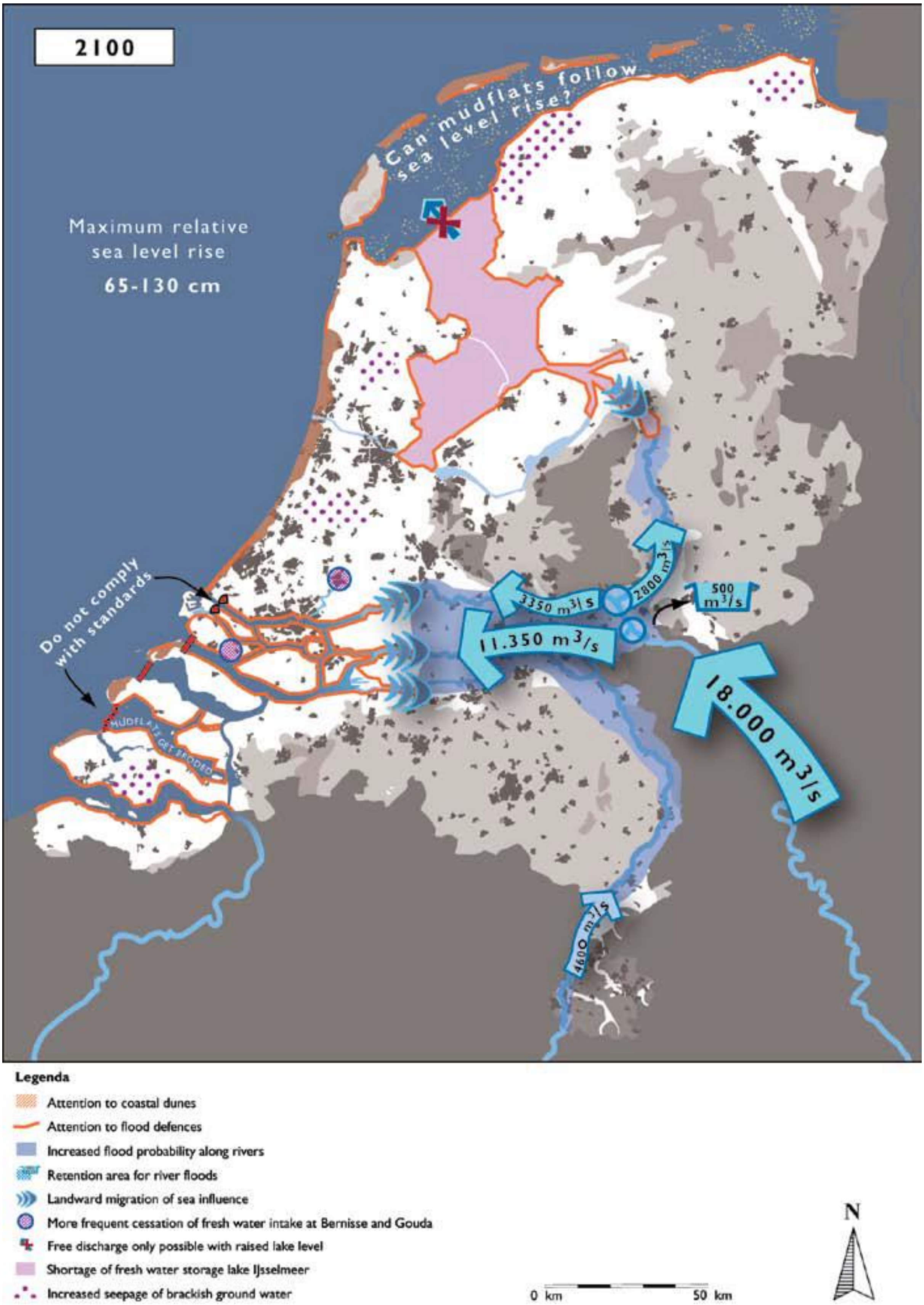
Source: http://www.knmi.nl/climatescenarios/knmi06/index.php (accessed: 2011).

The KNMI (2012, p.19) indicates that the scenarios are still in line with the IPCC projections for global warming as: *"By means of the global mean temperature, an indirect relationship between the KNMI scenarios and emission scenarios can be established. This involves estimating a "likelihood of occurrence" given future GHG emissions. For example, each of the four KNMI'06 scenarios may occur under each IPCC emission scenario for 2050. For 2100, the G/G+ scenarios (2°C global temperature rise) are most representative for a low B1 emission scenario under an average estimate for the climate sensitivity, whereas the W/W+ scenarios (4°C rise) are more likely under a high A1FI scenario"*.

The high-end climate scenarios of the second Delta Committee

To safeguard the Netherlands from floods and guarantee the availability of sufficient fresh water a second *'Delta Committee'*[100] was installed in 2007 to prepare an outline strategy for dealing with the main challenges ahead up to year 2100/2200 (Delta Committee, 2008). This committee investigated the high-end spectrum of the effects of climate change for flooding (Vellinga et al., 2009). The Delta Committee concluded that the Dutch sea level may rise by 0.65 to 1.3 meter in 2100, and by 2 to 4 meter in 2200 (including the effect of land subsidence). In addition the summer discharge will decrease and the winter discharge will increase for the river Rhine and Meuse due to changed precipitation patterns. For the year 2100 the maximum (design) discharges of the Rhine and Meuse are defined as 18,000 m^3/s and 4,600 m^3/s, respectively. Present design discharges are 16,000 m^3/s and 3,800 m^3/s. The high-end scenarios of the second Delta Committee should be interpreted in a different way than the abovementioned scenarios of the IPCC (2000) and KNMI (2006), because they are *"explicitly concerned with the upper limit of the possible values under certain assumptions rather than the bandwidth of most probable values"* (Delta Committee, 2008, p. 108). The implications of the high-end scenario of the Delta Committee are indicated in Figure 9-3.

[100] The first Delta Committee was installed directly after the disastrous flood of 1953. Based on the advice of the first Delta Committee the Dutch coastal zone has been completely reshaped by the *'Delta Project'*.



Source: Deltacommissie (2008, p. 30)

Figure 9-3: High-end Scenario of the Delta Committee for the year 2100

In case of extreme sea level rise and river discharge the Eastern Scheldt and Maeslant barriers will no longer comply with their design standards; the IJsselmeer will no longer be able to discharge freely into the North Sea unless the water levels are raised significantly; and the sea influence (i.e. salt intrusion) will migrate further upstream towards Gorinchem and Kampen.

In response to the recommendations of the second Delta Committee, the Dutch government started a new programme that is referred to as the second *'Delta Programme'*. It is interesting to note that the Delta scenarios for water discharge and sea level rise, that are applied in the new Delta Programme, are not based on the high-end scenarios of the Delta Committee, but on the KNMI'06 scenarios for sea level rise that preceded them (Bruggeman et al., 2013). This implies that the high-end scenarios of the Delta Committee are somehow perceived too extreme. However, despite the relatively small chance that the high-end scenarios of the Delta Committee will occur they are still relevant, because they clearly indicate the perceived upper limits for the effects of climate change on the Dutch water system.

<u>The next generation KNMI'14 scenarios</u>
By the time of finalising this thesis the KNMI published its new KNMI'14 scenarios (KNMI, 2014). The new KNMI'14 scenarios are not very different from the KNMI'06 scenarios that I took into account, though the names have changed from G, G^+, W, and W^+ to G_L, G_H, W_L, and W_H. In addition the far time horizon is set at the year 2085 instead of the year 2100. This was done because the climate is generally defined by a 30 year period (in this case 2071 to 2100) and because most climate models do not go beyond the year 2100. The reference year shifted from 1990 to 1995 (the year 1995 represents the period from 1981 to 2010). Global temperature rise is assumed to increase by +1.0°C and +2.0°C in the year 2050 and by +1.5°C and +3.5°C in the year 2085 (compared to the reference year 1995). This implies that global temperature rise is slightly higher in the KNMI'14 scenarios than in the KMNI'06 scenarios. Sea level rise is also not much different and now expected to increase by 15 to 40 cm in the year 2050 and by 25 to 80 cm in the year 2085 (compared to the year 1995).

9.3 Effect of Climate Change on Discharge and Water Levels

The changing climate conditions will also affect the discharge volumes on the waterways. For free flowing rivers such as the river Rhine and the Gelderse IJssel the discharge volumes will directly affect the height of the water levels. In case of low water the maximum draft and loading capacity of inland barges is restricted by the most critical waterway section on the route (i.e. the one that contains the lowest available water depth). The most critical sections on the Rhine are located near Lobith[101] for the stretch between Rotterdam and Ruhrort (i.e. the port area within the city of Duisburg) and near Kaub for all shipments further upstream up to Basel (EICB, 2011). The effect of climate change on the water levels is much smaller for canalized rivers such as the Meuse, because it is relatively easy to retain water on the stretches in-between the locks. Research efforts are therefore mainly devoted to the effect of climate change on the discharge volumes and corresponding water levels of free flowing rivers. This section addresses the effects of climate change (as reported by the IPCC SRES and KNMI'06 scenarios) on the river discharge volumes and water levels for the rivers Rhine and Meuse.

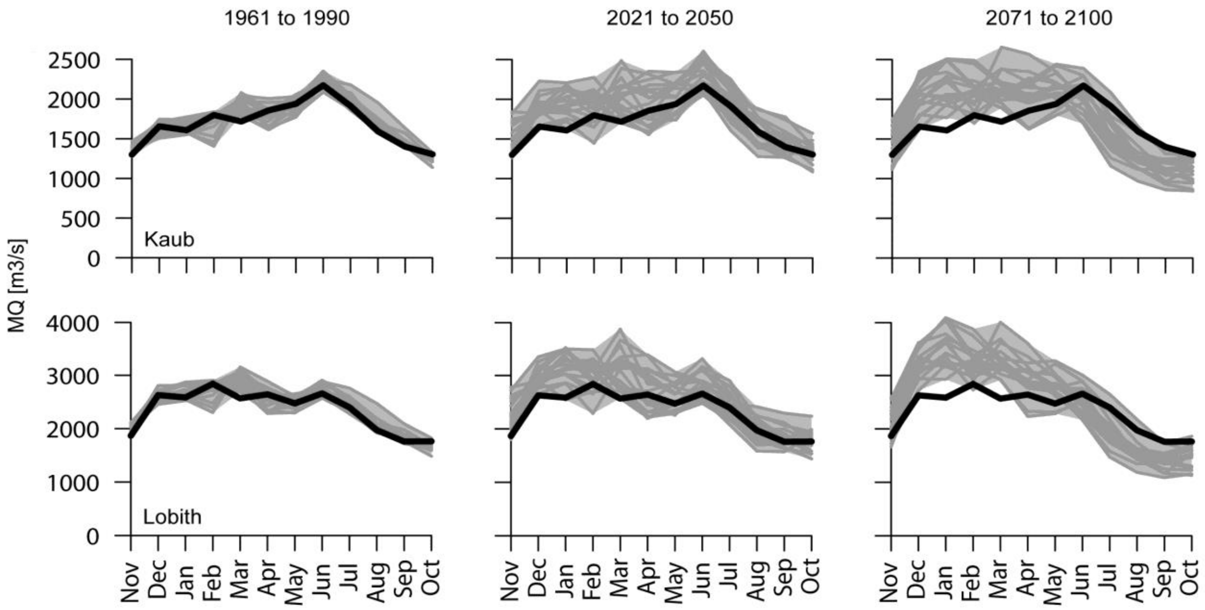
[101] It should be noted that the exact location of this critical river section is not fixed and changes over time. It was understood from a river expert of Rijkswaterstaat that the most critical section is in fact not yet located at Lobith, but expected to be located at Lobith in the near future.

9.3.1 The effect of climate change on river discharge volumes

Regional climate projections can be used for the development of river discharge projections by applying hydrological models. Much research efforts have been put into the modelling of the hydrological effects of climate change since the early 1990s, in particular for the river Rhine. The *RheinBlick2050* project (Görgen et al., 2010) of the expert group KLIMA of the International Commission for the Protection of the Rhine (ICPR) for instance referred to the: *ACER*, *AdaptAlp*, *AMICE*, *CCHydro*, *ClimChAlp*, *FLOW-MS*, *KlimaLandRP*, *KLIWA*, *KLIMAS*, *InKlim*, *NeWater*, *ParK*, *SWURVE*, and *VULNAR* projects. In the Netherlands research on the effects of climate change has been conducted in the framework of the two projects: *'Climate Changes Spatial Planning'* (Dutch: *'klimaat voor ruimte'*) and *'Knowledge for Climate'* (Dutch: *'kennis voor klimaat'*)[102].

Water discharge projections of the RheinBlick2050 Project

The RheinBlick2050 project provides a good overview of the existing projections, because it was designed as an advanced 'meta'-project, that combines the results of large ensembles of scenario runs from earlier climate studies. The Rheinblick2050 study covers large ensembles of scenario runs for many combinations of SRES emission scenarios (mainly A1B and a few A2 and B1), general circulation models (GCMs), regional climate models (RCMs), and hydrological models into a joint bundle of projections. The output was reported for a total of eight different gauge stations along the Rhine. The results for the gauge stations of the two most critical river sections near Lobith and Kaub (i.e. those imposing the most important draft restrictions for inland shipping; see Figure 2-5 for their location) are indicated in Figure 9-4.



Note: Dark grey lines provide simulation results, black line shows reference simulation for 1961-1990 period; MQ stands for the mean discharge volume in the various months that are shown in the figure.
Source: Görgen et al. (2010, p.112, reduced content).

Figure 9-4: Rheinblick2050 Ensembles of River Discharge Projections

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[102] Reference can be made to the websites of these research programmes, which are: www.klimaatvoorruimte.nl, and http://kennisvoorklimaat.klimaatonderzoeknederland.nl/.

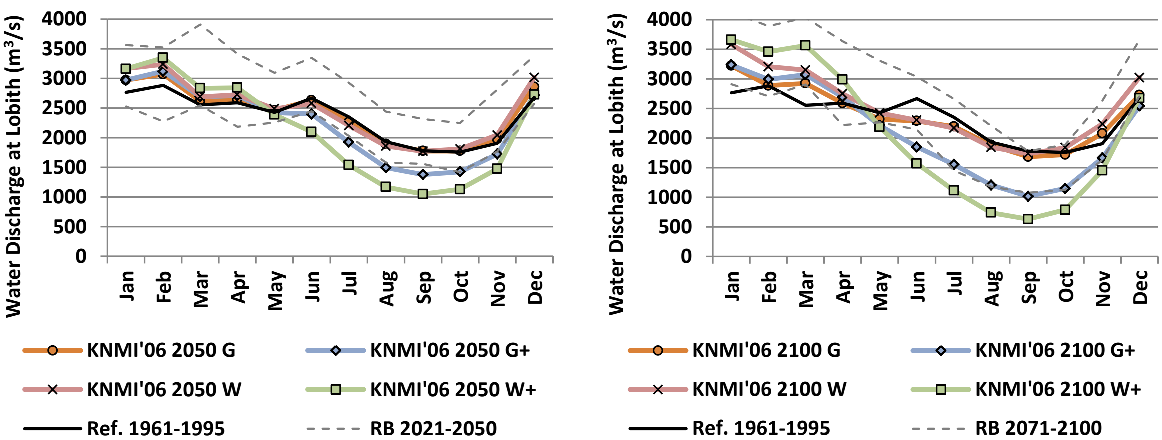
The results indicate that the applied methodology to combine large ensembles of scenario runs into a single bundle of projections works out well, but there remain some drawbacks:

- The method is very data intensive, which makes it expensive and impractical;
- The output is biased as not all the SRES scenarios were covered (it does for example not cover the implications of the most severe A1FI scenarios);
- Knowledge on climate change modelling is still incomplete and the exercise has been dominated by a few GCMs, RCMs, and hydrological models;
- The effects of morphological changes are not yet included in the calculations.

The results of the Rheinblick2050 project nevertheless provide a sensible indication of the possible effects of climate change in the A1B, A2, and B1 scenarios.

Water discharge projections based on the KNMI'06 climate scenarios

River discharge projections are also available for the KNMI'06 climate scenarios. These projections may provide additional insight as they are not biased towards a few scenarios and implicitly cover the possible effect of the 1AFI scenario. The hydraulic implications of the KNMI'06 climate scenarios for water discharge into the rivers Rhine and Meuse are reported by Te Linde (2007, 2011) and De Wit et al. (2007) for the year 2050, and by Kwadijk et al. (2008, p.73) for the year 2100. I am unaware of any research on water distribution and water discharge levels into the Gelderse IJssel, but insight in the effect of climate change on the Gelderse IJssel is also important and further research is therefore recommended.



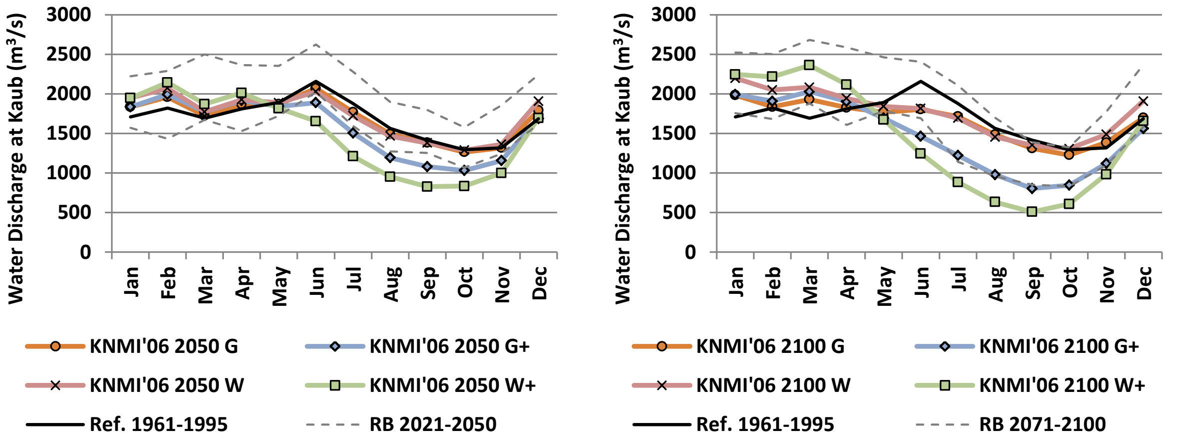
Source: Data measured from Te Linde (2011, p.65) for the year 2050, Kwadijk et al. (2008, p.73) for the year 2100, and Görgen et al. (2010, p.112) for the periods 2021-2050 and 2071-2100.

Figure 9-5: Discharge of Rhine near Lobith in KNMI'06 Scenarios for 2050 and 2100

Figure 9-5 shows the available projections for the discharge volumes of the Rhine near Lobith based on the KMNI'06 climate scenarios for the years 2050 and 2100 as well as the upper and lower bandwidths of Rheinblick2050 (RB) project for the periods 2021-2050 and 2071-2100. It is interesting to observe that the extreme Rheinblick2050 projections for the wet season are considerable higher than those of the KNMI'06 climate scenarios. On the other hand the W+ scenario fills in the gap of the lacking A1FI projections in the Rheinblick2050 study as it shows a considerable lower summer discharge.

Figure 9-5 further points out the existence of a six months lasting wet season (December – May) and a six months lasting dry season (June – November). All scenarios indicate an increase in river discharge during the winter. This increase is mainly related to the rising global temperature. The Rhine is traditionally a combined rain-snow river for which the melting of snow provides a stable steady water flow throughout the year. The global temperature rise causes the river to become more rain orientated, which is reflected by the higher discharge volumes in the winter for all scenarios. The summer discharge can, at least in theory, be expected to decrease as a result of the reduced snow based water flow into the river. This is clearly observed in the enhanced air circulation change scenarios (i.e. the + scenarios), but quite interesting almost no change can be observed in the standard G and W scenario. For these scenarios the reduced snow based flow is fully compensated by an increased amount of rain during the summer.

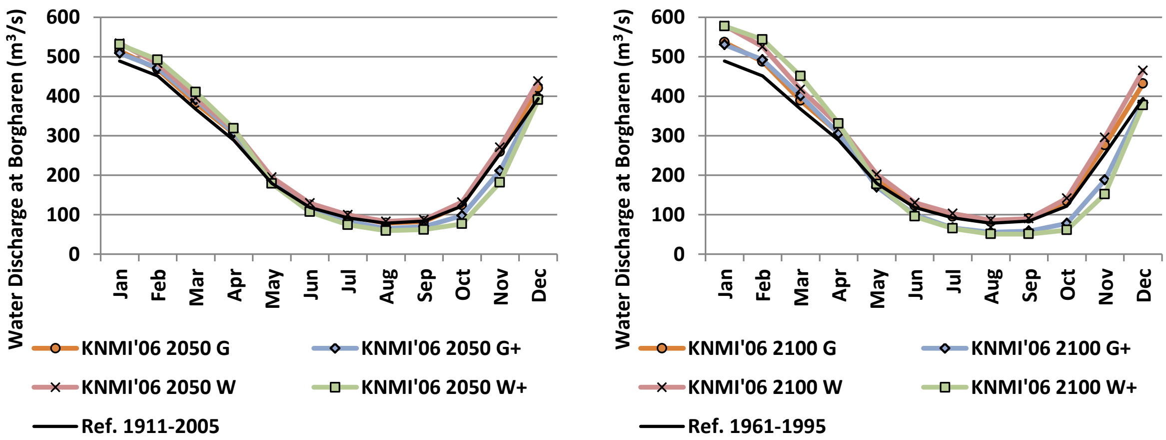
River discharge projections based on the KNMI’06 climate scenarios were not reported for the Kaub station, but insight in the development of the river discharge volumes near Kaub is still required to investigate the effect of climate change for shipping in the upper Rhine segment. I have therefore estimated the discharge volumes for the KNMI’06 climate scenarios at Kaub on the basis of the discharge volumes at Lobith, and an approximate relation between the upper and lower discharge values based on the Rheinblick2050 projections for Lobith and Kaub (i.e. for each month the relation between the discharge volumes at Lobith and Kaub were defined as a straight line between the lower and upper bandwidth of the projections; see also the corresponding calculation file that is referred to in Appendix F). The estimated values are indicated in Figure 9-6.



Source: Own calculation based on Te Linde (2011, p.65) for the year 2050, Kwadijk et al. (2008, p.73) for the year 2100, and Görgen et al. (2010, p.112) for the periods 2021-2050 and 2071-2100.

Figure 9-6: Discharge of Rhine near Kaub in KNMI’06 Scenarios for 2050 and 2100

River discharge projections based on the KNMI’06 climate scenarios have also been reported for the river Meuse at Borgharen. The available scenarios are indicated in Figure 9-7. It can be observed that the river Meuse shows a similar seasonal effect as the Rhine. Winter discharge is expected to increase in all scenarios. Summer discharge remains more or less similar in the G and W scenario, and decreases in the enhanced air circulation scenarios G+ and W+. For the latter scenarios the lowest average discharge volumes are reduced from about 80 m^3/s historically to 60 m^3/s in 2050 and 50 m^3/s in 2100.

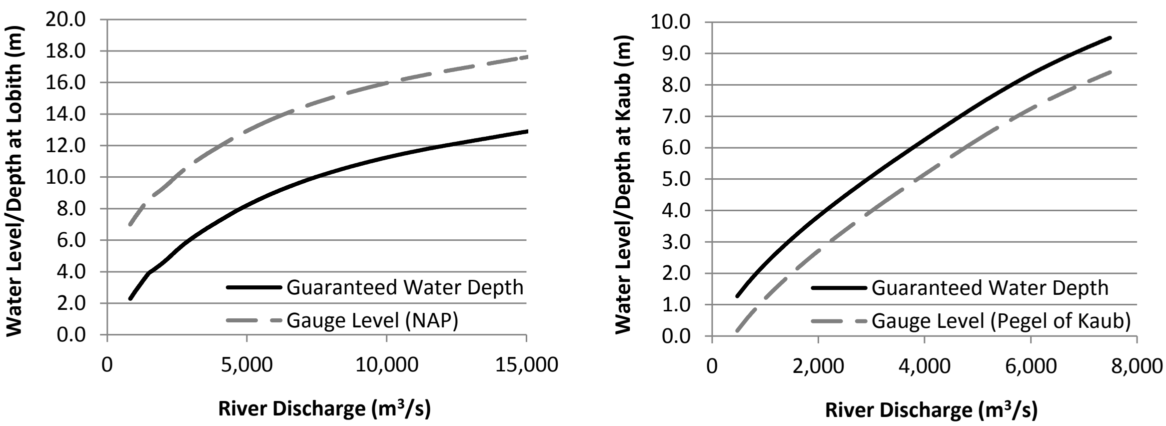


Source: Data measured from De Wit et al. (2007), and Kwadijk et al. (2008, p.73).

Figure 9-7: Discharge of Meuse near Borgharen in KNMI'06 Scenarios 2050 and 2100

9.3.2 The effect of climate change on the available water levels on the Rhine

The absolute height of the water levels (compared to a fixed reference level) is measured at various sections along the river. For the Netherlands the water levels are all compared to NAP which stands for *'New Amsterdam Level'* (Dutch: *'Nieuw Amsterdams Peil'*) in Germany the water levels are compared to various regional reference levels that are referred to as *'pegels'*. The Q-H relation between river discharge (Q) and water levels (H) is well documented for a number of gauge stations along the Rhine and can be used to convert the projected discharge flows into water levels. The Q-H relations for Lobith and Kaub are indicated with the dotted lines in Figure 9-8. The continuous line shows the water depth.



Source: The Q-H relation for Lobith was obtained from Bosschieter (2005, p.107). The Q-H relation for Kaub was kindly provided by Deltares (Personal contact in 2010).

Figure 9-8: Q-H relation and guaranteed Water Depth for Lobith and Kaub

For free flowing rivers the absolute water level varies along the river. Specific reference levels are used to define the draft at each river section. For the Netherlands this so called *'agreed lowest river level'* (In Dutch: Overeengekomen Laagste Rivierstand, or OLR) refers to the water levels, that are not undercut more than 5% of the year on average. Rijkswaterstaat now guarantees a minimum water depth of 2.80 meters on the stretch between Rotterdam and the German border at the OLR water level (this used to be 2.50 meters up to the year 2006). The absolute height of this OLR value (compared to the Dutch NAP chart datum) varies along the river and changes over time due to morphological changes. The OLR level corresponds to a height of 7.52 meters relative to the Dutch NAP chart datum at the gauge station of Lobith (EICB, 2011; please note that this level changes over time). The guaranteed water depth at the river stretch between Rotterdam and Ruhrort can therefore be defined as:

- Gauge value of Lobith + 2.80 meter – 7.52 meter.

In Germany a similar system is in place though the OLR is replaced by a similar *'equal river level'* (In German: Gleichwertiger Wasserstand, or GLW) for which the chart datum varies for the different river stretches. The GLW depth at Kaub is defined as 1.90 meter at a gauge value (referred to as pegel) of 0.80 meter at Kaub. The available water depth for barges sailing upstream the Rhine towards a location beyond Kaub can therefore be defined as:

- Gauge value of Kaub + 1.90 meter – 0.80 meter.

The projections of the critical water depths in the various scenarios for 2050 and 2100 are obtained by applying the above relations to the available discharge projections. The results of this exercise are indicated in Figure 9-9 for the stretch between Rotterdam and Ruhrort, and in Figure 9-10 for the Rhine all the way up to Basel (restricted by Kaub area).

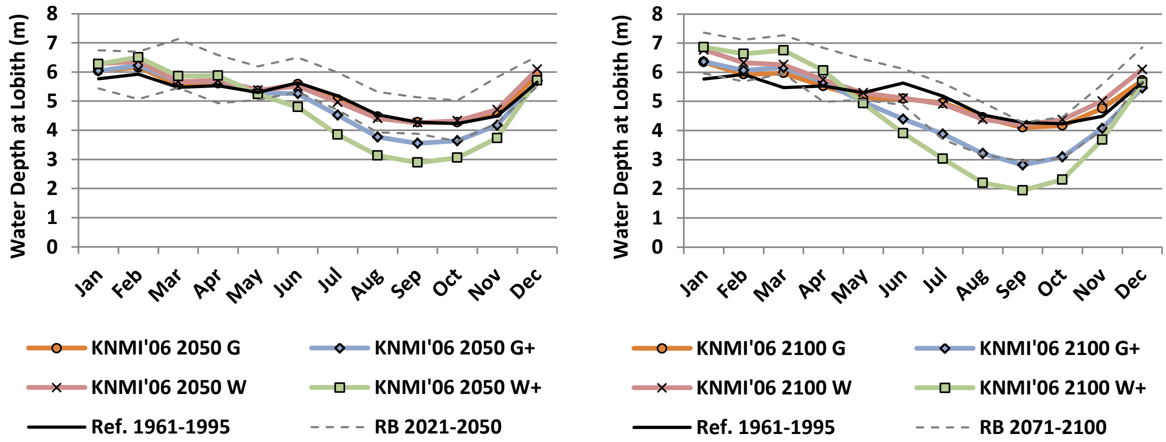


Figure 9-9: Critical Water Levels for the Rhine up to Ruhrort in years 2050 and 2100

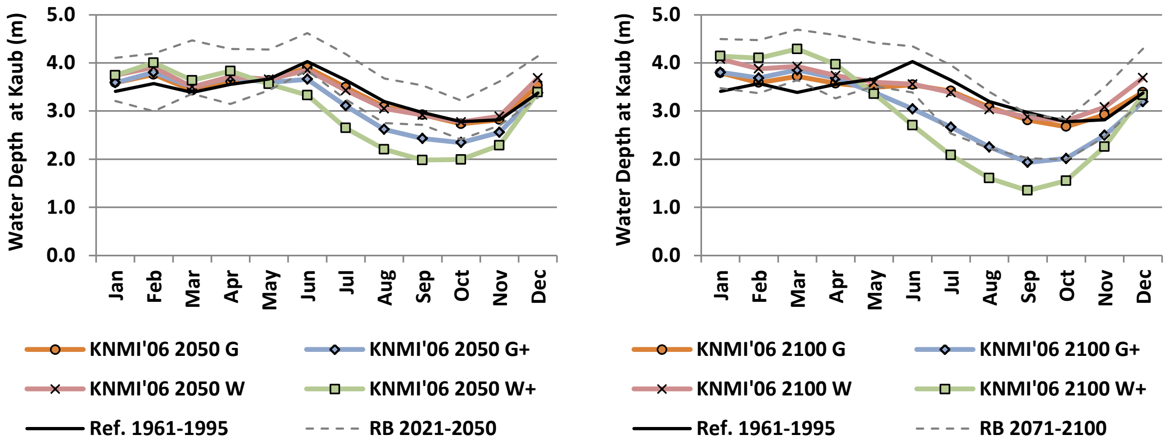


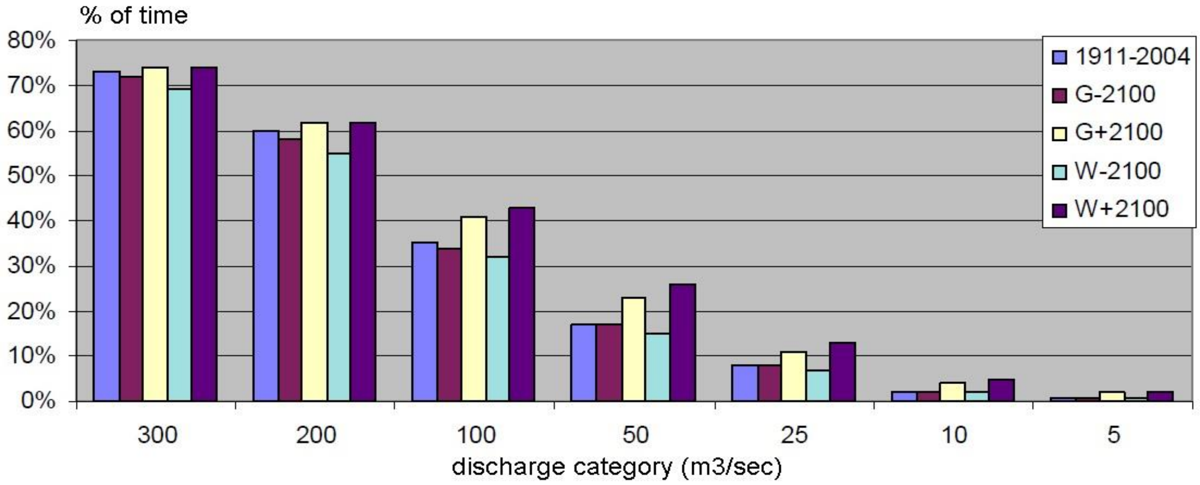
Figure 9-10: Critical Water Levels for the Rhine up to Basel in years 2050 and 2100

Figure 9-9 and 9-10 indicate that the navigability of the rivers during periods of low water discharge is not much affected in the standard W and G scenarios. The situation is different for the W+ and G+ scenarios in which inland shipping on the Rhine is expected to be severely affected. The effects are the most severe for inland shipping towards the Kaub region.

It should be noted that the estimates following from this approach are based on the current shape and maintenance level of the river. In the future new OLR and GLW water levels will be defined[103] and different standards for the minimum guaranteed water depth may be applied. The primary aim of this analysis is to provide a reasonable indication of the possible effects of climate change on the minimum available water levels for inland shipping.

9.3.3 The effect of climate change on available water levels on the Meuse

For canalised rivers such as the Meuse a one to one relation between the discharge volumes and the water depth does not exist, as the water is contained in the river stretches between the weirs. In general sufficient water depth can be guaranteed on the river Meuse by using weirs and locks that retain the water. The last time that the water levels in the river stretches sagged due to lack of water inflow was in August 1976 when the average monthly discharge of the Meuse dropped to its lowest ever measured value (measurements available since 1911) of 22 m^3/s at Liege and 2 m^3/s at Borgharen (RIZA, 2005, p.82; Beersma et al., 2004, p.52; www.waterbase.nl). Similar problems with sagging of water levels did not occur in the more recent low water periods of 1991 and 2003 that came with a discharge flow of respectively 42 and 50 m^3/s at Liège and respectively 14 and 13 m^3/s at Borgharen. The event of sagging water levels is therefore very rare (about once every century). However, it may occur slightly more frequent in the G+ and W+ scenarios for the year 2100 than today. Figure 9-11 indicates the time for which the daily discharge volumes fall below certain threshold values.



Source: Kwadijk et al. (2008, p.74), translated.

Figure 9-11: Percentage of Time that Discharge Volume at Borgharen falls below

[103] The Central Commission for Navigation on the Rhine (CCNR) defines the so called OLR and GLW water levels about every 10 years in consultation with the Rhine states. The applied levels of 7.52 meters and 0.80 meters still relate to the water levels of 2002. New levels may be defined soon after publishing this thesis.

It can be observed that the lowest threshold value for which sagging of the water levels may take place remains similar for the G and W scenarios and roughly doubles in the G+ and W+ scenarios for the year 2100. This implies that the rare event of sagging water levels may then occur once every 50 years instead of once in a century, which is still very rare. I therefore conclude that low water discharge will hardly affect inland shipping on the river Meuse.

9.4 Effect of Low Discharge and Water Levels on IWT

Low discharge and water levels affect inland shipping in three different ways (see Table 9-1 item A1, A2, and A3). These are: restrictions imposed by lack of sufficient water depth to remain sailing, restrictions on the loading capacity of the barge caused by insufficient water depth, and a restriction on the number of dumb barges that may be used in a large push barge combination. All these effects increase the average costs per tonne and thereby weaken the competitive position of inland shipping. This section addresses the effects of low river discharge on the overall performance of inland shipping. The possible adverse effects of morphological changes are not yet included. They will be discussed in Section 9.5.

9.4.1 Properties of representative barges sailing on the Rhine

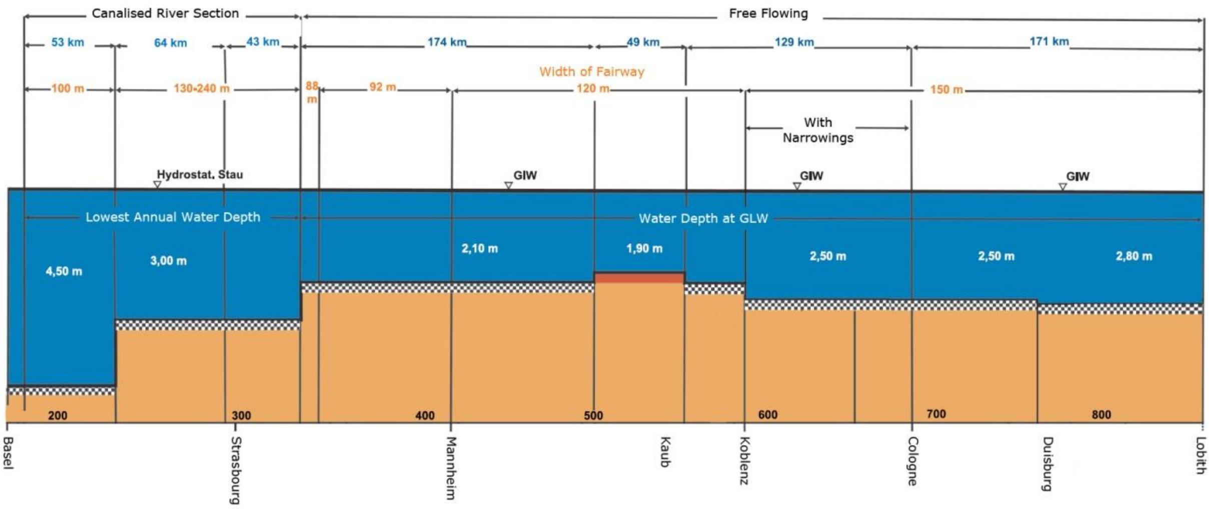
The adverse effects of climate change depend on the size of the applied barges. In general the effect of low water is more severe for larger deep drafted barges than for smaller barges with an inherent shallower draft. Impact studies often apply a certain fleet mix to take the effects on the various barge types properly into account (see e.g. Bosschieter, 2005; HKV, 2007, Turpijn and Weekhout, 2011); but this approach requires detailed insight in the very long term development of the fleet mix up to the year 2100, which cannot be obtained at such a very long time horizon. I therefore applied a simpler approach in which two representative barge types were selected for the two largest inland shipping markets on the Rhine.

The aim of this approach is to gain insight in the order of magnitude of the possible adverse effects of climate change for inland shipping, that may occur on the Rhine throughout the 21st century. It makes clear why it is necessary to take the effects of climate change into account in very long term IWT scenario studies. In future studies a more detailed analysis can be made for a larger number of geographic regions as well as a larger number of barge types that sail in these regions (e.g. by assuming a number of very long term scenarios for the development of the fleet mix up to the year 2100).

For the analysis in this chapter I took the two most important geographical market segments of the Rhine into account, which are: the Kaub Market, that is restricted by the water levels at Kaub; and the Ruhr market, that is restricted by the water levels at the critical river section somewhere between Emmerich and Lobith (see Figure 2-5 for locations). The reasoning behind the selection of these two market segments is that roughly half of all IWT to and from Germany via the Rhine has an origin or destination upstream the critical river section at Kaub, and that roughly a quarter of all transport to and from Germany via the Rhine has an origin or destination at Ruhrort. By selecting these two market segments one therefore covers about three quarter of the IWT flows that are shipped on the German part of the Rhine[104].

[104] These estimates are based on a graphical representation of the freight volumes on the German waterways for the year 2002, that stems from the Statistisches Bundesambt in Wiesbaden. The graphical representation was obtained indirectly from a presentation of the Wasser- und Shifffahrsverwaltung des Bundes (Heinz, 2009).

For barges sailing up to Ruhrort a critical water depth of 2.8 meter is guaranteed at GLW (and OLR) and for barges passing the stretch at Kaub the water depth is reduced to 1.9 meters at GLW. Further upstream the water depth is once again increased, which makes Kaub the most critical section on the route (see Figure 9-12).



Note: The numbers at the bottom indicate the distance from the beginning of the Rhine at Constance.
Source: Obtained from http://www.wsd-west.wsv.de/wasserstrassen/verkehrsweg_rhein/Technische_daten/index.html; reduced content, translated.

Figure 9-12: Guaranteed Water Depths along the Rhine at GLW

For each of these two market segments I defined a representative barge, that more or less corresponds to the larger commonly applied barges on this route. For the Kaub market the choice for the representative barge was very clear as the locks further upstream are all based on the size of the standard Class V Rhine barges, and therefore the most commonly applied barge that sails on this route has a length of 110 meter and a width of about 11.40 to 11.45 meter[105] (see Chapter 2). I therefore consider a barge of 110 x 11.45 meter representative for the Kaub market. For the Ruhr market the situation is more complicated as there is more variance in the size of the barges that sail on this route. Three of the larger barges that are commonly applied on this route have a size of about 110 x 11.45, 135 x 14.20, and 135 x 17.20 meter. I selected the middle one of these barges as the representative barge.

In order to define the effects of climate change on the loading capacity of the representative barges one should know the physical relation between the loading capacity of the barge and its draft[106]. I have therefore asked for copy of the loading certificates of two real barges that are very similar to the representative barges defined above. Figure 9-13 shows the draft relations according to these two certificates.

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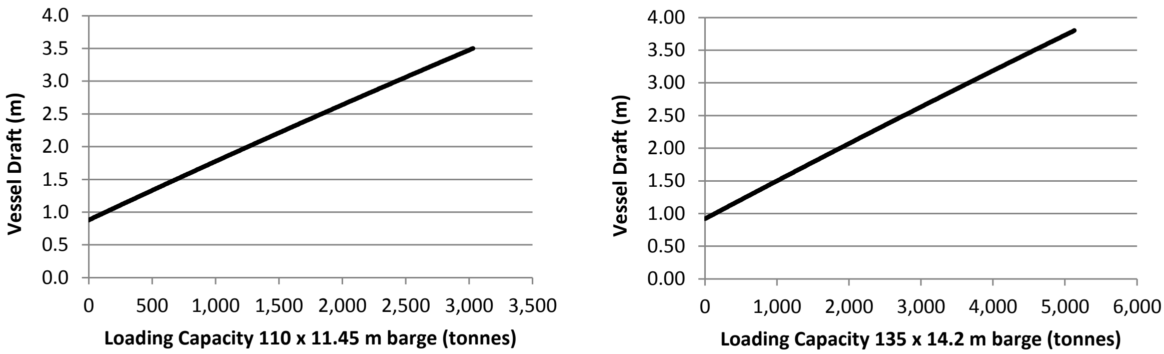
[105] This can clearly be observed when measuring the length of the barges that sail in this area from Google Earth.

[106] Note that the loading capacity of an inland barge follows the law of Archimedes which states that the mass of a floating body equals the displaced mass (or displacement) of the fluid on which it floats. Loading more weight into a barge increases the displaced volumes and thereby the draft.



Source: Relations obtained from the loading certificates of two representative barges.

Figure 9-13: Loading Capacity and Draft for 110 x 11.45 and 135 x 14.2 meter Barge

I defined the maximum loading draft, that corresponds with a full utilisation of the barges, by a two-step approach in which I first selected the barges within the corresponding size range from the IVR database (data as per 27 February 2013); and then defined the maximum draft for the representative barge as the median value of the reported maximum drafts within the selected size range. I used the median value instead of the average value because it is less affected by outliers in the dataset. By applying this methodology to a dataset of 591 barges in the size range of 109-110 x 11.40-11.45 meter I obtained a maximum loading draft of 3.5 meter for the representative 110 meter barge. In a similar way I obtained a maximum loading draft of 3.8 meter for the representative 135 x 14.20 meter barge on the basis of a dataset of 34 barges in the size range of 134-135 x 14.15-14.35 meter.

The maximum loading draft depends on the available water depth and the applied safety margin to avoid grounding. The applied safety margin depends on the type of cargo shipped (smaller margins are used for dry bulk than for chemicals), the type of river bottom (smaller margins are applied for sand bottoms than for rock), and the trim angle of the barge. It is common for loaded barges to apply a trim of about 2 to 5 cm over the length of the barge. When sailing upstream the bow of the barge is loaded slightly deeper than the aft to avoid the risk of spinning around when getting grounded[107]. In a similar way the aft of the barge is loaded deeper when sailing downstream. In general a safety margin of about 20 to 40 cm is applied against grounding (EICB, 2011). I have therefore applied a safety margin of 30 cm in the calculations.

In addition to the effects of climate change on the average annual loading capacity, I have also studied the limiting conditions for which shipping on the Rhine will no longer be feasible. Barge operations require a minimum draft to keep the propellers submerged. Riquelme Solar (2012, p.28) investigated the minimum required draft by interviewing three renowned barge operators. These operators indicated that a minimum draft of 1.6 meter can be considered as a reasonable fleet average. However, for smaller barges the required drafts may go down to 1.4 meter while for large push barge combinations a higher minimum draft of about 1.8 to 1.85 meter is required by the pusher tugs. I assumed a minimum draft of 1.6 meter for the representative barges sailing on the stretch between Rotterdam and Ruhrort and a minimum draft of 1.5 meter for the representative barges sailing in the Kaub market.

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[107] This discussion is based on conversations with barge owners affiliated to the Mercurius Shipping Group.

9.4.2 Restricted barge loading and sailing conditions

I estimated the effect of climate change on the performance of inland shipping towards Rurhort and Basel (Kaub market) by considering the effect of reduced water levels on the full loading capacity of the representative barges. For Basel the full 100% loading capacity corresponds with the full capacity of a 110 meter barge at a draft of 3.5 meters; for Ruhrort the full loading capacity corresponds with the full capacity of a 135 meter barge at a draft of 3.8 meters. Figure 9-14 and 9-15 indicate the maximum loading draft towards Ruhrort and Basel when taking into account the applied safety margin of 30 cm against grounding.

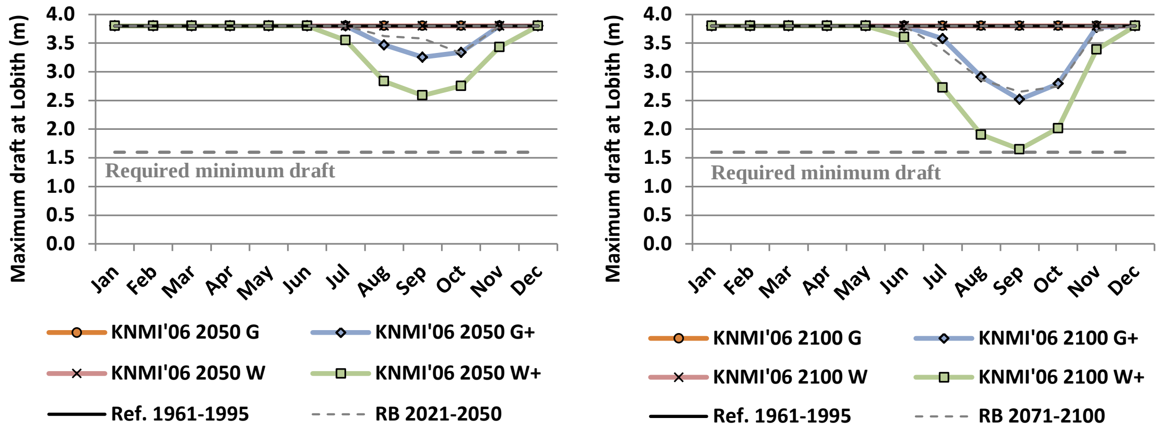


Figure 9-14: Maximum Loading Draft of Barges on Route via Lobith to Ruhrort

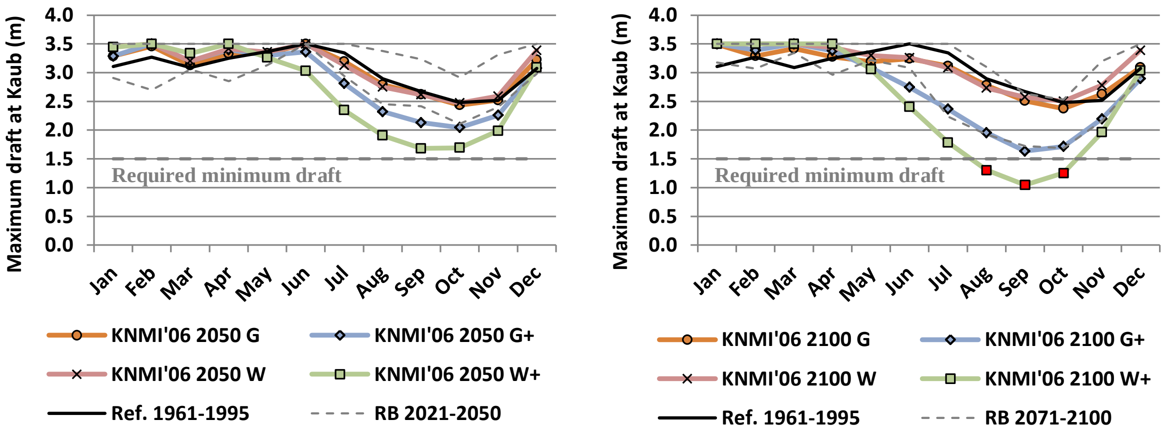


Figure 9-15: Maximum Loading Draft of Barges on Route via Kaub to Basel

The figures clearly indicate that the maximum utilisation of the barges is not much affected in the G and W scenario, but considerably reduced in the more extreme G+ and W+ scenarios. For the most extreme W+ scenario the maximum draft up to Ruhrort is reduced to just over 1.6 meter in an average September month of the year 2100. This implies that sailing on this route will just remain feasible for the representative barges (not for all barges) in an average year (this will not be the case for every year). For the Kaub region the maximum draft drops below the 1.5 meter level. This implies that the representative barges will no longer be able to maintain their sailing operations in August, September, and October. Even if sailing remains possible climate change will still have a considerable effect on the utilisation of the barges. The effects on the utilisation of the barges are indicated in Figure 9-16 and 9-17.

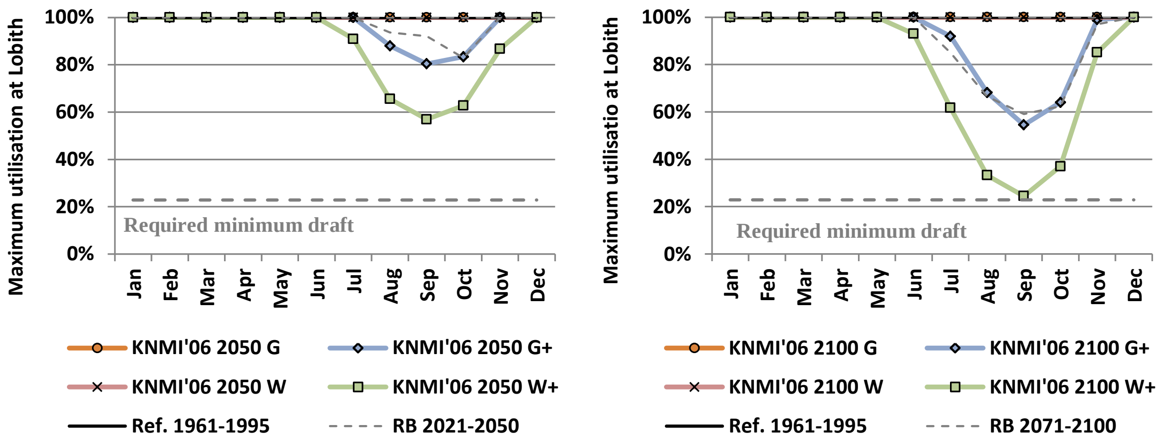


Figure 9-16: Maximum Barge Utilisation on Route via Lobith to Ruhrort

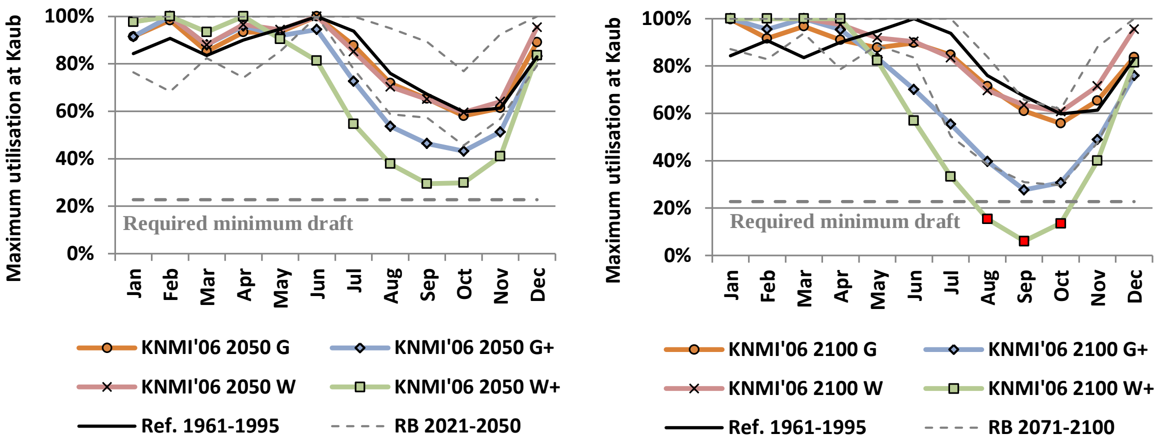


Figure 9-17: Maximum Barge Utilisation on Route via Kaub to Basel

For the Ruhr market the effects of climate change turn out to be negative in all circumstances. For the Kaub market this is generally also the case, though a slight increase in barge utilisation may occur in the period from November to April. A comparison of the annual effects of the reduced barge capacity due to climate change is provided in Table 9-3. The calculations of Figure 9-16 and 19-17 as well as Table 9-3 (and the following figures and tables in this chapter) are made available for further research and referred to in Appendix F.

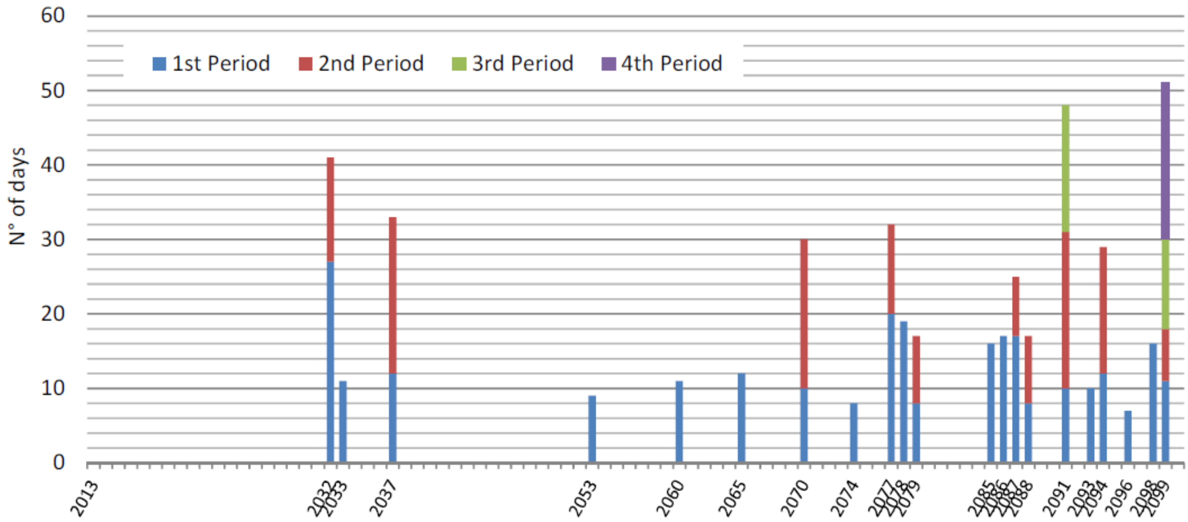
Table 9-3: Effect of Climate Change on the Average Annual Barge Utilisation Rate

Scenario \ Issue	Maximum Barge Utilisation		Effect on Barge Capacity		Effect on Transport Costs	
	Ruhrort	Kaub	Ruhrort	Kaub	Ruhrort	Kaub
- Ref. 1961 - 1995	100%	82%	0%	0%	0%	0%
- KNMI'06 - 2050 G	100%	83%	0%	1%	0%	-1%
- KNMI'06 - 2050 G+	96%	76%	-4%	-7%	4%	8%
- KNMI'06 - 2050 W	100%	85%	0%	3%	0%	-3%
- KNMI'06 - 2050 W+	89%	70%	-11%	-15%	13%	17%
- KNMI'06 - 2100 G	100%	82%	0%	-1%	0%	1%
- KNMI'06 - 2100 G+	90%	69%	-10%	-16%	11%	20%
- KNMI'06 - 2100 W	100%	85%	0%	4%	0%	-4%
- KNMI'06 - 2100 W+	78%	61%	-22%	-26%	28%	35%

The maximum barge utilisation in Table 9-3 is defined as the average of the draft restricted capacity for the individual months divided by the maximum capacity of the barges. For the months in which the utilisation of the barges dropped below the minimum sailing draft a utilisation of zero percent was applied. For the standard G and W scenarios the effects of climate change on the average annual barge capacity are very moderate and sometimes even slightly positive. In the more extreme G+ and W+ scenarios this is no longer the case, as the effects of climate change may then become very substantial. In the G+ scenario the reduction in the maximum barge utilisation is estimated at 10% for the Ruhr market and 16% for the Kaub market in the year 2100. In the W+ scenario these numbers go up to 22% and 26%.

9.4.3 Effect of unnavigable waterways

The low barge utilisation levels for the W+ scenario in the year 2100 (see Figure 9-16) indicate that sailing will just remain feasible up to Ruhrort in an average year, but this is no guarantee that this will also be the case for every individual year. Riquelme Solar (2012) investigated the tipping point from which sufficient water depth on the Rhine may no longer be guaranteed. Her analysis was based on the hydrological projections of Hurkmans et al. (2010) for the SRES AIB, A2, and B1 scenarios. The tipping point was defined as the moment in time from which the lower Rhine up to Ruhrort will no longer be navigable for inland barges with a draft of 1.4 to 1.8 meters over a period of at least 7 consecutive days. The results for the periods in which the draft levels are less than 1.8 meter (corresponding water depth of 2.1 meter) in the A1B scenario are indicated in Figure 9-18.



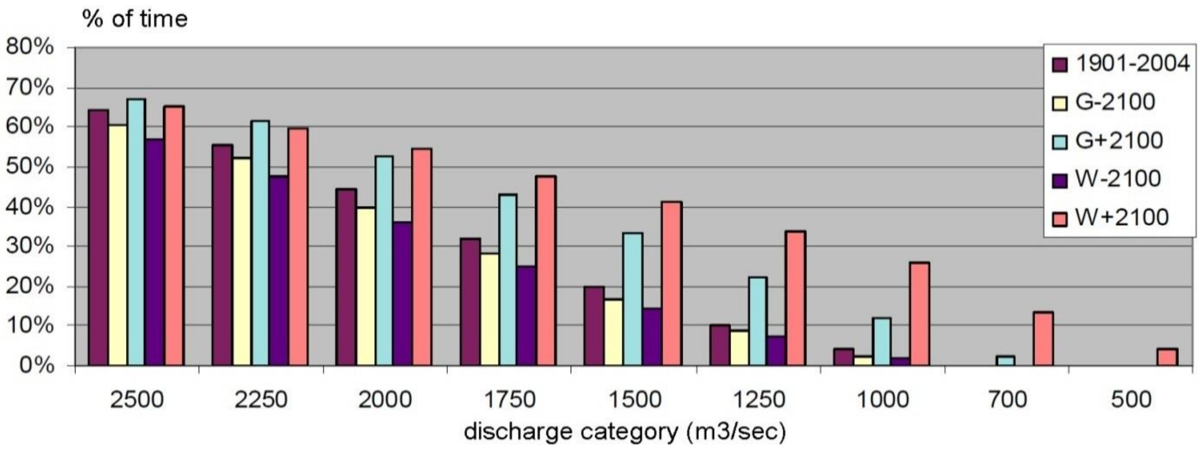
Source: Riquelme Solar (2012, p.38).

Figure 9-18: Periods in which sailing with 1.8 meter Draft is restricted (A1B scenario)

The figure indicates that even on the relatively deep water stretch between Rotterdam and Ruhrort the water levels can become too low to continue barge operations. In the A1B scenario problems can occur almost every one or two years and sailing at a draft of 1.8 meters can be restricted up to about 4 times a year. A similar analysis was also provided for barges with a draft of just 1.4 meter (i.e. the lowest possible draft at which sailing is still possible). The results of this analysis indicated that from about 2085 onwards the river will become totally unnavigable for one or two periods per year (with a total up to about 30 days) once every five years. The year 2085 was therefore identified as a tipping point. Comparable, but slightly less severe results were also found for the A2 scenario. I expect the impact to be even more severe for the KNMI'06 G+ and W+ scenarios, but this is still to be verified.

9.4.4 Restricted use of large push barge combinations

Apart from the effects of reduced loading capacity and unnavigable waterways the push barge operations are also likely to face some additional restrictions. According to the Rhine Police Regulations (RPR, article 11.02) and the Dutch Inland Shipping Police Regulations (BPR, article 9.06) the use of large push barge combinations containing six (instead of four) dumb barges is only allowed between Bad Salzig (Rhine km 564) and Gorinchem (Rhine km 952) if the gauge of Lobith is in-between 8.5 and 13.5 meter and if the gauge of Ruhrort is in-between 2.75 and 7.15 meter. This roughly corresponds with a discharge volume of about 1,430 to 5,675 m^3/s at Lobith and 1,194 and 4,570 m^3/s at Ruhrort[108] (please note that this relation changes over time due to morphological changes of the river). The discharge volumes at Lobith and Ruhrort are almost similar. The total time for which shipping with six barges is restricted can therefore be approximated by analysing the period in which discharge volumes at Lobith drop below 1,430 m^3/s. Figure 9-5 indicates that this has generally been the case from August to December (for the period 1961 to 1995), but that the length of time in which these restrictions hold may increase by one or two months in the G+ and W+ scenarios.



Source: Kwadijk et al. (2008, p.74), translated.

Figure 9-19: Percentage of Time that Discharge Volumes at Lobith are Undercut

More specific insight in this effect can be obtained by looking at the number of days that the discharge volume is less than 1,430 m^3/s. These values can be obtained for the KNMI’06 scenarios in the year 2100 by interpolation from Figure 9-19. For the historical data the water levels were over 1,430 m^3/s some 83% of the time. This reduces to 70% in the G+ and 60% in the W+ scenario, which implies that the average number of barges drops from 5.66 barges in the past to respectively 5.40 or even 5.20 barges in the G+ and W+ scenarios for the year 2100. This increases the costs of pushing the dumb barges by about 4.8 to 8.8 percent[109].

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[108] It is interesting to note that Bosschieter (2005, p.34) indicates that push convoys containing six dumb barges are not allowed on the Dutch part of the Rhine (Waal) if water levels at Lobith are below +9 meter NAP (corresponding discharges of 1,780 m3/s and water depth of 3.8 meter). This may imply that the restrictions have been loosened after executing the upgrade of the waterway from 150 x 2.5 m ORL to 170 x 2.8 m ORL in 2006.

[109] In practice these numbers will be slightly lower because less fuel is used when pushing four instead of six barges, but at least the capital and labour costs will increase by the abovementioned factor.

9.5 The effect of Morphological Changes

The available water depth at a given river discharge volume changes over time as a result of morphological changes (i.e. changes to the shape of the river bed). In particular for free flowing rivers the river bottom is continuously subject to erosion and sedimentation, which are mainly a function of the encountered river discharge volumes and the type of soil on the river bottom. Waterway managers interact with the system and try to stabilise it in order to provide an up to standard waterway connection (i.e. one that meets the OLR requirements) at an acceptable level of maintenance dredging and replenishment works. For this reason many groynes and other river training works have been constructed along the rivers over time.

The tasks of the waterway managers are however not limited to the provision of a sufficient deep and wide navigational waterway (see Chapter 2). The highest priority of the waterway managers is: (1) to provide sufficient protection against flooding, and (2) to provide sufficient clean fresh water. Other policies, such as the *'EU Water Framework Directive'*, the program *'Room for the River'*, and the new *'Delta Programme'*, will also have an effect on the spatial arrangement and morphology of the river (see e.g. Rense, 2009; and Crijns et. al. 2013). These policies constrain the available options of the waterway managers to meet the desired standards for inland shipping. The Water Framework Directive, that is mainly concerned with water quality, may for instance have an effect on the quality of the river soil and thereby affect the morphology; the measures taken in the program *'Room for the River'* are likely to cause additional siltation, that may ask for additional measures, such as the construction of longitudinal dams; and the implementation of the Delta Programme will also have a considerable effect on the spatial arrangement and morphology of the river.

On the very long term the challenges of the waterway managers are expected to become larger, because climate change causes more variation in river discharge volumes and thereby: (1) an increased level of erosion and sedimentation; (2) more difficulties to guarantee a sufficient level of safety against flooding in periods of high river discharge; and (3) more difficulties to provide sufficient fresh water in periods of extreme drought. These changes are all likely to affect the options to provide a sufficient high quality waterway infrastructure for inland shipping at a reasonable cost level for the waterway provider.

In addition to the above the morphology of the rivers is also affected by subsidence and uplift (i.e. the vertical movement of the entire river bottom)[110], because the vertical movement of the river bottom does not take place at a similar pace over the entire river stretch. Some areas show considerable movement, while other areas contain *'hard spots'*, for which the bottom is stable and no vertical movement takes place. The effects of subsidence and uplift on the riverbed in the Dutch part of the Rhine were evaluated in the framework of the project *'Sustainable Navigable Depth Rhine Delta'*[111]. The measured and predicted movement of the river bottom in the section between Rhine km 800 to 920 are indicated in Figure 9-20.

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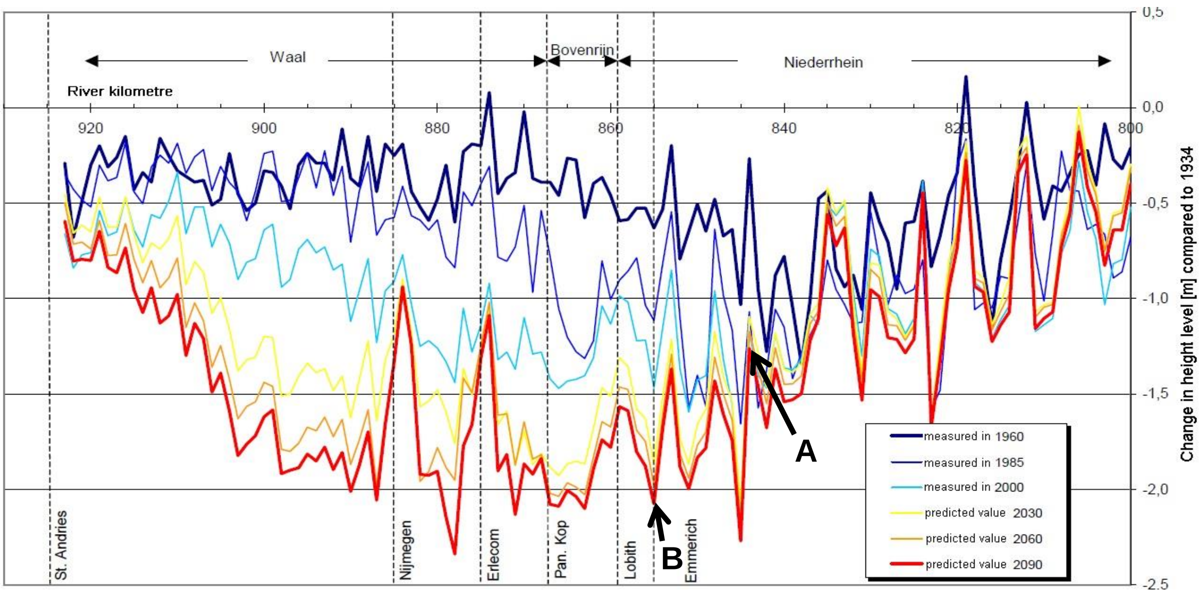
[110] According to Wikipedia (www.wikipedia.com, 2011): *"Subsidence is the motion of a surface (usually, the Earth's surface) as it shifts downward relative to a datum such as sea-level. The opposite of subsidence is uplift, which results in an increase in elevation"*.

[111] In Dutch: Duurzame Vaardiepete Rijndelta.



Source: Turpijn and Weekhout (2011, p.46), adjusted layout, translated.

Figure 9-20: Effects of Subsidence and Uplift between Rhine kilometre 800 and 920

The unequal movement of the river bottom results in the emergence of sills that have a negative effect on inland shipping. This causes problems with the water depth on the 10 km long river section between location A and B in Figure 9-20. The lowering of the river bed between the year 2000 and 2090 is only 20 cm for location A while it reaches up to about 70 cm for location B. This leads to problems at the sill near Emmerich (Havinga, 2012, p.4). If no further measures are taken the unequal lowering of the river bed will affect the available water depth. This notion is confirmed by Turpijn and Weekhout (2011, p.48, translated) who indicate that *"Within 5 to 10 years from now a nautical bottleneck is expected between Lobith and Emmerich"*. Figure 9-20 indicates that the largest effects of subsidence are likely to take place in the period between 2000 and 2030. In the subsequent period from 2030 to 2090 the bottom gradually starts to stabilise and less additional problems will occur.

The effects will be even worse if the erosion levels near location B are also higher than near location A, which is presently the case. Havinga (2012, p.2) noticed that the Germans successfully stopped erosion after the upgrade of the river in 2006 (from 2.5 to 2.8 meter water depth) while this is not the case for the Netherlands. As a result erosion now directly adds to the problem of subsidence (i.e. one cm erosion results in one cm reduced water depth). In response to these problems the nautical depth on the Waal has already been reduced by about 10 centimetres in the period between 2007 and 2012. Measures are now being prepared to stop bottom erosion, but it is still unclear how successful they will be and if they will be in time. If not the current ORL water level of 2.8 meter may no longer be sustained.

Havinga (2012, p.5-6) indicates that bottom erosion could reduce the available water depth on the Benedenrijn (i.e. the Dutch Rhine between Spijk and Lobith) by about 60 centimetres over the next 30 years if insufficient counter measures are taken. To address the possible impact of such large adverse morphological changes I defined a hypothetical worst case scenario in which no measures are taken to mitigate the effects; and in which the guaranteed OLR water levels are reduced by 50 cm in 2050 and by 60 cm in 2100. The effect of this scenario on the maximum loading draft and barge utilisation is indicated in Figure 9-21 and 9-22. Further research is recommended to investigate the effects in case counter measures are taken.

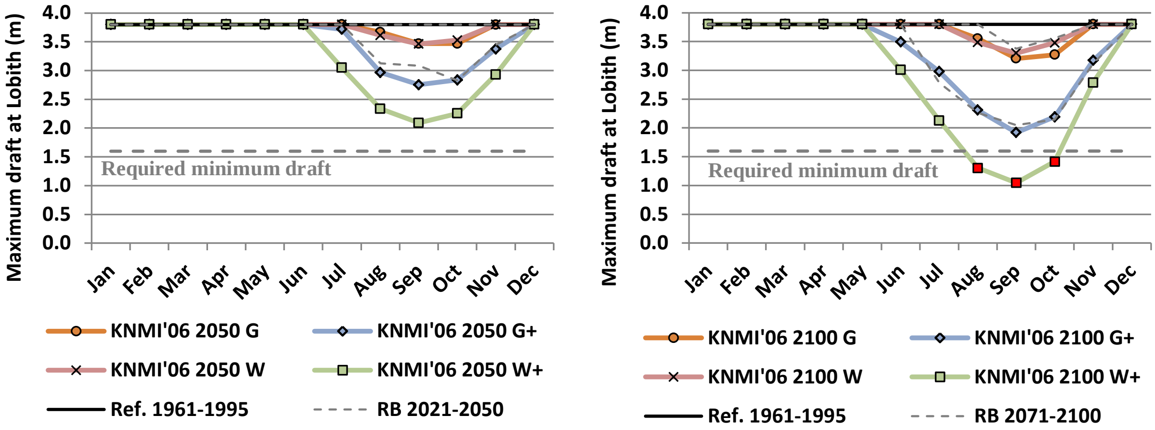


Figure 9-21: Maximum drafts in the Ruhr market for Hypothetical Scenario

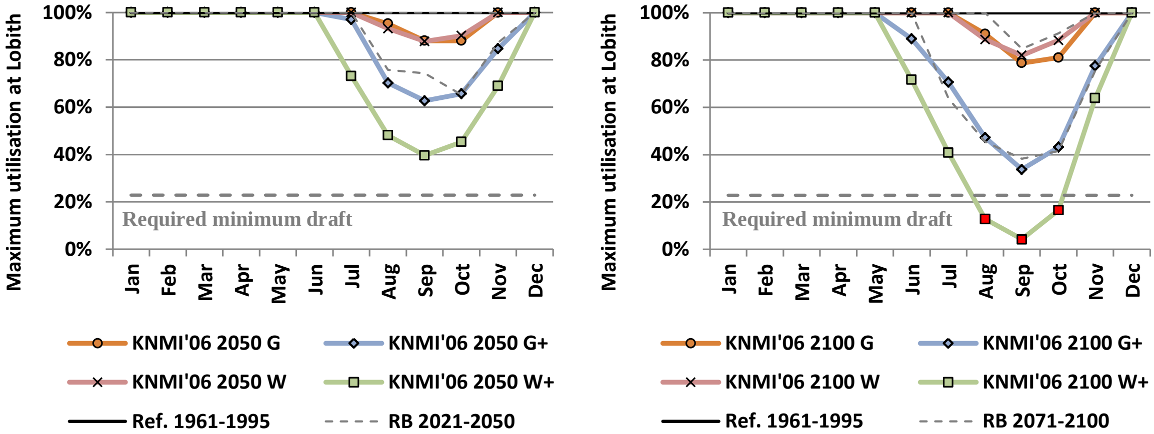


Figure 9-22: Barge utilisation in the Ruhr market for Hypothetical Scenario

Figure 9-21 indicates that in absence of adequate measures to mitigate the effects sailing may no longer remain possible on the stretch between Rotterdam and Ruhrort in an average August, September, or November month towards the end of the century. In practice waterway managers will however take measures (that may or may not be sufficient). This hypothetical worst case scenario therefore only provides an upper limit of the possible effects.

Table 9-4: Effect of Subsidence and Erosion on Maximum Barge Utilisation

Scenario \ Issue	Effect MC on Water Depth	MBU at Ruhrort	Effect on Barge Capacity		Effect on Transport Costs	
			Excl. MC	Incl. MC	Excl. MC	Incl. MC
- Ref. 1961 - 1995	0 cm	100%	0%	0%	0%	0%
- KNMI'06 - 2050 G	-50 cm	98%	0%	-2%	0%	2%
- KNMI'06 - 2050 G+	-50 cm	90%	-4%	-10%	4%	11%
- KNMI'06 - 2050 W	-50 cm	98%	0%	-2%	0%	2%
- KNMI'06 - 2050 W+	-50 cm	81%	-11%	-19%	13%	23%
- KNMI'06 - 2100 G	-60 cm	96%	0%	-4%	0%	4%
- KNMI'06 - 2100 G+	-60 cm	80%	-10%	-20%	11%	25%
- KNMI'06 - 2100 W	-60 cm	97%	0%	-3%	0%	4%
- KNMI'06 - 2100 W+	-60 cm	67%	-22%	-33%	28%	48%

Note: MC stands for Morphological Changes of the Hypothetical Scenario; WD stands for Water Depth; MBU stands for Maximum Barge Utilisation; MBU values include effect of morphological changes.

The effects of the assumed water depth and draft reductions on the average year round barge capacity are indicated in Table 9-4. For the standard G and W scenarios the combined effect of adverse morphological changes and climate change remains relatively small, in the order of a 2% reduction for the year 2050 and a 3% to 4% reduction for the year 2100. For the more extreme G+ and W+ scenarios the effects are much larger. In the most extreme W+ scenario for the year 2100 the maximum barge utilisation is reduced from 78% (see Table 9-3) to 67% if the hypothetical worst case scenario for the effects of morphological changes occurs.

9.6 Effect of High Discharge and Water Levels on IWT

Exceptionally high river discharge and water levels also cause restrictions to inland shipping. Such restrictions relate to safety measures, that are for instance imposed to protect the environment (e.g. avoid problems with dyke stability or flooding of quay walls) or to enhance safe navigation of inland barges (e.g. such as on the river section near the Loreley, a dangerous sharp rocky curve in the middle part of the river Rhine; see also Figure 2-5). In general the following safety measures are applied: reduced number of dumb barges allowed in a large push barge combination; speed limits; bans on overtaking; and eventually a complete ban on sailing at a certain river stretch. Apart from safety measures, high water levels can also impose a restriction on the number of container layers that can be loaded onto a container barge, which considerably reduces the loading capacity of inland container barges.

9.6.1 Implications of high water for sailing with large push barge combinations

Extreme high water levels can impose a restriction on the maximum number of push barges that are allowed in a push barge combination. Push barge combinations containing six dumb barges are no longer allowed for gauge values over 13.5 meter at Lobith or for gauge values over 7.15 meter at Ruhrort (see Section 9.4.4). According to the corresponding Q-H relations this relates to a discharge volume of about 5,700 m^3/s at Lobith and about 4,600 m^3/s at Ruhrort. Assuming that the discharge volumes near Lobith and Ruhrort are more or less similar one can compare the value of 4,600 m^3/s with the values reported for Rheinblick2050- and KNMI'06 scenarios at Lobith (see Figure 9-4 and 9-5). These values indicate that the highest average monthly water levels will remain considerably below the 4,600 m^3/s level. As a result I conclude that the effects of high water restrictions on sailing with large push barge combinations are less severe than the effects following from low water restrictions. Further research will nevertheless be required to quantify the effects.

9.6.2 Bans on sailing at certain river stretches

Under normal circumstances Rijkswaterstaat will not impose any restrictions for navigation on the river Waal during floods. However, in exceptional cases, such as the extreme high water discharges of 1993 and 1995, a temporary ban on sailing can be imposed to reduce the loads on the dykes (that were not all up to standard at that time). Exceptionally high water levels may also result in very high flow velocities that are dangerous for shipping on the river Meuse. For this reason shipping is sometimes prohibited at certain stretches of the Meuse (Bolwidt et al., no date, p.22). Navigation is sometimes also prohibited on other waterways. In January 2012 sailing was for instance prohibited in the northern provinces of the Netherlands for about five consecutive days due to extreme high water levels (Schuttevaer, 2012).

The German waterway authorities apply a strict regime in which all sailing restrictions are linked to fixed water levels (i.e. pegels). They distinguish between two predefined high water levels that are referred to as *'Mark I'* and *'Mark II'*. At the Mark I water level some minor restrictions are imposed such as a ban on overtaking and a reduction of the allowed sailing speed. At the Mark II water level an overall ban on sailing is applied (Bosschieter, 2005, p.94). Information on the reference levels for the Mark I and II pegels is obtained from the website *www.elwis.de* (accessed: 2013). For Ruhrort the Mark I and II levels are defined at a pegel of 930 and 1130 cm. For Kaub these levels are defined at 460 and 640 cm. Mark II water levels are rarely reached and when they occur they generally do not last much longer than a few days. Jonkeren and Rietveld (2009, p.10) listed the Mark II sailing bans on the Rhine for the period from 2000 to 2008. This list is presented in Table 9-5.

Table 9-5: Ban on Inland Shipping on the Rhine due to high Mark II Water Levels

No	Date	Location	Length (in days)
1	23-03-2002	Bingen	3
2	04-11-2002	Maxau	4
3	14-01-2004	Maxau	2
4	16-01-2004	Koblenz	1
5	17-01-2004	Andernach	1
6	23-08-2005	Maxau	3
7	24-08-2005	Mainz	n.a.
8	10-03-2006	Maxau	3
9	09-08-2007	Maxau	3
10	23-04-2008	Maxau	1

Note: Some items such as item 3, 4 and 5 as well as item 6 and 7 refer to the same floods.

Source: Jonkeren and Rietveld (2009, p.10).

Given the fact that these bans do not occur frequently, and the fact that that a large part of the shipments remain in the lower part of the Rhine where bans occur less frequent, it can be concluded that the effects of high water blockage on the IWT volumes transported via the Rhine are still rather limited, but one may question if this will remain the case in the future. To answer this question one can look at the water discharge volumes for the Mark II levels at Kaub. From the Q-H relation it can be observed that the 640 cm pegel value corresponds with a discharge of about 5,100 m^3/s. This volume is still much higher than the maximum value of about 2,700 m^3/s that was reported in for the Rheinblick2050 and KNMI'06 scenarios (see Figure 9-4 and 9-6). For this reason I expect future sailing bans to remain quite rare (e.g. only once every year). The effects of prohibited navigation due to extreme high water levels are therefore expected to be considerably smaller than the effects of unnavigable waterways caused by extreme low water restrictions. Further research is however recommend to verify these preliminary conclusions and to quantify the effects.

9.6.3 Implications of reduced bridge heights for container barge operations

In order to define the effect of high water levels on the loading capacity of inland container barges one should compare the available bridge height with the required air draft of a representative barge. I investigated an adverse loading condition for a 110 x 11.45 meter barge that has ballast capacity in the side wing tanks and is loaded with four layers of empty 40 foot high cube containers (of 2.9 meter high)[112]. For such a barge the average loading draft will be about 1.5 meters[113] and the even keel loaded (no trim or heeling effect) air draft will be

[112] Note that the worst case condition would be to use a barge that has no ballast capacity in the side wing tanks.

[113] A standard Rhine barge (110 x 11.45 meter) is generally able to carry thirteen 20 foot containers in front of each other which implies that six 40 foot containers can be loaded in front of each other. If the containers are loaded four wide and four high this results in a total of 96 empty 40 foot containers. Taking into account an

about 10.6 meter[114]. Allowing for a slight trim of about 10 centimetres at the aftship (to keep the propellers submerged at a desired minimum level of 1.6 meter) the air draft at the front of the barge will increase by a similar trim of about 10 centimetres. This implies that the overall air draft will raise to about 10.7 meters. When adding the recommended safety margin of 30 centimetres (see Chapter 2) the minimum required bridge height becomes 11.0 meters. If only three layers of empty high cube containers are loaded the minimum required bridge height will be about 8.3 meters[115]. For sailing with three or four layers of standard empty 40 foot containers (of 2.6 meter high) the required air draft is respectively 7.4 and 9.8 meters.

These numbers can be compared with the available bridge clearance. Turpijn and Weekhout (2011, p.74) estimated the available bridge clearance for the worst 10 day period in the year 2004 (which was considered a normal dry year). In addition the W and W+ scenarios for 2050 were projected on the year 2004 and comparable results were derived for the worst 10 day periods in these scenarios. The results of this analysis are indicated in Table 9-6.

Table 9-6: Minimum Clearance in Projected Years

Lowest bridge	Clearance 2004	Clearance 2050 W	Clearance 2050 W+
Waal	15.15	14.59	14.54
Neder Rijn/Lek	12.04	11.54	11.49
Rotterdam*	11.89	11.53	11.53
Moerdijk	9.53	9.24	9.24
IJssel	8.68	8.37	8.35

Note*: It should be noticed that opening of the bridges in Rotterdam is possible.

Source: Turpijn and Weekhout (2011, p.74 and p.75).

It can be concluded that the height on the two main river connections between Rotterdam and Ruhrort (via the Neder Rijn and Lek and via the Waal) remains sufficient to guarantee the transport of four layers of empty high cube 40 foot containers in a standard Rhine barge. For this relatively bad loading condition no major problems with bridge heights are expected on these two main routes (though barges sailing with 5 layers of containers will still face height restrictions). It should however be noticed that the analysis for the base year 2004 and the projected years 2050 W and 2050 W+ are related to an average dry year while problems with reduced bridge height will mainly arise in wet years. In addition the effects for the year 2100 are not yet taken into account. This analysis is therefore incomplete.

For IWT via the Merwede (Moerdijk Bridge), Gelderse IJssel, and certain canals constructed at the Rhine height of 9.1 meters (such as the Amsterdam Rijnkanaal) there is no guarantee that shipping will always be possible with four layers of containers. The available bridge height is only sufficient to allow for sailing with three layers of empty high cube containers.

average weight of 3.9 tonnes per container and an effective ballast capacity of 300 tonnes in the side wing tanks the total deadweight becomes 675 tonnes. Figure 9-13 shows that this corresponds with a draft of 1.5 meter.

[114] The loading floor of a typical container barge is generally located about 50 cm above the lowest part of the keel. This implies that containers are loaded from a level of 0.5 meter – 1.5 meter (draft) = -1.0 meter. Adding four high cube containers of each 2.90 meters results in an average air draft of 10.6 meters.

[115] Average draft of 1.4 meter, draft at aftship of 1.6 meter, draft at front of hold about 1.2 meter. Airdraft: 0.5 meter – 1.2 meter (draft at front of hold) + 3 x 2.9 meter = 8.0 meter. Required height: 8.0 + 0.3 = 8.3 meter.

The possibility to sail with four layers of containers depends on the actual water levels, the weight of the cargo, and the ballast capabilities of the applied barges. The higher the water levels, the more often a barge will have to sail with three instead if four layers of containers. Clearly this will have a considerable cost effect. In fact, the drop from four to three layers of containers implies an overall increase in transport costs of up to 33%[116] (when assuming a balanced container flow and a full utilisation of the barge). Further research is required to quantify the overall effects of reduced bridge heights due to climate change.

9.7 Other effects of Climate Change on IWT

Apart from the impacts of low and high river discharge there are a few other issues that will also affect the performance of IWT (see Figure 9-1). Most important is probably the effect of sea level rise, in particular in combination with high river discharge and strong onshore winds. In addition one can think of the effects of extreme wind conditions and the effects of adverse winter weather. All these effects will be discussed in this section.

9.7.1 Effect of sea level rise on inland waterway transport

The Delta Committee (2008) investigated the effects of the high-end scenarios for extreme climate change in the Netherlands with respect to:

- The protection of the coastal areas against sea level rise;
- The protection of the river areas against flooding; and
- The availability of sufficient fresh water supply.

This subsection deals with the implication of sea level rise for which the effects mainly relate to raised water levels on the IJsselmeer and increased closure of sea barriers. According to the high-end scenario of the Delta Committee (2008, p.31; see also Section 9.2.2) the free discharge of the IJsselmeer into the Wadden Sea may no longer be possible from the year 2050 onwards: *"A higher sea level means that water in the polders and drainage ditches will have to be pumped over ever-increasing heights into the North Sea or the inlets and estuaries that drain into it. Added to that, it is anticipated that precipitation peaks will be more frequent and more severe. In combination, this will lead to increased demands for water storage and pump capacity. From 2050 on, free discharge of the IJsselmeer lake into the Wadden Sea will be imperilled and a combination of pumps and/or increased lake water levels will be necessary".* The Delta Committee (2008, p.13) therefore suggested to allow the water level in the IJsselmeer lake to rise by a maximum of 1.5 meter after which pumping will be required, but at present there are no plans to implement this suggestion.

The Delta Committee (2008, p.29) further concluded that: "*The storm-surge barriers in the Eastern Scheldt and Nieuwe Waterweg have been designed in anticipation of a sea level rise of 20 and 50 cm per century, respectively. If the sea level rises further, then the storm-surge barriers will have to be modified or replaced. The Maeslantkering (Nieuwe Waterweg) barrier may be closed far more frequently in 2050 and 2100 than the once per decade originally envisaged. If the sea level rises by 85 cm, the Maeslantkering will have to be closed roughly three times a year. A rise of 1.3 m will mean closing the barrier about 7 times a year. If closure coincides with a high river discharge, then for a time the river cannot discharge*

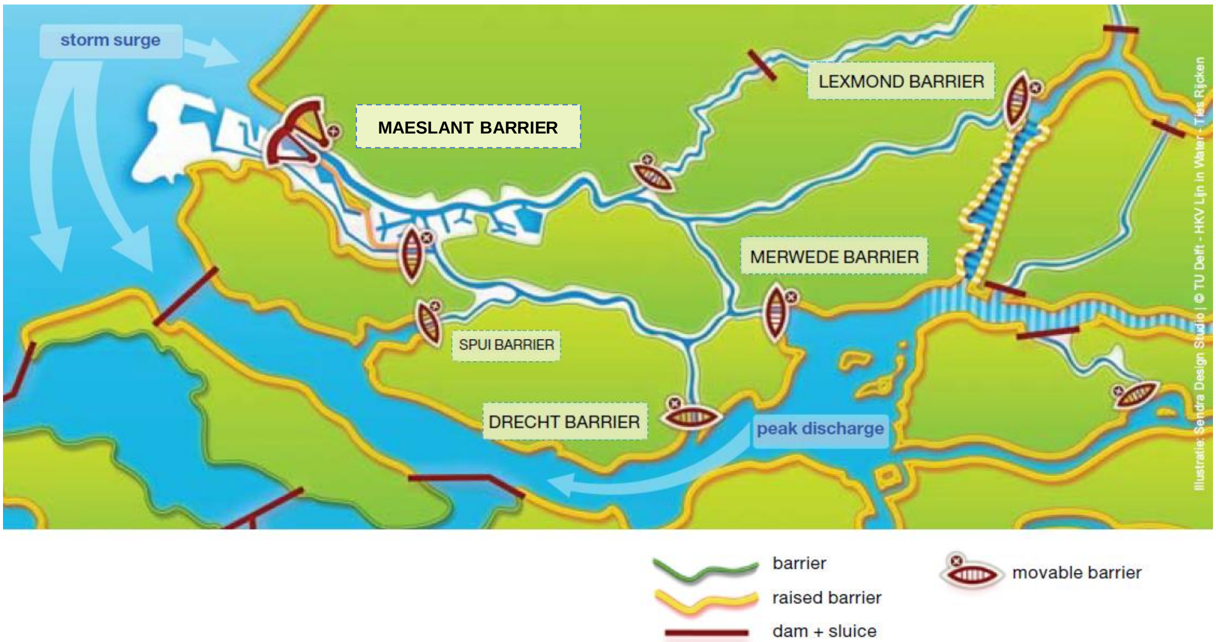
[116] Note that, if the full costs of the barge need to be spread over 3 instead of four layers. This implies that the costs per layer are 4/3 times as high and therefore a 25% capacity reduction results in a 33% cost increase.

into sea and its water will accumulate upstream of the closed barrier. The frequency with which the floodplains are inundated will increase as a result, as will the area under water. Moreover, if the flood defences remain unchanged, flood probability in Rijnmond and the Dordrecht region will increase: every 40–60 cm of sea level rise will increase flood probability by a factor of 10 in this region".

The Rijnmond area (Meuse-Waal delta) encounters serious flood risks when high sea water levels (caused by storm conditions) and high river discharges take place simultaneously. Under these conditions discharge of the rivers into the North Sea is no longer possible. This is particularly a problem for the lower lying areas in the Rijnmond region, such as Dordrecht and Rotterdam. At first instance these problems can be coped with by measures like:

- Increasing the water storage capacity of the Krammer/Volkerak/Zoommeer (see Kwadijk et al., 2008);
- Changing water distribution flows between the river Waal and its branches such as the Gelderse IJssel or the Amsterdam-Rijnkanaal (see Termes and Paarlberg, 2011);
- Construction of stronger and higher *'Delta Dykes'* that are designed to withstand more extreme water levels (see Knoef and Ellen, 2011; and Bruijn and Klijn, 2011);
- Placement of flexible barriers on quays that for instance afloat themselves at higher water levels (see Kamphuis, 1999);
- Other measures to design floodproof urban riverfront areas (see Stalenberg, 2010).

In case all these options will be insufficient to counter the effects of increasing seawater levels and peak river discharges, a more radical approach will be required. In that case one can for instance consider the development of a 'closable-open' Rijnmond region, for which a possible design is indicated in Figure 9-23.



Source: Delta Committee (2008, p.66), initially adopted from Ties Rijcken, adjusted.

Figure 9-23: Possible Design for a 'Closable-Open' Rijnmond Region

It should be noted that the option to develop a 'closable-open' Rijnmond is no longer taken into consideration by the present Delta Programme (Deltacommissaris, 2014). This implies that it should be considered as a last fall back option that will presumably not be necessary. However, in case the alternative measures turn out to be insufficient it may still be reconsidered in the future. When developed it will have considerable negative effect on the accessibility of the inland waterways in the Rijnmond area during closure periods, in particular if no locks to/from the area are provided.

The impact of flood protection measures on the competitiveness of the port of Rotterdam, as well as on the performance of IWT, is still subject to further research. Krekt at al. (2011, p.47) indicate that the effects of sea level rise on the accessibility of the port of Rotterdam in the W+ 2050 scenario will be limited to an increased closing frequency of the Maeslant Barrier, from once every 10 years to once every 5 years. Sea level rise is therefore not likely to have much effect on the competitive position of the port of Rotterdam in the period up to the year 2050. However, in case sea level rise increases further to about 85 or even 130 cm, as presumed in the more extreme KNMI'06 and high-end Delta scenarios for the year 2100, the closing frequency will increase to about 3 to 7 times per year. During these closure periods the sea terminals at the 1st and 2nd Maasvlakte will remain accessible for seagoing vessels, but the city ports are no longer accessible for the deeper drafted seagoing vessels. Smaller coastal vessels and inland barges may still reach the inner and outer port areas by means of the locks in the Hartelkanaal, but the capacity of these locks may not be sufficient.

9.7.2 Adverse effects of extreme wind conditions

Van den Hurk et al. (2006, p.44) noticed that the regional development of extreme wind conditions is still ambiguous and not yet completely understood, but that historical data from 1962 to 2002 indicate that medium wind events (occurring about 10 times per year) and strong wind events (occurring about 2 times per year) are decreasing with a rate between 5% and 10% per decade. Lambert and Fyfe (2006) confirm that the overall number of storms on the Northern Hemisphere is likely to decrease as a result of the increased greenhouse gas concentrations, but they also state that the number of intense storm events (defined as cyclones with a core pressure below 970 millibar) is likely to increase. The latter is also confirmed by the increased annual maximum daily average wind speeds in most of the KNMI'06 climate scenarios (see Table 9-2). I therefore conclude that storms are likely to occur less frequent in the future, but that the intensity of the encountered storms is likely to increase. The combined effects of fewer more intense storm conditions on inland sipping are therefore still ambiguous. Further research will be required on this topic. I would suggest to start with an analysis of the frequency of wind speeds for which barge and terminal operations may need to be ceased (i.e. above 15 m/s; see PIANC, 2008, p.23).

9.7.3 Adverse effects of extreme winter conditions

The adverse effects of cold winter weather are mainly related to ice on canals and rivers. A discussion of the historic incidences of ice on the rivers is provided by the KNMI (2013, translated): *"The 20th century counted 10 winters with solid ice on the river Waal, in the 19th century ice on the Waal near Nijmegen occurred more often, in total 31 times. Mainly due to canalisation and heat disposal the event of frozen rivers is now occurring less often: the last time was in the winters of 1985 and 1987. The winter of 1963, the coldest of the century, was the last one to show solid ice on the Nederrijn and Lek for successively 24 and 18 days. On January 20th of 1963 shipping was obstructed on the German part of the Rhine for 39 days, the Waal was then obstructed for 26 days. The year 1947 accounted the largest overall number of days with river ice: The Nederrijn and Lek were frozen for 64 days while the Waal was obstructed for 39 days"*. Obstruction of waterways due to ice cover now appears to occur less frequent than in the past. PIANC (2008, p.34) indicates that, in general, freeze up is now taking place later and break up of ice occurs earlier on many rivers of the world.

The KNMI'06 climate scenarios (see Table 9-2) indicate that the average winter temperature is likely to increase by 0.9 to 2.3 degrees in the year 2050 and by 1.8 to 4.6 degrees in the year 2100. For the coldest day of the year an even larger increase of 1.0 to 2.9 degrees in the year 2050 and 2.1 to 5.8 degrees in the year 2100 is expected. This implies that the number of persistent cold periods is likely to be reduced. For this reason no increase in adverse effects of extreme cold winter weather is expected. However, there is a possibility that the freezing point of the water in the rivers will raise as a result of improved water quality stemming from a reduction in the emission of heat disposals and pollutants (CCR, 2012, p.25).

9.8 Impact of Increased Cost Levels on IWT Volumes

The previous sections addressed the effects of climate change on the overall cost levels for inland shipping. It was concluded that the most severe impacts are stemming from the effects of low river discharge. The impact of low river discharge and adverse morphological changes on the average barge utilisation and cost levels were discussed in Section 9.4 and 9.5. This section addresses the effects on the overall IWT volumes shipped via the Rhine.

9.8.1 The elasticity of demand for inland shipping

An estimate of the combined effects of climate change and morphological changes on the IWT volumes can be made by applying transport elasticities. Elasticities relate the relative change in price levels (or generalised costs) to the relative change in output (or transport volumes). An elasticity of -0.5 indicates that a 1% increase in price levels results in a 0.5% decrease of transport volumes. If the relative change in output is smaller than the relative change in price the response is called inelastic, if it is larger, it is called elastic.

Table 9-7: Literature on Price Elasticities of Demand in Inland Waterway Transport

Source	Elasticities	Details
Yu and Fuller (2003)	[-0.5, -0.2]	Concerns grain transport, -0.5 for Mississippi and -0.2 for Illinois river.
Drager et al. (2005)	[-0.7, -0.3]	Concerns corn shipments on Mississippi and Illinois rivers.
Oum (1979)	-0.7	Intercity freight transport in Canada for period 1945 to 1970.
Train and Wilson (2005)	[-1.4, -0.7]	Revealed and stated preference data to analyse both mode and O-D changes as a result of an increase in the barge rate for grain shipments.
Hendrickson and Wilson (2005)	[-1.9, -1.4]	Concerns grain transport on Mississippi and accounts for spatial characteristics of the shippers.
Beuthe et al. (2001)*	[-10.8, -0.2]	Estimated elasticities for 10 different commodities of cargo based on a multimodal model for Belgian freight transport.
Jonkeren (2009)**	[-0.6. -0.4]	Estimated price elasticities for Kaub market on the Rhine.
Jonkeren (2009)**	[-1.2, -0.4]	Estimated elasticities for 10 different commodities of cargo based on a multimodal modal for Rhine based (Kaub market) freight transport.
PLATINA (2010)**	[-0.2, -0.0]	Estimated elasticities for NSTR1 cargo commodities based on freight transport models for the EU.

Note: *Numbers adjusted on basis original source; **Item added to update original table of Jonkeren.
Source: Jonkeren (2009, p.32), Beuthe et al. (2001, p.261-262), PLATINA (2010, p.28).

Jonkeren (2009) provided a list of transport elasticities for IWT that are reported in literature. An updated version of this list is provided in Table 9-7. The reported elasticities tend to vary between -0.2 and -1.9, although Beuthe et al. (2001) and PLATINA (2010) also reported much higher and lower values. On the basis of the original table Jonkeren (2009, p.32) concluded that the median reported value for the elasticity of IWT is about -1.0.

However, with respect to IWT on the Rhine he argued that *"it is plausible that demand for inland waterway transport may be more inelastic"*[117]. In order to obtain a more specific estimate for the Rhine, Jonkeren (2009, p.34) investigated the short term price elasticity of demand for the Kaub market on the basis of a dataset that includes shipments and tariffs (Vaart!-database, 2003-2007). Price elasticities of -0.4 and -0.6 were found depending on the control variables that were applied in the regression model. In order to validate the price elasticities that he obtained from the Vaart!-database, Jonkeren (2009) also defined the cost elasticities for road-, rail-, and IWT by applying the Nodus transport model (see also Jonkeren et al., 2011). This approach is more or less similar to the approach applied by Beuthe et al. (2001) for Belgium and the approach applied by PLATINA (2010) for Europe. The reported cost elasticities for these studies are indicated in Table 9-8. I consider the use of cost elasticities as a substitute for price elasticities quite sensible when it concerns long term effects, because measured over a longer period of time the profit margins in freight transport tend to be rather small, which implies that the prices are very well reflected by the costs.

Table 9-8: Reported Elasticities by NSTR1 Category for Inland Waterway Transport

NSTR	Commodity	Jonkeren (2009) Results for Kaub	PLATINA (2010) Results for EU	Beuthe et al. (2001) Results for Belgium
0-9	Total	-0.66 (tonnes)	-0.071 (tonnes)	-1.44 (tonnes) -1.53 (tonne km)
0	Agricultural products and life animals	-0.70 (tonnes)	-0.055 (tonnes)	-0.26 (tonne km)
1	Foodstuffs and animal folder	-0.59 (tonnes)	-0.034 (tonnes)	-0.36 (tonne km)
2	Solid mineral fuels	-0.56 (tonnes)	-0.015 (tonnes)	-1.51 (tonne km)
3	Petroleum products	-0.41 (tonnes)	-0.015 (tonnes)	-1.05 (tonne km)
4	Ores and metal waste	-1.00 (tonnes)	-0.071 (tonnes)	-7.20 (tonne km)
5	Metal products	-0.78 (tonnes)	-0.097 (tonnes)	-10.82 (tonne km)
6	Minerals and building materials	-0.85 (tonnes)	-0.059 (tonnes)	-0.17 (tonne km)
7	Fertilizers	-0.61 (tonnes)	-0.237 (tonnes)	-0.35 (tonne km)
8	Chemicals	-1.23 (tonnes)	-0.048 (tonnes)	-1.44 (tonne km)
9	Machinery, transport equipment, etc.	-0.62 (tonnes)	-0.076 (tonnes)	-9.89 (tonne km)

Source: Beute et al. (2001, p.261-262), Jonkeren (2009, p.56), PLATINA(2010, p.28).
Note: Values Beute et al. taken from set 2; Values Jonkeren based on average of M+ and W+ scenario.

It should however be noted that very large differences are observed in the outcomes of these three studies as: Jonkeren (2009) estimated a reasonable inelastic demand; Beute et al. (2001) expected the demand to be far more elastic; and PLATINA (2010) indicated the elasticity to be far more inelastic. In my opinion these differences do not only imply that the elasticities

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[117] Jonkeren (2009, p.32): *"First, the price for transportation by inland waterway vessel for most bulk goods is substantially lower than transport by another mode. Consequently, the price per tonne has to rise substantially before other transport modes become competitive and modal shift effects are expected to be small. Second, inland waterway vessels transport such large quantities that other modes of transport by far do not have enough capacity to transport all cargo originally transported by inland waterway vessels. Third, and more fundamentally, shippers aim to prevent their production process from costly interruptions and costs of inland waterway transport are only a small part of total production costs".*

vary considerable with the region taken into consideration, but also that there may be some serious issues with the quality of the estimates that have been obtained from transport models in which the calibration of the IWT flows played a less important role than the calibration of the road- and rail transport flows, which has presumably been the case for the models of Beuthe et al. (2001) and PLATINA (2010). This analysis of the effects of climate change on the transport volumes that are shipped via the Rhine will therefore be based on the work of Jonkeren (2009), because: (1) his work is related to the IWT volumes on the Rhine; and (2) his results have been derived with a primary focus on IWT.

Jonkeren (2009, p.56) concluded that: *"the demand for inland waterway transport is rather inelastic with almost all values lying between -1 and 0"* and that: *"These results are close to the value of the elasticity of demand for inland waterway transport of about -0.50, estimated"*. He therefore suggested to apply the price elasticity of -0.5 for IWT on the Rhine. I nevertheless think that the cost models (such as Nodus) are better capable of taking the long term options of shippers to shift to other modes of transport into account than the regression models that estimated the short term price elasticities. For this reason I think that a higher cost elasticity of -0.7 (based on -0.66 value obtained from Nodus model) is likely to provide a better estimate of the long term effects. I will therefore not only present the effects of the -0.5 price elasticity (as proposed by Jonkeren), but also the effects of a higher -0.7 cost elasticity. On the very long term the elasticity may be even higher, but I am not aware of any studies on which a proper very long term estimate can be based.

9.8.2 Effect of climate change and morphological changes on IWT volumes

A rough indication of the combined effects of climate change and adverse morphological changes on the overall IWT volumes shipped via the Rhine can be obtained by multiplying the obtained price and cost elasticities of -0.5 and -0.7 with the estimated cost effects as reported in the last two columns of Table 9-3 and Table 9-4. The results of this analysis are indicated in Table 9-9.

Table 9-9: Effect of climate change and morphological changes on IWT volumes

Scenario \ Issue	Applied elasticity of -0.5			Applied elasticity of -0.7		
	Kaub	Ruhrort	Ruhrort+MC	Kaub	Ruhrort	Ruhrort+MC
- Ref. 1961 - 1995	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
- KNMI'06 - 2050 G	1%	0%	-1%	1%	0%	-2%
- KNMI'06 - 2050 G+	-4%	-2%	-6%	-6%	-3%	-8%
- KNMI'06 - 2050 W	2%	0%	-1%	2%	0%	-2%
- KNMI'06 - 2050 W+	-9%	-6%	-12%	-12%	-9%	-16%
- KNMI'06 - 2100 G	0%	0%	-2%	0%	0%	-3%
- KNMI'06 - 2100 G+	-10%	-6%	-12%	-14%	-8%	-17%
- KNMI'06 - 2100 W	2%	0%	-2%	3%	0%	-2%
- KNMI'06 - 2100 W+	-17%	-14%	-24%	-24%	-20%	-34%
- After canalisation	9%	0%	0%	13%	0%	0%

Note: +MC implies that the hypothetical worst case scenario for morphological changes is applied.

For the standard G and W scenarios the combined effects of climate change and adverse morphological changes on the overall IWT volumes are quite small and vary between -2% and 2% for the year 2050 and between -3% and 3% for the year 2100. The G+ scenario shows that the overall IWT volumes on the Rhine may be reduced by 2% to 8% in the year 2050 and by 6% to 17% in the year 2100. For the W+ scenario the reduction in IWT volumes is expected to be about 6% to 16% in the year 2050 and about 14% to 34% in the year 2100.

The results can be compared with the results of a few other studies. Jonkeren (2009, p.54) estimated a loss of tonnage transported by IWT of 2.3% in the 2050G+ scenario and of 5.4% in the 2050W+ scenario. Krekt et al. (2011, p.47) conclude for the 2050W+ scenario that: *"The modelling exercise with BIVAS and TRANS-TOOLS shows that the climate change can have substantial impact on the competitive position of inland waterway transport on specific markets [...]. A loss of 8% annually or 28% in the worst case 10-day period in transport demand for all navigation within, to, from, and through the Netherlands might occur (on specific corridors such as Rotterdam – Germany, these percentages are substantially higher)"*. My estimates for the Rhine are somewhat higher, but still in line with the estimates of Jonkeren (2009) and Krekt et al. (2011), in particular when considering the fact that these estimates do not include the possible effects of adverse morphological changes to the river.

9.9 Adaptation Strategies

The major impact of the G+ and W+ scenarios asks for clear adaptation strategies. This section provides an inventory of possible measures to respond to the changing climate conditions for IWT. It is based on the work of Bosschieter (2005), PIANC (2008), Krekt et al. (2011), CCR (2012), and Riquelme Solar (2012). The identified response measures are categorised into three categories. The first category deals with the response measures that can be taken by the logistical sector to improve the reliability of the logistical chain; the second category deals with the response measures that can be taken by the IWT companies to adjust the design of the inland barges; and the third category deals with the response measures that can be taken by the infrastructure providers to maintain a sufficient high quality inland waterway connection.

9.9.1 Response measures that can be taken by the logistical sector

Literature revealed a number of response measures that can be taken by the logistical sector (including the IWT sector) to guarantee reliable and cost effective freight transport to/from waterborne industrial production areas. The identified measures are indicated in Table 9-10.

Table 9-10: Response Measures that can be taken by the Logistical System

Response measure	Effect	Examples
Better use of spare barge fleet capacity.	This already happens, but climate change may lead to an incremental increase of spare capacity.	Intensify sailing regime, temporary increase of sailing speeds, extra capacity due to ultra slow steaming during normal operations.
Improved inland shipping operations.	Incremental improvement in the efficiency of the IWT system.	More efficient barge routing, increased barge handling rates at terminal, improved service levels at locks and bridges.
Cooperation with other modes of transport.	Incremental improvement in the robustness of the transport system.	Develop synchro-modal transport solutions that offer a more robust supply chain.
Provision of additional storage capacity.	Effective solution for slow moving bulk commodities, but it comes at a relatively high cost.	Provide additional storage capacity for raw materials used in for instance the steel industry (e.g. coal and ores).
Relocation of industrial complexes	Effective solution that may cause loss of regional economic activity.	Shift of industrial plants from for instance the Ruhr area to an alternative location.

Source: Own composition based on Bosschieter (2005), PIANC (2008), Krekt et al. (2011), CCR (2012), and Riquelme Solar (2012).

The first two measures refer to actions that can be taken to increase the overall capacity of the IWT fleet during low water periods. These measures are quite effective as the IWT fleet has a very high intrinsic short term supply elasticity (CCR, 2012). The overall fleet capacity can for instance be increased by an increase in the speed of the barges or a shift to a more intense sailing regime[118]. In addition the capacity of the fleet can be further increased by reducing the waiting and handling times in the ports.

Riquelme Solar (2012, p.34) indicated that, for extreme low water periods of up to about 7 to 10 days on a row, the hinder may still be manageable for the logistic sector. However, for longer extreme low water periods the receiving industries will have to take additional measures. On the short term they can intensify the cooperation with other modes of transport, for instance by developing co-modal or synchro-modal transport solutions (see also Chapter 8); on the medium term they can increase the capacity at their storage facilities; and on the long term they can relocate their production facilities to other locations that are closer to the seaport and/or to the origin of the raw input materials[119].

The shift from IWT to other modes of transport is not very desirable from an environmental point of view, nor is the relocation of industrial production facilities to overseas locations desirable from a regional economic point of view. Therefore, in case of extreme conditions of climate change (such as in the W+ scenario for the year 2100) it may be necessary to adapt the IWT system to the new situation, at least when this can be done in a cost effective way.

9.9.2 Response measures to improve the design of the inland barges

Literature revealed a number of response measures that can be taken by IWT operators to adjust the design of their inland barges in such a way that they are able to cope with very low water levels on the inland waterways. The identified response measures are all related to the development of shallow draft barges and listed in Table 9-11.

Table 9-11: Response Measures with respect to the Design of the Barges

Response measure	Effect	Examples
Reduction of the weight of the barge.	Possible solution that provides an incremental improvement in the barge capacity in case of sufficient water depth to remain sailing, but overall performance remains poor.	Use of light weight construction materials such as composites or high tension steel. Hekkenberg (2012, p.226) indicates that light weight structures and equipment may increase the cargo capacity by 9% to 15%.
Development of very shallow draft propulsion systems (e.g. for a draft down to 1 meter, if possible).	Possible solution that allows barges to remain sailing at more extreme low water depths, but at costs of more expensive installations and a significant higher fuel consumption.	Use of smaller (and far less efficient) ship propellers; use of new propulsion techniques such as the whale-tale propulsion; use of waterjet propulsion; sails or air propellers (see also Blaauw, 2009).
Development of wide shallow draft barges with a limited height of the holds.	Theoretic solution that allows more cargo to be loaded during extreme low water periods, but such barges will only be cost effective if low water condition occur most of the year which is not the case.	Construction of barges with a low hold that are slightly lighter and better suitable for operations during periods of extreme low water. Blaauw (2009) indicates that the loading capacity during low water may be up to 20% higher than for standard barges.

Source: Own composition based on Bosschieter (2005), PIANC (2008), Krekt et al. (2011), CCR (2012), and Riquelme Solar (2012).

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118 IWT operators are free to choose between three sailing regimes for which different staffing requirements hold. The options are: daytime (14 h/day); semi-continuous (18 h/day); and continuous sailing (24 h/day).

119 See Chapter 4 for the applied definition on short-, medium-, and long term developments.

The construction of shallow draft barges does however face a number of drawbacks (see also Hekkenberg, 2012). The first drawback relates to the fact that shallow draft barges require a relatively heavy construction, which implies that they have a very poor deadweight to lightweight ratio. The second drawback relates to the fact that the maximum achievable efficiency of the ship propeller decreases considerably at lower available water depths, which causes a relatively high fuel consumption per barge kilometre. And finally, the labour costs remain similar for barges with a similar length (regardless of the draft). Shallow draft barges are therefore less cost effective than normal barges that operate at deeper water levels. As a result of these drawbacks the cost levels per tonne kilometre are likely to be a few times higher, which makes it harder to compete with other modes of transport. This also holds for the carbon emissions per tonne kilometre.

Investments in shallow draft barges are only profitable if low water conditions occur most of the year. From the business perspective of an IWT operator it is not sensible to construct a dedicated shallow water barge, with a consequently much lower carrying capacity during high water, if low water conditions occur only a few months per year (Riquelme Solar, 2012). Krekt et al. (2011) estimated the break-even point between a standard large Rhine barge (of 110 x 11.45 meter) with a draft of 3.5 meters and an adapted large Rhine barge for which the draft is reduced to 2.0 meters. They concluded that the break-even point purely based on transport costs (per tonne of transported cargo) will not be reached unless low water occurs 80% of the time. When taking into account higher revenues during low water for the barge operator the break-even point shifts to 60%. Considering the fact that problems with low water will occur at most 40% of the time (Section 9.4 and 9.5 indicate problems during 3 to 5 months per year) it can be concluded that there will presumably not be a business case for such barges, unless cargo shippers are willing to pay much higher tariffs (e.g. 3 to 6 times the annual amount that they pay for normal barge operations) for a more reliable all year round operation in which they for instance hire the climate adjusted shallow draft barges on a dedicated all year round basis. At such rates it is however questionable if climate adjusted barges will still be able to compete with other modes of transport and/or with the relocation of production facilities. I think that this may very well not be the case, and for that reason I will further presume, in the scenarios that will be developed in Chapter 13 and 14, that there is no economic rationale for developing dedicated shallow draft barges on the Rhine.

In case the development of shallow draft barges is not economically feasible other solutions will have to be sought. One can then for instance expect the Rhine basin to attract a part of the Danube fleet during low water periods, because these barges are designed for much lower water levels on the Danube (see also Platz, 2009, Annex 32 and 37 for discussion of available draft on the Danube). The size of the Danube fleet is however small compared to the Rhine fleet and offers only a partial solution; and in addition it will also lead to shortage of barges on the Danube (assuming that this river remains navigable).

9.9.3 Response measures to maintain a sufficient high quality waterway

From the above analysis I conclude that, in case of extreme conditions of climate change, such as foreseen in the second half of the 21st century for the W+ scenario, there will presumably not be a business case for the development of shallow draft barges. This implies that a large share of the IWT flows may then shift to other modes of transport and/or that many industrial facilities will be relocated at other locations, unless waterway managers are able to secure a sufficient high quality navigable inland waterway. Literature reveals a broad range of options to guarantee a sufficient high quality waterway connection in case of adverse climate change conditions. I have grouped these options into a number of response measures that are listed in Table 9-12.

Table 9-12: Response Measures to improve the Quality of the Waterways

Response measure	Effect	Examples
Further canalisation of the river Rhine.	Last fall back option for IWT, that has an extraordinary impact on the environment, but guarantees sufficient water depth on the Rhine during low water periods. Comes with an increase in sailing times due to passage of locks.	The Rhine is now canalised up to Rhine km 334 near Rastatt. One could consider further canalisation to a lower river section or even the full canalisation over the entire river stretch. Krekt et al. (2011) indicated that canalisation of the Waal up to the Ruhr area could be cost effective in the W+ scenario.
Provision of improved nautical information.	Effective option to improve the loading of inland barges (reduce required safety margins).	Improved river maps, water level forecasts, information on lock service times, and other river information services (RIS).
Apply advanced river training works.	Effective option to improve water depth at smaller discharge flows. May not be sufficient in case of extreme low discharge volumes.	Measures that can be taken to deepen the river instead of widening it such as: barriers with an adjustable opening, adjustable groins, and/or longitudinal dams.
Increased dredging and suppletion operations.	Effective option to improve water depth at smaller discharge flows. May not be sufficient in case of extreme low discharge volumes.	Apply ongoing maintenance dredging to improve the shape of the fairway to provide optimal navigable draft and width at a given discharge flow level.
Control water flow in canalised river section upstream Rastatt.	Additional option that may offer some additional water depth during low water periods.	Use of water basins between locks in upper sections of the Rhine as large retention basins.
Development of large water retention areas.	Ineffective, very large retention areas required for relatively small increase in water levels.	Develop very large water basins in areas attached to the river that can be emptied in case of low water incidents.

Source: Own composition based on Bosschieter (2005), PIANC (2008), Krekt et al. (2011), CCR (2012), and Riquelme Solar (2012).

At present, waterway managers are able to cope with the challenges that confront them by improving the available information on the depth of the waterways, applying advanced river training works, increasing dredging and suppletion operations, and controlling the water flow in the canalised river section upstream Rastatt. These response measures can be expected to remain sufficient as long as the effects of climate change are still moderate.

However, in case climate changes follows the swift path set out by the more extreme G+ and W+ scenarios, these measures may, at a certain stage, no longer be able to guarantee sufficient water depth for inland shipping. Extreme conditions of climate change, such as in the W+ scenario, may call for very far reaching measures to prevent flooding, guarantee fresh water supply, and keep IWT going. In case all other options to prevent flooding and maintain sufficient navigational draft for inland shipping turn out to be insufficient one can, as a last fall back option, consider the full canalisation of the river Rhine, but the canalisation of the Rhine will be very expensive and causes large social and environmental impacts. In addition the full canalisation of the Rhine will also be a major technological challenge, as locks will need to be developed that are able to cope with a massive flow of water during high water peaks as well as an unprecedented number of ship passages through the locks[120]. Canalisation of the Rhine is nowadays not perceived beneficial to IWT, as it involves additional passage time for the inland barges, but I think that this option should not be ruled out in advance as an ultimate solution in case of extreme climate change.

When successfully implemented the full canalisation of the river Rhine allows the stretch between Rotterdam and Ruhrort to remain free of draft restrictions and in addition the maximum utilisation for the barges sailing in the Kaub market will increase from 82% in the historical reference years to 100% after canalisation. This results in a reduction of the IWT cost by about 18% compared to the historical reference period. Table 9-9 indicates that such cost reductions are likely to correspond with an increase of the IWT volumes in the Kaub market by about 9% to 13%. When comparing the situation with and without canalisation for the W+ scenario in the year 2100 one finds a 17% to 25% increase of the IWT volumes for Ruhrort (compared with the situation without adverse morphological changes) and a 32% to 49% increase of the IWT volumes for the Kaub market[121]. It should however be noted that these estimates concern an upper limit, as they deal with the effect of climate change on the maximum loading capacity of the barges, while in practice the barges will not always be loaded to their full draught limits as a result of smaller parcel sizes, imbalance in transport flows, and/or shipments of relatively light cargoes (such as containers).

For the remainder of this thesis I will presume that far reaching adaptation measures, such as the full canalisation of the Rhine, will be required to guarantee all year round navigation for IWT on the Rhine in the most extreme W+ scenario towards the year 2100 – and that these adaptation measures will turn out to be technically feasible. This implies that the scenarios in Chapter 13 and 14, will either take large negative effects of climate change on IWT into account, or assume major efforts to be made in order to mitigate the effects. Further research is therefore recommended to verify the technical-, economic-, and social feasibility of such far reaching adaptations measures (taking into account the possible mind-set of future generations that are confronted with the large effects of climate change).

9.10 Concluding Summary

This chapter addresses methodological sub question 2c (MSQ 2c): *“How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system”* of which the third driver has been identified as: *“the adverse very long term effects of climate change and morphological changes on the performance of the IWT system?”*. Literature reveals various effects of climate change and morphological changes on the IWT system. A schematic structure for dealing with the adverse effects of climate change and morphological changes is provided in Figure 9-1. This chapter addresses: (1) the effects of climate change, (2) the effect of morphological changes in combination with climate change, and (3) the options to mitigate the effects and/or to adapt to the new situation.

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[120] In this respect one can think of a structure more or less similar to the weirs and ship locks in the Lek near Hagestein, where barges sail through the open barrier at high water levels and are directed through the locks at low water levels when the barrier is closed.

[121] Calculation example for 49% value of Kaub market: (1+13%)/(1-24%)-1 = 49%.

9.10.1 The effect of climate change on the performance of the IWT system

The Intergovernmental Panel on Climate Change (IPCC) is the leading international organisation for the assessment of climate change. The global climate scenarios of the 4th IPCC (2007) assessment report are based on the IPCC (2000) *"Special Report: Emission Scenarios"* (SERS), that consist of four story lines (A1, A2, B1, and B2) for which a range of ramifications is made. For the Netherlands four additional scenarios were published in 2006. These four so called KNMI'06 scenarios (G, W, G+, W+) are developed around two driving forces being: (1) the degree of global temperature rise, and (2) the anticipated changes of the atmospheric circulation patterns in our region. The applied letters G and W stand for moderate (G) and high (W) temperature rise. Strong changes to the atmospheric circulation patterns are indicated with a '+'. In addition the 2nd Delta Committee (2008) published a high-end climate scenario for the Netherlands. A new 5th assessment report was published by the IPCC in 2013; and a new set of KNMI'14 scenarios followed in 2014. These updated scenarios could not yet be taken into account because the corresponding hydrological effects on the inland waterways still need to be defined.

The changing climate conditions will affect the discharge of the rivers. For free flowing rivers the discharge will directly affect the height of the water levels. During low water periods the maximum draft (and loading capacity) of an inland barge is limited by the most critical waterway section on the applied route. The critical sections on the Rhine are located near Lobith (for the stretch between Rotterdam and Ruhrort) and near Kaub (for all shipments further upstream the Rhine). For canalised rivers such as the Meuse the effect of climate change on the available water depth is small and hardly considered a problem. Navigational restrictions are sometimes imposed for safety reasons during periods of extreme high water. In exceptional circumstances this may lead to a temporary ban on sailing at a certain river stretch. High water levels will also reduce the available air draft underneath bridges which affects the loading height for container barges. The lower delta area may also show problems with sea level rise, in particular when strong onshore winds are combined with very high river discharges. Under these adverse conditions the Maeslant Barrier in the port of Rotterdam may be closed for a certain period of time (resulting in a full closure of the inner port for large seagoing vessels). The effects of climate change on adverse wind conditions for IWT are still ambiguous. River ice events are expected to occur less frequent as a result of higher overall temperatures. This effect may however be countered by reduced heat disposal and a higher freezing point of the river due to improved water quality.

The most severe adverse effects of climate change on inland shipping are related to extreme low water levels on free flowing rivers. These effects can be modelled by the following chain of activities: (1) convert the global climate scenarios into regional climate scenarios; (2) use hydraulic models to anticipate future river discharge volumes; (3) convert river discharge volumes into water levels; (4) define the effect of changing water levels on the average loading conditions and cost levels for inland barges; and (5) apply cost elasticities to define the overall effect on the IWT volumes.

I have analysed the effects of extreme low water for the critical waterway sections at Lobith and Kaub. For each of the KNMI'06 scenarios the estimated discharge at both sections was converted into water levels and corresponding water depths. The obtained water depths were then confronted with the specific loading characteristics of two representative barges. I applied a barge of 135 x 14.2 x 3.8 meter for the section up to Ruhrort (the port area within the city of Duisburg), and a barge of 110 x 11.45 x 3.5 meter for the section beyond Kaub. From this analysis I conclude that the navigability of the Rhine is not much affected during the low water levels of the standard G and W scenarios, but that it is severely affected in the more extreme G+ and W+ scenarios. The estimates for the G+ and W+ scenarios in the year 2100 indicate that the maximum annual barge capacity is reduced by respectively 10% and 22% for the Ruhr market and by 16% and 26% for the Kaub market.

Apart from the effects of climate change on the average annual loading capacity, I have also studied the limiting condition for which shipping on the Rhine will no longer be feasible. Barge operations require a minimum draft to keep the propellers submerged. This minimum draft varies from about 1.4 meters for small barges to about 1.85 meter for a larger push-barge combination. I assumed a minimum draft of 1.6 meter for a representative barge sailing on the stretch between Rotterdam and Ruhrort and a minimum draft of 1.5 meter for a representative barge sailing in the Kaub market. The maximum loading draft up to Ruhrort is reduced to just over 1.6 meter in an average September month of the W+ scenario for the year 2100. This implies that sailing on this route will just remain feasible in an average year, but this will certainly not be the case for every individual year. Riquelme Solar (2012) indicated that a tipping point may occur around the year 2085 from which all year round navigation on the Rhine up to Ruhrort can no longer be guaranteed. For the Kaub region the expectations are even worse. The average maximum loading draft in the most adverse W+ scenario for the year 2100 is likely to drop below 1.5 meter in the August, September, and October months of an average year (i.e. not for a few days on a row, but on average throughout the entire period). During these three months standard barge operations will no longer be feasible, unless sufficient response measures are taken to mitigate the effect.

9.10.2 The effect of morphological changes in combination with climate change

The effects of climate change may become even worse in combination with adverse effects of morphological changes to the shape of the river. If no adequate measures are taken in time to mitigate these adverse effects one can already expect a severe reduction of the water depth on the medium term up to the year 2020. To address the order of magnitude of these effects in combination with the effects of climate change I defined a hypothetical worst case scenario in which no measures are taken to mitigate the effects and the guaranteed water levels are consequently reduced by 50 cm in 2050 and by 60 cm in 2100. For the moderate G and W scenario the combined effect of morphological changes and climate change on the maximum annual barge utilisation rate remains relatively small, but this is not the case for the more extreme G+ and W+ scenarios. If no measures are taken to mitigate the effect of adverse morphological changes the maximum loading draft for Ruhrort is likely to drop below the 1.6 meter threshold value in the August, September, and October months of the W+ scenario for the year 2100, which implies that sailing up to Ruhrort will no longer remain feasible with a standard barge in this period. In practice waterway managers can however be expected to take measures that mitigate these effects. Further research is recommended to study the effects of adverse morphological changes in combination with such mitigation measures.

The reduced annual capacity of the barges will increase the unit costs per transported tonne of cargo and this will affect the competitive position of IWT. The overall effect on the IWT volumes can be defined by applying price (or cost) elasticities. The price elasticity for IWT on the Rhine is expected to be in the order of -0.5 to -0.7. This implies that every 10% price level increase is likely to result in a 5% to 7% volume decrease. I defined the overall effects of climate change on the IWT volumes shipped via the Rhine by applying these elasticities. For the standard G and W scenarios the anticipated effects of climate change and morphological changes on the overall IWT volumes are quite small and vary between -2% and 2% in the year 2050 and between -3% and 3% in the year 2100. The G+ scenario shows that the overall

IWT volumes on the Rhine may be reduced by 2% to 8% in the year 2050 and by 6% to 17% in the year 2100. For the W+ scenario the reduction in IWT volumes may be about 6% to 16% in the year 2050 and about 14% to 34% in the year 2100.

9.10.3 Mitigation of the adverse effects of climate change

Literature reveals quite a number of options to deal with the adverse effects of climate change. These options relate to response measures that can be taken to improve the reliability of the logistical chain; adjust the design of the inland barges; and/or adjust the infrastructure to maintain a sufficient high quality IWT system.

During normal low water periods IWT operators are able to temporarily increase the capacity of their fleet by shifting to a higher sailing regime and/or increasing the speed of the barges. In case of extreme low water conditions, when there is insufficient draft to remain sailing for a longer consecutive period of time, such as in the W+ scenario towards the end of the century, the receiving industries are likely to search for alternative options. At first instance they are likely to shift towards other modes of transport and/or increase their storage capacity, but on the long term they can also be expected to shift to other locations that are closer to the seaports and/or the origin of their raw input materials.

Investments in climate adapted shallow draft barges will presumably not be financially feasible unless the extreme low water conditions occur most of the year (which is not the case). This implies that, in case of extreme effects of climate change, such as foreseen in the second half of the 21st century for the W+ scenario, there will not be a business case for such barges, unless cargo shippers are willing to pay a multiple of the present tariffs for a more reliable all year round operation. At such rates it is questionable if climate adjusted barges will still be able to compete with other modes of transport and/or with the relocation of production facilities. This may very well not be the case. One can however expect the Rhine basin to attract a part of the Danube fleet during low water periods because these barges are designed for lower water levels on the Danube. The size of the Danube fleet is nevertheless much smaller than the Rhine fleet and offers only a partial solution. In addition the use of Danube barges on the Rhine will also cause a shortage of barges on the Danube.

At present, waterway managers are able to cope with the challenges that confront them by improving the available information on the depth of the waterways, applying advanced river training works, increasing dredging and suppletion operations, and controlling the water flow in the canalised river section upstream Rastatt. These response measures can be expected to remain effective as long as the effects of climate change are still moderate. However, in case climate change follows the swift path as set out in the more extreme G+ and W+ scenarios, these measures may, at a certain stage, no longer remain adequate to guarantee sufficient water depth for inland shipping. In that case it may become necessary to consider far reaching adaptation measures, such as the full canalisation of the river Rhine. Such far reaching adaptation measures will be very expensive and cause large social and environmental impacts. These measures should therefore be regarded as a last fall back option.

For the remainder of this thesis I will presume that far reaching adaptation measures, such as the full canalisation of the Rhine, will be required to guarantee all year round navigation for IWT on the Rhine in the most extreme W+ scenario towards the year 2100 – and that these adaptation measures will turn out to be technically feasible. This implies that the scenarios in Chapter 13 and 14, will either take large negative effects of climate change on IWT into account, or assume major efforts to be made in order to mitigate the effects.

9.10.4 Answer to Methodological Sub Question 2c

In answer to MSQ 2c, I conclude that the most adverse effects of climate change are related to extreme low river discharge volumes and water levels on free flowing rivers; thereafter follows the effect of extreme high river discharge volumes and water levels; and finally there may also be some effects of extreme wind conditions and extreme winter weather. The primary effects of climate change on IWT can be modelled by the following chain of activities: (1) convert global climate scenarios into regional climate scenarios; (2) use hydraulic models to anticipate future river discharge volumes; (3) convert river discharge volumes into water levels; (4) define the effect of changing water levels on the average loading conditions and cost levels for inland barges; and (5) apply price (or cost) elasticities to estimate the overall effect on the IWT volumes.

Present scenarios indicate that climate change will either have a small effect on the IWT system if the regional air circulation patterns and corresponding precipitation levels remain unchanged (KNMI'06 G and W scenarios) or a very severe effect on IWT if this is not the case (KNMI'06 G+ and W+ scenarios). All year round navigation on the Rhine will, presumably, no longer remain possible in the most extreme W+ scenario for the year 2100, unless far-reaching adaptation measures are taken to mitigate the effect, such as the full canalisation of the river Rhine.

Literature:

AVV (2000) *Bevindingennotitie: Scheepvaart in WB21*, Adviesdienst Verkeer en Vervoer, Ministerie van Verkeer en Waterstaat, Rotterdam.

Beersma, J.J., and T.A. Buishand (2002) *Droog, droger, droogst: Bijdrage van het KNMI aan de eerste fase van de Droogtestudie Nederland*, KNMI, De Bilt.

Beersma J., T.A. Buishand, and H. Buiteveld (2004) *Droog, droger, droogst, KNMI/RIZA-bijdrage aan de tweede fase van de Droogtestudie Nederland*, De Bilt.

Beuthe, M., B. Jourquin, J.F. Geerts, and C. Koul à Ndjang' Ha (2001) *Freight transportation demand elasticities: a geographic multimodal transportation network analysis*, Transportation Research Part 3, vol. 37, no. 4, pp. 253-266.

Bolwidt, L., M. Schoor, L. van Hal, M. Roukema, Rijkswaterstaat RIZA (no date) *Hoogwater op de Rijn en de Maas*, Ministerie van Verkeer en Waterstaat.

Bosschieter, C. (2005) *Klimaatverandering en binnenvaart: Effecten op de binnenvaart van meer extreme lage (en hoge) waterstanden op de Rijn*, Port Reserch Centre, Rotterdam-Delft.

Bruggeman, W., E. Dammers, G.J. van den Born, B. Rijken, B. van Bemmel, A. Bouwman en K. Nabielek, J. Beersma, B. van den Hurk, N. Polman, Vincent Linderhof, C. Folmer, F. Huizinga, S. Hommes, and A. te Linde (2013) *Deltascenario's voor 2050 en 2100, Nadere uitwerking 2012-2013*, Deltares, KNMI, PBL, CPB, and LEI.

Bruijn, K. de, and F. Klijn (2011) *Deltadijken: locaties waar deze het meest effectief slachtofferrisico's reduceren*, Deltares, Delft.

Buishand, T.A., and A.M.G. Klein Tank (1996) *Regression model for generating time series of daily precipitation amounts for climate change impact studies*. Stochastic Hydraulogy and Hydraulics, vol. 10, no. 2, pp. 87-106.

Buisman, J. (2003) *Duizend jaar weer, wind en water in de lage landen deel 3*, van Wijnen, Franeker.

CCR (2012) *Klimaatverandering en Rijnvaart – Gemeenschappelijk verslag van de CCR, Besluit 2011-II-9*, CCR, Straatsburg.

Crijns L., D. Verhoeven, and A. de Kruif (2013) *HoofdFiche RWS-inbreng Deltaprogramma*, internal document of RWS, version: 21-10-2013.

Dager, C.A., L.G. Bray, C.M. Murphree, and C.A. Leibrock (2005) *Elasticity of Demand for Barged Corn Shipments on the Upper Mississippi and Illinois Waterways*, Journal of the Transportation Research Record, no. 1909: Inland Waterways; Ports and Channels; and the Marine Environment, p.1-7.

Delta Committee (2008) *Working together with water, A living land builds for its future*, www.deltacommissie.com.

Deltacommissaris (2014) *Deltaprogramma 2014, Werk aan de Delta, Kansrijke oplossingen voor opgaven en ambities*, Ministerie van Infrastructuur en Milieu en Ministerie van Economische Zaken.

Demirel (2011) *Economic Models for Inland Navigation in the Context of Climate Change*, Vrije Universiteit, Amsterdam.

Deursen, W.P.A. (1998) *Invloed van klimaatverandering op de binnenscheepvaart*, Chartago Consultancy, Rotterdam.

De Wit, M., H. Buiteveld, and W. van Deursen (2007) Klimaatverandering en de afvoer van Rijn en Maas, Rijkswaterstaat RIZA WRR and Carthago Consultancy, Arnhem.

EICB (2011) *Schip afladen op waterstand. Hoe werkt dat?*, Expertise- en InnovatieCentrum Binenvaart, http://www.informatie.binnenvaart.nl/veiligheid/522-afladen-op-waterstand.html.

Geenhuizen, M. van, G.J. Muilerman, and R. van der Heijden (1996) *Een peiling van aanpassingen in de binnenvaart bij extreme waterstanden*, Rapport i.o.v. Gemeentelijke Havenbedrijf Rotterdam, TU-Delft, Delft.

Görgen, K., J. Beersma, G. Brahmer, H. Buiteveld, M. Carambia, O. de Keizer, P. Krahe, E. Nilson, R. Lammersen, C. Perrin, and D. Volken (2010) *Assesment of Climate Change Impacts on Discharge in the Rgine River Basin: Results of the RhineBlick2050 Project*, International Commission for the Hydrology of the Rhine Basin, Lelystad.

Harris, F.R. (1997) *Invloed klimaatverandering op vervoer over water*, Den Haag.

Havinga, H. (2012) *Morfologie Bovenrijn en Waal – Het autonome process maatregelen*, Rijkswaterstaat Oost-Nederland, Deltaprogramma Rivieren, TU-Delft.

Hekkenberg (2013) *Inland ships for efficient transport change*, Delft, The Netherlands.

Henrickson, K.E., and W.W. Wilson (2005) A Model of Spatial Market Areas and Transportation Demand, Journal of the Transportation Research Record, No. 1909: Inland Waterways; Ports and Cannels; and the Maritime environment, pp.31-38.

HKV (2007) *MIT-Verkenningennota: Duurzame Vaardiepte Rijndelta*, Lelystad.

Hurkmans, R, W. Terink, R. Uijlenhoet, P. Torfs, and D. Jacob (2010) *Changes in Streamflow Dynamics in the Rhine Basin under Three High-Resolution Regional Climate Scenarios*, Americal Meteorological Society, pp. 679-699.

IPCC (1990) *Climate Change: The IPCC Scientific Assessment*, [Houghton J.T., G.J. Jenkins and J.J. Ephraums (eds.)], Cambridge University Press, Cambridge.

IPCC (2000) *Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*, [Nakicenovic, N. and R. Swart (eds.)], Cambridge University Press: Cambridge, UK and New York. 570 p.

IPCC (2007) *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Pachauri, R.K, and A. Reisinger (eds.)], IPCC, Geneva, Switzerland.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jonkeren, O. E. (2009) *Adaptation to Climate Change in Inland Waterway Transport*, Vrije Universiteit, Amsterdam.

Jonkeren, O., and P. Rietveld (2009) *Impacts of low and high water levels on inland waterway transport, literature review for 'kennis voor klimaat'*, VU University, Amsterdam.

Jonkeren, O., B. Jourquin, P. Rietveld (2011) *Modal-split effects of climate change: The effect of low water levels on the competitive position of inland waterway transport in the river Rhine area*, Transportation Research Part A, vol. 45, no. 10, pp. 1007-1019.

Kamphuis, E.H. (1999) *Automatisch drijvende waterkering voor de stad Kampen*, TU-Delft, Delft.

Klein Tank, A.M.G., and G.P. Können (1997) *Simple temperature scenario for a Gulf Stream induced climate change*, Climate Change, vol. 37, no. 3, pp. 505-512.

KNMI (2012) *Advisory Board report : towards the KNMI '13 scenarios*, De Bilt.

KNMI (2013) *IJs op rivieren*, www.knmi.nl/cms/content/32732/ijs_op_rivieren.

KNMI (2014) *KNMI'14: Climate Change scenarios for the 21st Century – A Netherlands perspective*, B. van den Hurk, P. Siegmund, A. Klein Tank (Eds), J. Attema, A. Bakker, J. Beersma, J. Bessembinder, R. Boers, T. Brandsma, H. van den Brink, S. Drijfhout, H. Eskes, R. Haarsma, W. Hazeleger, R. Jilderda, C. Katsman, G. Lenderink, J. Loriaux, E. van Meijgaard, T. van Noije, G. J. van Oldenborgh, F. Selten, P. Siebesma, A. Sterl, H. de Vries, M. van Weele, R. de Winter and G.-J. van Zadelhoff. Scientific Report WR2014-01, KNMI, De Bilt, The Netherlands. www.climatescenarios.nl.

Knoeff, H., and G.J. Ellen (2011) *Verkenning deltadijken*, Deltares, Delft.

Koetse, M.J. and P. Rietveld (2009) *The impact of climate change and weather on transport: An overview of empirical findings*, Transportation Research Part D, vol. 14, no. 3, pp. 205-221.

Können, G.J. (2001) *Climate Scenarios for impact studies in the Netherlands*, KMNI, De Bilt.

Kors, A.G., F.A.M. Claessen, J.W. Wesseling, and G.P. Können (2000) *Scenario's externe krachten voor WB21*, RIZA/WL and KNMI publication.

Krekt, A.H., T.J. van der Laan, R.A.E. van der Meer, B. Turpijn, O.E. Jonkeren, A. van der Toorn, E. Mosselman, J. van Meijeren, T. Groen (2011) *Climate change and inland waterway transport: impacts on the sector, the port of Rotterdam and potential solutions*.

Kwadijk, J., A. Jeuken, and H. van Waveren (2008) *De klimaatbestendigheid van Nederland Waterland: Verkenning van knikpunten in beheer en beleid voor het hoofdwatersysteem*, Deltaris, commissioned by Rijkswaterstaat.

Lambert, S.J., and J.C. Fyfe (2006) *Changes in winter cyclone frequencies and strengths simulated in enhanced greenhouse warming experiments; results from the models participating in the IPCC diagnostic exercise*, Climate Dynamics, vol. 26, pp. 713–728.

Middelkoop (1999) *The impact of climate change on inland navigation on the river Rhine,* Universiteit Utrecht, Utrecht.

Nomden, E.J. (1996) *De invloed van klimaatveranderingen op de bevaarbaarheid van de Rijn*, Universiteit Utrecht, Utrecht.

Nomden, E.J. (1997) *Een goed klimaat voor de binnenvaart?*, Gemeentelijk Havenbedrijf Rotterdam, Rotterdam.

Oum, T.H. (1979) *Derived demand for freight transport and inter-modal competition in Canada*, Journal of Transport Economics and Policy, vol. 21, no. 6, pp.707-731.

PIANC (2008) *Waterborne transport, ports and waterways: A review of climate change drivers, impacts, responses and mitigation*, EnviCom – Task Group 3, Climate Change and Navigation, PIANC, Brussels.

PLATINA (2010) *Inventory of available knowledge on strategic inland waterway projects, ANNEX*, D5-5_Strategic_IWT_projects_31-03-2010_Annex_(final_draft).doc.

Platz, T.E. (2009) *The Efficient Integration of Inland Shipping into Continental Intermodal Transport Chains: Measures and Decisive Factors*, TRAIL Thesis Series Volume T2009/11, Trail Research School, Delft, The Netherlands.

Rense, R. (2009) *Klimaatverandering en scheepvaart op de grote rivieren*, helpdesk water, http://www.helpdeskwater.nl/publish/pages/18866/klimaatveranderingenscheepvaartopdegrot erivieren.pdf.

Riquelme Solar, M. (2012) *Inland waterway transport in the Rhine river: searching for adaptation turning points*, Wageningen University, Wageningen.

RIZA (2005) *Aard, Ernst en omvang van watertekorten in Nederland*.

Schuttevaer (2012) *Overlast door hoog water, maar begrip voor vaarverbod in Noord-Nederland*, Groningen, 7 January 2012.

Stalenberg, B. (2010) *Design of floodproof urban riverfronts*, TU-Delft, Delft.

Te Linde, A. H. (2007) Effect of climate change on the rivers Rhine and Meuse, WL | Delft Hydraulics, prepared for Rijkswaterstaat.

Te Linde, A. H. (2011) *Rhine at risk? Impact of climate change on low-probability floods in the Rhine basin and the effectiveness of flood management measures*, Vrije Universiteit, Amsterdam.

Termes, P., and A. Paarlberg (2011) *Splitsingspuntengebied Rijntakken: Verkenning beheer bodemligging en waterverdeling*, HKV.

Timmermans, G. (1995) *Het goederentransport op de Rijn in relatie tot klimaatverandering*, Universiteit Utrecht, Utrecht.

Train, K., and W.W. Wilson (2005) *Transportation Demand for Grain Shipments: A Revealed and Stated Preference Approach*, Working Paper.

Turpijn, B., and R. Weekhout (2011) *Klimaat en Binnenvaart*, Rijkswaterstaat.

Van den Hurk, B., A. K. Tank, G. Lenderink, A. van Ulden, G. J. van Oldenborgh, C. Katsman, H. van den Brink, F. Keller, J. Bessembinder, G. Burgers, G. Komen, W. Hazeleger, and S. Drijfhout (2006) *KNMI Climate Change Scenarios 2006 for the Netherlands,* KNMI Scientific report WR 2006-01. KNMI, De Bilt.

Vellinga, P., C. Katsman, A. Sterl, J. Beersma, W. Hazeleger, J. Church, R. Kopp, D. Kroon, M. Oppenheimer, H. Plag, S. Rahmstorf, J. Lowe, J. Ridley, H. von Storch, D. Vaughan, R. van de Wal, R. Weisse, J. Kwadijk, R. Lammersen, and N. Marinova (2009) *Exploring high-end climate change scenarios for flood protection of the Netherlands,* KNMI, De Bilt.

Yu, T, and S.W. Fuller (2003) *Estimated Grain Barge Demands for the Upper Mississippi and Illinois Rivers: Tentative Findings*, U.S. Department of Agriculture, Agriculture Marketing Service, Washington D.C.

Presentations:

Blaauw, H. (25 June 2009) *Potential for the inland navigation fleet to adapt to changes in the water discharge*, CCNR Congress, Bonn.

Heinz, M. (25 June 2009) *Aktuelle Rheinkonzeption und abflussbezogene Nutzung*, ZKR - Kongress, Bonn.

Websites:

Elwis (accessed: 2013) *Pegelstanden op de Rijn* [www.elwis.de]

Hochwasser-rlp (accessed: 2013) *Waterstanden op de Rijn* [www.hochwasser-rlp.de]

IVR (accessed: 2014) *Access to IVR database* [www.ivr.nl]

KMNI (accessed: 2013) *Dutch Climate Scenarios* [www.knmi.nl]

WSV (accessed: 2014) *Information on depth of Rhine* [www.wsv.de]

Waterbase (accessed: 2013) *Historical data on Dutch water levels* [www.waterbase.nl]

Wikipedia (accessed: 2011) *Definition of Subsidence* [www.wikipedia.com]

10 Major Shifts in the Mode of Transport

"We may have all come on different ships, but we're in the same boat now."
- Martin Luther King (1929 - 1968)

10.1 Introduction

This chapter addresses methodological sub question 2d (MSQ 2d): *"How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system"* of which the fourth driver has been identified as: *"the possible major shifts in the mode of transport stemming from major changes to the cost structure of the inland transport modes?"*. It aims to investigate the effect of major changes to the primary cost drivers (i.e. land use, labour, energy, materials, capital, and infrastructure taxes) as well as the effects of a number of other important drivers on the competitiveness of IWT vis-à-vis road and rail transport.

Modal split effects of changes to the cost drivers of transport will be dissimilar for different freight segments. Changes to the relative transport costs are likely to have the largest impact in the most competitive market segments. For bulk cargoes IWT is not very sensitive to changes in the relative cost- and price levels[122] (assuming that on average the long term cost levels for the transport operator are reflected by the long term price levels). To a lesser extent this also holds for deepsea containers that are shipped on the main routes to/from the hinterland, for which intermodal barge- and rail operations are able to gain considerable economies of scale and provide a very competitive transport solution. The largest potential shifts in the mode of transport can be expected to occur for continental cargoes, that are still predominantly transported by road. For these cargoes the European Commission (2011a) now has the policy that: *"Thirty per cent of road freight over 300 km should shift to modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors"*. Given the large volumes of continental road transport compared to IWT, even a moderate shift of these cargoes could already have a substantial effect on the freight volumes shipped by IWT (as will be further discussed in Chapter 12). In order to keep the scope manageable I have limited the discussion in this chapter to an investigation of the

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[122] See also Jonkeren (2009, p.32) who states that: *"the price for transport by inland waterway vessel for most bulk goods is substantially lower than transport by another mode. Consequently, the price per tonne has to rise substantially before other transport modes become competitive and modal shift effects are expected to be small"*.

possible effects of major changes in the primary cost drivers on the competitiveness of intermodal continental container barge transport. The possible effects of such changes on the bulk- and deepsea container segments are left for further research.

Chapter 8 presumed the possible development of intermodal continental container barge transport to take place in the period from about 2020 to 2045 – and in addition it further presumed that, if continental container barge transport is successfully developed, one can also expect the development of continental pallet distribution networks on the inland waterways in the subsequent period from 2045 to 2070. I consider the presumed timing reasonable as it is defined in line with the historical patterns in the development of transport infrastructures, but one should realise that the precise timing of such developments cannot be predicted. The presumptions are primarily intended as input for the scenario analysis in Chapter 13 and 14.

In addition to the uncertainties regarding the timing of these expected developments it is also very uncertain how successful these developments will eventually be. Continental container transport is already booming in short-sea shipping (as well as in rail transport connecting the hinterland to the seaports), but still very few continental containers are shipped by barge. On the other hand one can now (by the year 2014) observe an increased interest in continental container barge transport. This chapter investigates the future competitiveness of intermodal continental container barge transport[123] and concludes that these transport flows may either become competitive (i.e. a noticeable market share for IWT) or may hardly have any chance to evolve. This conclusion feeds directly into the scenario analysis of Chapter 13 and 14.

In order investigate what can be expected I developed an integrated cost model that provides insight in the possible development of the competitiveness of intermodal continental container barge transport. This model compares the costs of unimodal road transport (in standard truck with a semi-trailer) with the costs of intermodal transport (in a continental 45 foot container) on the basis of year 2010 cost data. The model is intended to define the break-even-distance (BED) for intermodal continental barge- and rail transport on the basis of the assumption that sufficient bundling of continental cargoes can take place. The output of the model provides a clear indication of the conditions under which a major shift towards intermodal continental container transport can be expected at the present year 2010 cost levels[124].

However, on the very long term one cannot expect the cost levels to remain the same. In order to study the possible effects of future changes to the cost structure of inland transport, I assumed the primary cost drivers, of which the costs of all different transport modes are composed (i.e. the cost of land use, labour, energy, materials, capital, and infrastructure taxes), to vary within a certain range (or envelope). In addition I looked at the effects of major changes to some other important cost drivers, that can also have a large impact on the

[123] I have not made a similar analysis for the potential development of pallet distribution flows by barge, because these flows are presumably smaller and less certain than the continental container flows. The analysis of the possible effects for these flows is left for further research.

[124] It should be noted that I defined my own cost assumptions in such a way that they are all intended to reflect the year 2010 cost levels. The fact that some of the consulted sources are older does not imply that the numbers relate to the costs of earlier years. Where necessary adjustments for inflation have been made. All the applied assumptions are made available in the calculation sheet that is referred to in Appendix F.

competitiveness of the intermodal transport chain. This approach allowed me to identify the possible effects of major changes to the cost structure of the inland transport modes on the relative competitiveness of unimodal versus intermodal transport.

Having analysed a broad range of possible future conditions for the competitiveness of the intermodal transport chain, I defined a high- and low-end business as usual scenario for the competitiveness of intermodal continental container barge transport in the year 2050. The phrase *'business as usual'* was added to indicate that transport decisions will still be made on the basis of cost minimisation, and that no additional carbon taxes will be applied. The year 2050 was selected because it reflects the period in which continental container barge transport is presumed to have become mature, and because it is the last year for which the European Commission (2011a, 2011b) makes an explicit statement on the intended modal shift and emission levels. For the period beyond the year 2050 even larger changes may be expected that are very hard to foresee. The cost drivers in the high-end scenario are all set in such a way that they reflect a very favourable condition for intermodal continental container barge transport, while the cost drivers in the low-end scenario reflect a very adverse condition. The obtained scenarios provide clear insight in the possible conditions under which a major shift towards continental container barge transport can take place in the future.

It is conceivable that future generations will base their transport decisions on different criteria. The European Commission (2011b, p.3) now aims to reduce greenhouse gas emissions by 80% to 95% in the year 2050 compared to the year 1990. I have therefore added an additional high-end low carbon scenario in which all future transport decisions are based on the lowest achievable carbon emissions levels rather than the lowest achievable transport cost. The model therefore includes an estimate of the carbon emission levels.

I finally discuss two recent developments that could lead to the future development of continental container barge lines, which are: the present efforts to bundle cargoes for IWT; and the possible effects of a new Canal Seine-Nord Europe, that could enable a shift of the relatively large continental freight flows between the Ruhr area and Paris towards IWT.

Section 10.2 provides the necessary background on the characteristics of the intermodal transport chain and the break-even-distance (BED); Section 10.3 continues with a discussion on the cost structure of the inland transport system; Section 10.4 addresses the footprint of the various transport means; Section 10.5 defines the break-even-distance for a range of ten different barge types on the basis of the year 2010 cost and emission levels; Section 10.6 addresses the relation between the primary cost factors and the costs of transport (for which special attention is given to the relation between the crude oil price and the price of diesel fuels and electricity); Section 10.7 studies the effects of major changes to the primary cost drivers and defines the high- and low-end scenarios, that provide an upper and lower limit for the possible situation in the year 2050; Section 10.8 points out a few recent developments that could signpost the start of continental container transport on the inland waterways; and Section 10.9 contains a concluding summary that provides an answer to MSQ 2d.

10.2 The Intermodal Continental Transport Chain

The intermodal continental transport chain consists of many consecutive links that jointly have to compete with unimodal road transport. The competitive position of intermodal continental barge transport vis-à-vis unimodal road transport is indicated in Figure 10.1.

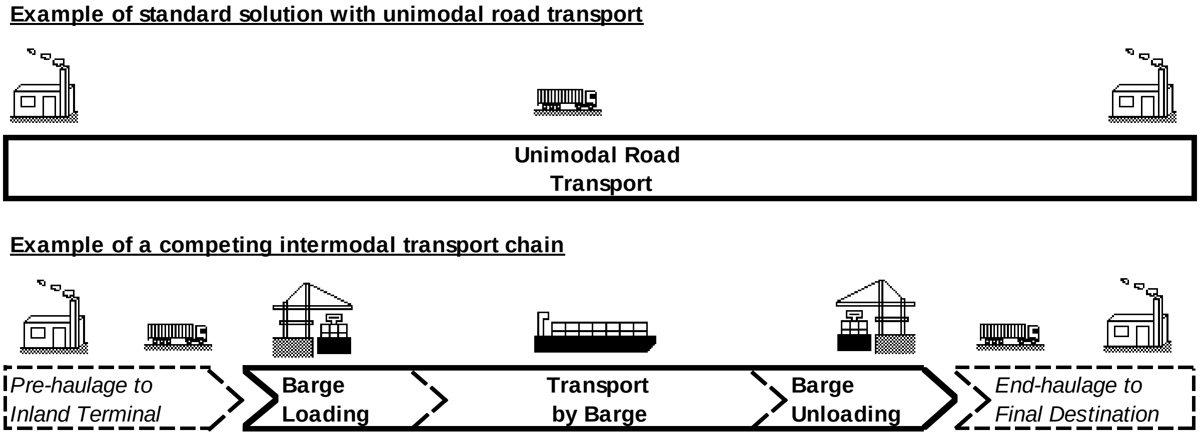
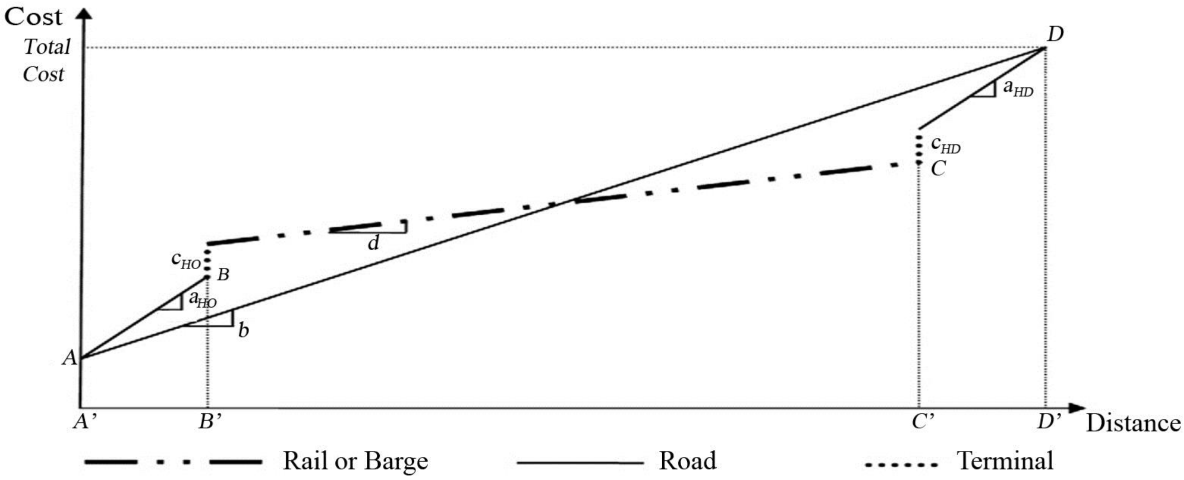


Figure 10-1: The Competitive Position of Intermodal Continental Barge Transport

The main factors that affect the competitiveness of an intermodal transport chain are amongst others discussed by Kim and Van Wee (2011) and Macharis et al. (2012). In order to make an intermodal transport chain competitive the cumulative costs of all individual chains should be less than the costs of unimodal road transport. This condition is not easy to meet as the costs of pre- and end-haulage as well as the costs for terminal handling weigh heavily in the overall costs of the intermodal transport chain. The longer the distance between the origin and destination location, the more the intermodal transport chain can benefit from the relatively low costs of the main haulage trip (e.g. by barge, rail, or short sea), and the more likely the intermodal transport solution will become competitive. The distance for which the intermodal transport chain becomes competitive is called the break-even-distance (BED).



Source: Kim and Van Wee (2011, p.861), adjusted layout.

Figure 10-2: Break-Even-Distance for an Intermodal Transport Chain

Figure 10-2 points out the main advantages and disadvantages of intermodal transport. The per kilometre unit costs of pre- and end-haulage (slope: a_{HO} and a_{HD}) are higher than for unimodal road transport (slope: b). This is logic as the waiting and loading times for the truck have to be spread over a relatively small number of kilometres, the average speed of a truck is lower at shorter distance, and less return cargo will be available on a shorter distance. The handling costs at the terminal (slope: c_{HO} and c_{HD}) do not bring the container closer to the end destination. In order to be competitive the per kilometre costs of the main intermodal haulage trip (slope: d) will have to be considerably smaller than those of unimodal road transport.

Because different transport means use different transport networks with different alignments it is not possible to compare the distances on a one to one basis. For this reason apostrophes are used to show the locations on the *'Distance'* axis. The numbers A', B', C', and D' can be regarded as projections on the horizontal line between the origin and the destination. If the distance between the origin and destination is smaller than D' the out of pocket expenses for unimodal road transport will be smaller than for intermodal transport. If the distance exceeds D' the out of pocket expenses for the intermodal transport solution will be lower. In practice the alignment of the various transport networks can play a very important role in the feasibility of intermodal transport, in particular when a straight transport link is lacking and one has to make a detour. The latter is not uncommon to IWT, for which the waterway follows the shape of the river, but it also applies to rail transport.

10.3 The Present Cost Structure for Intermodal Transport

I developed an integrated cost model to study the conditions under which a major shift of continental cargoes from unimodal road transport towards intermodal container transport can take place. The model makes a specific comparison of the year 2010 cost levels for unimodal road transport in a large truck with a semi-trailer and intermodal transport in a continental 45 foot container, because these loading units are frequently used in continental transport and offer a similar loading volume (see Chapter 8).

The cost comparison is made from the perspective of the shipper of the cargo who pays a certain price for the transport service to the transport operator and is further confronted with a number of other generalised cost items such as the capital costs for the goods that are being transported and the costs of insurance and paperwork. The estimation of the price of the transport services is based on a cash flow model for the transport operator that defines the required rates (or price levels) to cover the costs and obtain a sufficient long term rate of return. The obtained cost levels are presented in the remainder of this section. The estimates of the specific costs for each mode of transport as well as the references to the applied input data are provided in an Excel spread sheet that is referred to in Appendix F.

10.3.1 Introduction and modelling principles

The estimation of the unimodal and intermodal transport costs requires many cost items to be included in the model. The following items are covered by the model:

- Rent of the container;
- Time value of the transported goods;
- Unimodal road transport by a large truck with a semitrailer;
- Pre- and end-haulage by a large truck with a container chassis;
- Main haulage by rail;
- Main haulage by IWT;
- Terminal transfer road – rail;
- Terminal transfer road – IWT;
- Terminal transfer road – road.

I have not included all generalised costs in the model (see also Chapter 6). Not included are for instance costs related to: reliability, paperwork, and risk of damage. The reason for not including these items is that they are difficult to quantify and that they will presumably have a relatively small effect on the outcome of the analysis.

For the evaluation of long term effects I find the use of cost based shadow prices (that are based on a cost estimate for the transport operations) more appropriate than the use of actual price levels, because: (1) transport is a very competitive business in which the margins are rather small; (2) in times of overcapacity there is a tendency to lower tariffs to the level of the variable costs instead of the overall costs; and (3) in times of shortage of capacity good profits are made that compensate the losses during the bad times. The use of actual price levels would highly depend on the economic situation, while on the long term the transport operator needs to cover its expenses and gain a reasonable return on its investment. I have therefore defined the average long term price levels (further referred to as costs as they appear as costs to the shipper of the cargo) on the basis of a cash flow calculation in which the tariffs are set to meet a certain required return on investment, that reflects the profit margin for the transport operator. The required return on investment for the transport operator (i.e. the weighted average cost of capital: WACC) was set at a default pre-tax value of 6%. All cost levels are expressed in Euros of the year 2010. Inflation is not included in the model.

Please note that I deliberately speak about transport costs instead of transport prices because I make the analysis from the perspective of the shipper of the cargo, who pays for the transport services. The costs items in the model do however include a normal margin for the transport operator and are therefore intended to reflect the average long term price levels.

10.3.2 The cost for using the container

A prerequisite for intermodal transport is the availability of an intermodal loading unit. The use of this unit involves additional costs. I have therefore contacted a producer of containers and a container trader to obtain sufficient information for the development of the cost model. From these two companies I understood that the price of a new continental 45 foot container is about € 6,500 and that the remaining value is about € 1,000 after 10 years. In addition I understood that the annual costs for repair and maintenance are about 5% of the initial investment costs. I further assumed that the overhead costs add another 10% to the overall cost levels, and that the containers are effectively used for about 180 days per year. On the basis of these numbers I derived the following costs for the rent of the container per day:

- € 6.36 per 45 foot container per day.

10.3.3 The time value of the transported goods

The cost comparison for the shipper of the cargo also includes the time value of the goods, that will be defined as the capital costs of the goods during shipment and the lost business opportunities due to unavailability of the goods. The time value of the goods is dissimilar to the value of time (VoT) that is frequently reported in transport studies to address the overall cost of a vehicle and its cargo (see e.g. Significance et al., 2013). I based the estimate of the average time value for continental cargoes on the values reported for road transport by NEA (2007, p.20 and p.37). For the year 2004 NEA reported a total value of 1,962,078 million Euros and a transport volume of 773,392 thousand tonnes. After applying a 2% annual correction for inflation this results in an average value of 2,857 euro per tonne. Assuming an average payload of 20 tonnes per container, a weighted average cost of capital of 6% per annum, and an assumed mark-up of 25% for loss of business opportunities, I estimated the overall time value at:

- € 14.27 per full 45 foot container per day.

10.3.4 The costs of unimodal road transport by a large truck with a semi-trailer

Continental cargo is generally transported in trucks of various sizes. To obtain a fair cost comparison I defined the costs of unimodal road transport on the basis of a large truck with a semi-trailer (of which the inner dimensions are similar to those of a continental 45 foot container). It is common to estimate road transport costs on the basis of a time and a distance component (see e.g. Blauwens et al., 2002). The unit rates for time and distance are derived by my own cost model and amongst others based on information obtained from NEA (2004, 2011), Van Dorsser (2005), and Grosso (2011). I assumed an annual truck distance of 130,000 km and a total of 2,500 operational hours. The full details on the calculation are made available in Appendix F. The following base year 2010 unit rates were obtained:

- € 50.36 per hour;
- € 0.33 per km.

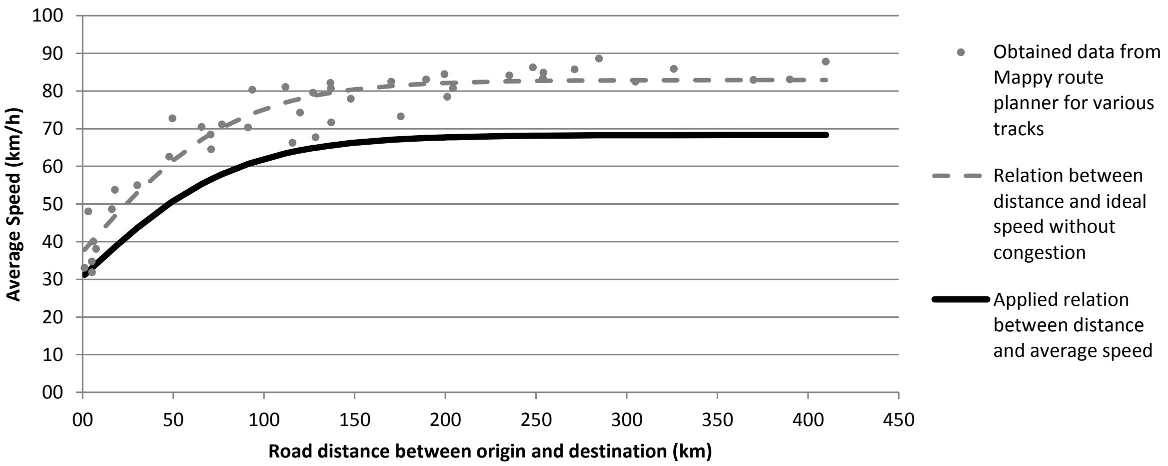
The costs of a road trip are estimated by applying the rate per hour to the overall time of the trip and the rate per kilometre to the overall distance (e.g. for a one hour trip that covers 30 km: 1 x € 50.36 + 30 x € 0.28 = € 58.76). The above numbers still exclude additional road taxes such as the German MAUT. These taxes vary with the size and emission category of the truck. For the cleanest 'Category A' truck type an additional € 0.155 per kilometre is charged on the German motorways and a large number of national roads (Transport Online, accessed: 2014). A comparable eco-tax has also been announced for the national roads in France (initially planned for October 1st 2013, but delayed), and the Belgium motorways (Nieuwsblad Transport, 2014). For the inclusion of road taxes I applied a default value of:

- € 0.15 per taxed km.

In order to define the overall fraction of the trip to which road taxes are applied I made the assumption that the first and last 20 km (total of 40 km) of a trip are taking place on local roads, that are exempted from road tax. The remaining distance is assumed to be taxed.

To estimate the total costs of unimodal road transport one should first define the overall time and distance required for the trip. For a one way trip without return cargo the overall time can be defined as the sum of the loading time at the origin location (I assumed one hour), the driving time (function of distance), the unloading time at the destination (I assumed one hour) and the time required for driving back to the origin. If return cargo is available on the route back one has to add two additional trips (from the points of unloading to the points of loading) and two additional loading and unloading periods. As default setting I assumed the returning main track to have a similar distance as the outward main track, and added an additional 50 km driving for relocation from the point of unloading to the point of re-loading. The overall distance of the roundtrip thereby becomes two times the distance between the origin and the destination plus two times an additional 50 km for relocation.

The average speed of a truck depends on the length of the individual trips. The longer the distance between the origin and destination, the larger the fraction of time that a truck spends on the highway and therefore the higher the average speed. Van Dorsser (2005) investigated this relation by first defining the ideal speed on a number of fictive routes in the Netherlands (obtained from www.mappy.com) and then correcting the ideal speed for congestion. The obtained results are indicated in Figure 10-3. It can be observed that for longer trips an average speed of 68 km/hour is assumed. This number is in line with the average speed in international transport as reported by NEA (2004) at 68 km per hour and the average speeds of Grosso (2011) ranging from 67 to 70 km per hour.



Source: Figure based on data of Van Dorsser (2005)

Figure 10-3: Relation between Distance and Average Speed for a Truck

10.3.5 The cost of pre- and end-haulage by a truck with a container chassis

The unit rates for pre- and end-haulage can be defined in a similar way as the costs for unimodal road transport, though instead of a truck with a semi-trailer, a truck with a container chassis will be used. For haulage operations the annual distance driven by the truck will also be considerably lower than for unimodal road transport (I assumed 50,000 km per year). The impact of these two differences is relatively small though it slightly reduces the costs of a truck per hour. For pre- and end-haulage the following unit rates were applied:

- € 47.02 per hour;
- € 0.33 per km.

The pre- and end-haulage costs can be estimated by assuming that an empty/full container is loaded on the truck at the terminal, driven to the sending/receiving company over an assumed distance of 25 km, loaded/unloaded at the company's premises, and returning full/empty to the terminal (i.e. one way trip with no return cargo). For haulage operations a turnaround time of about 20 minutes is assumed at the terminal. The turnaround time at the sending/receiving companies is assumed to be 45 minutes, which is lower than for unimodal road transport as the logistical processes tend to be organised in a more efficient way. The same speed to distance relation as for unimodal road transport is applied. Additional road taxes (such as the MAUT) can be included in a similar way as for unimodal road transport though the relative share of taxed kilometres will be quite low in practice. Because I applied a default haulage distance of about 25 km (< 40 km) no additional road taxes were included.

10.3.6 The main haulage costs for intermodal rail operations

A useful introduction and cost model for rail freight operations is provided by Flodén (2011). I used this model as the basis for my own cost model, but also included additional information from Grosso (2011) and NEA (2004, 2011). Due to the different characteristics of diesel and electric trains I considered both options in the model. However, given the large excise duties on diesel, and the virtual absence of excise duties for electric rail operations, the latter turns out to be the most cost effective.

The cost model of Flodén (2011) points out that the most influential factor for the cost of rail transport is probably related to the utilisation rate (effective traction hours) of the locomotive. Rail operations have to compete with passenger trains for the availability of the railway track and therefore rail freight operations are often restricted to the night-hours. This results in a fairly low number of traction hours (I assumed 3000 operational hours and 2200 traction hours per year)[125]. In addition trains also have to wait a fair amount of their running time on the track. As a result the average speed on the track (between origin and destination) is much lower than the average running speed (which is about 70 km/h). Roughly in line with the assumptions of NEA (2004, 2011) I assumed an overall performance of about 100,000 km per year. This implies that the average speed on the track is just 45.5 km per hour.

The main consequence of the low operational performance of freight trains is that the capital costs are relatively high. In addition a train will not always be fully loaded. I considered a train with 33 rail wagons that can each load a single 45 foot container. On average 26 of these wagons will be loaded (about 80%). The remaining wagons are empty. In addition there are some 20% additional wagons required to support efficient operations at the railway terminal. The unit rates per operational hour and per km were estimated by taking these operational considerations into account. The following unit rates were obtained for an electric train:

- € 290.41 per operational hour;
- € 7.80 per km for a train loaded with full 45 foot containers;
- € 6.37 per km for a train loaded with empty 45 foot containers.

The actual distance between two locations depends on the alignment of the railway track. In most circumstances the alignment of the railway track will be longer than for road transport, because the railway network is less dense than the road network. To deal with this aspect I assumed a default detour factor of 1.2 for rail transport compared to unimodal road transport. The running time of the train is defined by dividing the length of the track by the average speed on the track (i.e. 45.5 km per hour) and by adding a default turnaround time of four hours at each terminal (i.e. a total of 8 hours per roundtrip).

10.3.7 The main haulage costs for intermodal IWT operations

The applied cost model for IWT is based on the work of Hekkenberg (2013), Beelen (2011), a reasonable number of reference barges (data amongst others kindly provided by the Mercurius Shipping Group), and a few actual charter rates obtained from two inland barge operators. Unlike the work of Beelen my model is not only intended to define the cost levels for a few standard barges, but it also aims to investigate non-standard barges that are optimised for carrying 45 foot containers. For that reason I developed a model that, in line with the work of Hekkenberg, defines the cost of barge operations on the basis of parametric input regarding the length, width, and draft of the barge. On the basis of this parametric model the cost factors of ten different barge types were defined. The applied barge types are listed in Table 10-1.

The first five barge types reflect the current situation in which the infrastructure is not fully compatible with the requirements for efficient transport of continental 45 foot containers (see Chapter 8). Barge type 4 *'Class V Low'* is applicable to existing Class V waterways with an available air draft of 7.0 meter. Barge type 5 is applicable to existing Class V waterways with an air draft of 9.1 meter. Barge types 6 to 10 refer to barge dimensions for waterways that are upgraded to meet the requirements for efficient transport of 45 foot containers. The letters L, W, and H stand for additional available and/or allowed length, width, and height (air draft) of

[125] This assumption is based on an average distance of 500 km, an average speed of 45.5 km per hour on the track, and a turnaround time of the train at the station of four hours.

the barges. Table 10-1 indicates that the adjusted barges have a much higher loading capacity for continental 45 foot containers than the standard barges that are currently applied. An upgrade of the IWT infrastructure could therefore be very effective.

Table 10-1: Barge Types applied in the Cost Model

No.	Barge Type	Length (m)	Width (m)	Air draft* (m)	Capacity (45' Cont.)	Utilisation (%)	Avg. Load (45' Cont.)
1	CLASS II	55.00	6.60	2.30	2 x 2 x 1 = 4	80%	3
2	CLASS III	80.00	8.20	2.15	4 x 2 x 1 = 8	80%	6
3	CLASS IV	85.00	9.60	5.30	4 x 3 x 2 = 24	80%	19
4	CLASS V LOW	110.00	11.45	5.10	6 x 3 x 2 = 36	80%	29
5	CLASS V	110.00	11.45	8.15	6 x 3 x 3 = 54	80%	43
6	CLASS II+L,H	58.00	6.65	5.25	3 x 3 x 2 = 12	80%	10
7	CLASS III+H	80.00	6.65	5.20	4 x 2 x 2 = 16	80%	13
8	CLASS IV+H	80.00	9.25	8.15	4 x 3 x 3 = 36	80%	29
9	CLASS IV+L,H	95.00	9.25	8.10	5 x 3 x 3 = 45	80%	39
10	CLASS V+W,H	110.00	11.80	10.90	6 x 4 x 4 = 96	80%	77

***Note: Air draft based on even keel loaded barge that is loaded with empty containers and has ballast in side wing tanks. Air draft does not include recommended safety margin of about 30 cm (see Chapter 2).**

The physical properties (displacement, lightweight, and deadweight) and building costs are based on the advanced rules of thumb of Hekkenberg (2013). The capital costs were defined by applying a default 6% return on investment. The lifetime of the barge was set at 25 years with a residual value of 30%[126]. I have not applied a different lifetime for equipment and other outfitting items as I assumed the replacement costs to be included in the reservations for surveys and large maintenance. Most operational costs, such as the labour costs and the costs for repair and maintenance, were based on the cost model of Hekkenberg (2013) though additional data from Beelen (2011) and some other confidential data sources have also been used. For container operations I assumed a 24/7 continuous operation. In addition I assumed that on average 80% of the available container slots on board is utilised.

A major challenge in the development of the cost model was related to the development of a useful module for the estimation of the fuel consumption (on the basis of the length, width, draft, displacement, and speed of the barge, as well as the depth and width of the waterway), as the models of Beelen (2011) and Hekkenberg (2013) could not be made available. The estimation of the fuel consumption of inland barges has still received little attention in academic literature and the existing models developed by specialised institutes are generally not publicly available. Nevertheless a recent breakthrough has been made after the *'discovery'* of an empirical model for the prediction of the resistance of barges by Holtrop et al. (1990) and a literature study of Van Terwisga (1989), that includes the diagrams of the so called Karpov[127] correction for shallow water. Both documents served as input to the work of Van Hassel (2011), Beelen (2011), and Hekkenberg (2013). The Karpov method does however not

[126] Note that the lifetime of inland ships is generally even longer (see Chapter 2), but I consider this assumption that was made in consultation with R.F. Zimmerman (founder of Mercurius Shipping Group) reasonable for investments in new inland barges.

[127] Hekkenberg (2013, p.36) note that: *"The original paper by Karpov, (Karpov, A.B., "Calculation of Ship resistance in restricted waters", TRUDY GII T. IV, Vol. 2, 1946) is written in Russian and no longer available"*.

correct for the reduced width of the waterways (e.g. in canals). I therefore added an additional correction based on the Huuska (1976) formula as reported by Briggs (2006). This approach provided sufficient input for the development of a useful model for the estimation of the barge resistance, but a reasonable method for the estimation of the propulsion efficiency is still lacking[128]. I have therefore developed a new provisional empirical method that estimates the propulsion efficiency on the basis of the length of the barge, the actual draft in relation to the scantling draft, and the actual power in relation to the installed power (which is defined as a function of the length and width of the barge). For the development of this provisional method over 30 real reference conditions were obtained by interviewing a number of barge owners.

For each of the obtained reference conditions I compared the calculated barge resistance with the reported fuel consumption. This resulted in an estimate of the propulsion efficiency. The next step was to apply stepwise decomposition on the obtained propulsion efficiency data to derive a reasonable formula for estimating the propulsion efficiency of inland barges. The outcome of the fuel consumption model was finally discussed with the technical department of the Mercurius Shipping Group and compared to a few known open water measurements of other barges. From this comparison it was concluded that the overall model output provides fair results at open water conditions for normal speed conditions. Due to lack of sufficient low speed and shallow water measurements the fuel consumption estimates at fairly low speeds and restricted water conditions still need to be validated. The estimated fuel consumption for the standard barges at their design draft is indicated in Figure 10-4.

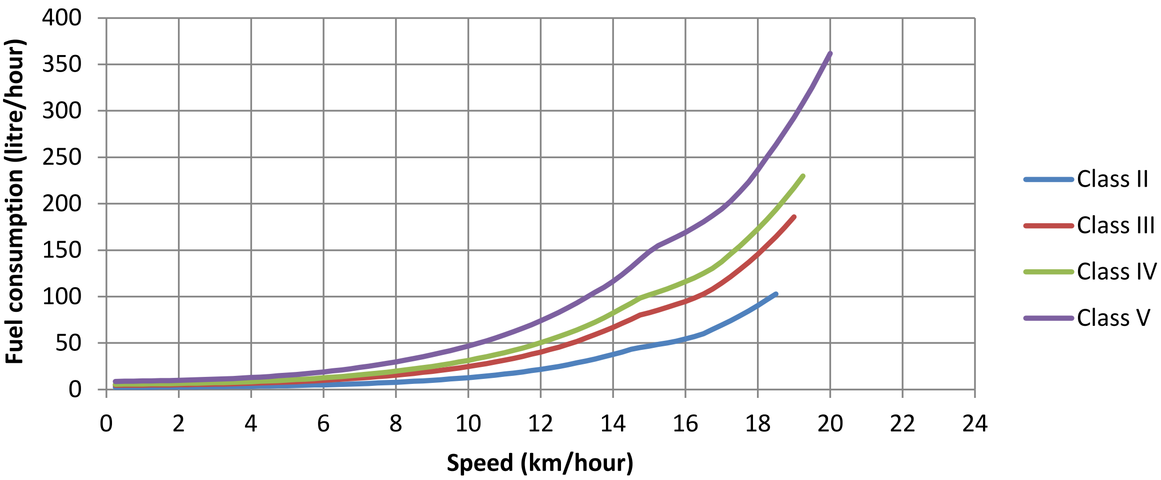


Figure 10-4: Fuel Consumption of Standard Barges at their Design Draft

The figure shows a small humb at a speed of about 15 km per hour. This hub is caused by the shift from a relatively high specific fuel consumption (per kWh output) at low engine load factors (and lower speed levels) to a lower specific fuel consumption at high engine load factors for which the barges are generally designed. Further improvement of the model is possible by taking the real engine configurations of the barges into account (i.e. the number of engines and propellers as well as the choice for direct or diesel electric propulsion).

[128] From a personal conversation with Hekkenberg (in year 2013) it was understood that simple methods to obtain a reasonable first estimate of the propulsion efficiency of inland barges are still lacking and that the department of Marine Engineering at the TU-Delft is now assigning two PhDs to work on this subject.

The fuel consumption of a barge that is loaded at its design draft is considerably higher than the fuel consumption of a barge that is loaded with relatively light continental 45 foot containers. This implies that the required fuel consumption for the transport of continental 45 foot containers would be much lower than indicated in Figure 10-4. An indication of the fuel consumption for a standard barge loaded with full continental 45 foot containers of 20 tonnes payload each is provided in Figure 10-5. For both figures it was assumed that the width of the waterway is ten times the width of the barge and that the depth of the waterway is 1.5 times the design draft of the barges. This assumption has been further applied as default setting.

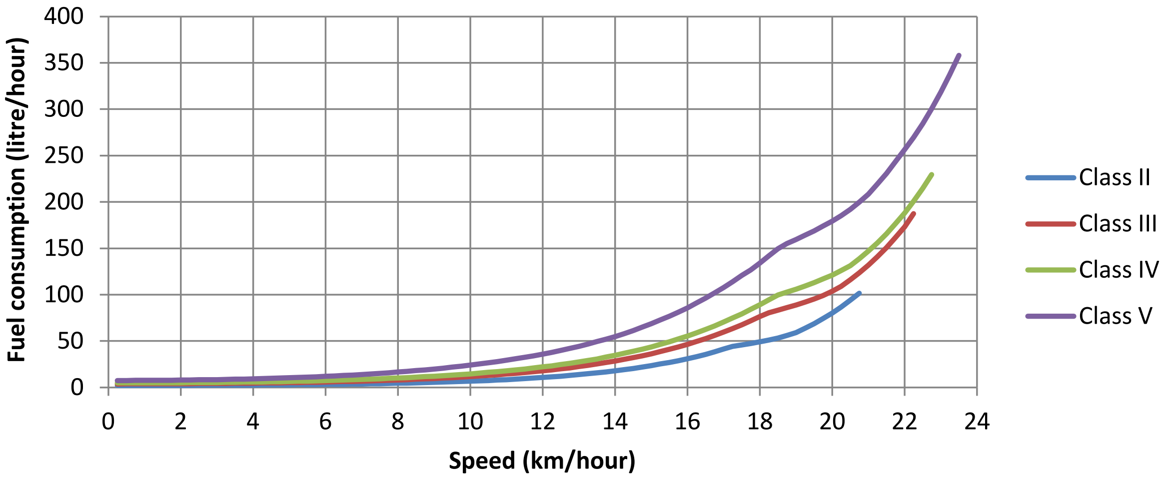


Figure 10-5: Fuel Consumption of Standard Barges loaded with Full 45 foot Containers

The economic speed of the barges (for which the overall costs per roundtrip are minimised) can be defined on the basis of the following parameters:

- The relative level of the fixed costs per hour (e.g. for capital and labour) compared to the variable costs of the fuel (as function of the main dimensions and loading draft);
- The relative number of sailing hours compared to the waiting and service times at inland terminals, bridges, and ship locks;
- The strength of the encountered currents on the river sections of the waterway;
- The planning constraints related to the fixed scheduling of the barge operations.

The cost model takes into account all above constraints except those related to the fixed scheduling of the barges. With respect to the encountered currents it was assumed that 50% of the roundtrip is subject to a current of 4 km per hour (see also Backer van Ommeren, 2011). The consequence of the encountered current is that the average speed over water needs to be higher than the average speed over ground. I dealt with this issue by first estimating the required constant speed over water that should be maintained throughout the entire roundtrip to obtain the desired average speed over ground and then defining the true fuel consumption on the basis of the required speed over water.

The model automatically defines the economic speed of the barges on the basis of the assumed length of the sailing track, which is a function of the distance between the origin and destination locations as well as the detour factor for IWT compared to road transport. The detour factor was set at a default value of 1.2 compared to unimodal road transport, which is considered reasonable for many routes along the waterways such as indicated in Table 10-2.

Table 10-2: Detour Factor for a number of Routes along the Waterways

Route		IWT Distance	Road Distance	Detour Factor
Kampen	Luik	311 km	275 km	1.13
Amsterdam	Willebroek	230 km	185 km	1.24
Amsterdam	Duisburg	222 km	217 km	1.02
Dortmund	Hannover	261 km	204 km	1.28
Hamburg	Dreesden	571 km	500 km	1.14
Utrecht	Frankfurt	496 km	419 km	1.18
Nijmegen	Basel	721 km	631 km	1.14
Groningen	Gent	393 km	361 km	1.09
Average				1.15

Source: Own estimates based on routes defined in PC-Navigo and Google Maps.

Table 10-3 presents the numbers for a predefined OD road trip distance of 300 km, but I also calculated the numbers for a smaller 100 km and a longer 500 km trip. The per kilometre rates were slightly different for the 100 km trip (in particular when a different optimal speed was selected) and almost identical for the 500 km trip. Please be aware that the fuel consumption rates are defined at a reasonably shallow draft when transporting 45 foot containers of some 20 tonnes each. For standard 20 and 40 foot containers the fuel costs will be higher.

Table 10-3: Unit Costs for a predefined Trip with an OD Road Distance of 300 km

No.	Barge Type	FC–SOG (km/h)	FC–Fixed (€/hour)	FC–Var. (€/km)	EC–SOG (km/h)	EC–Fixed (€/hour)	EC–Var. (€/km)
1	CLASS II	14.00	46.62	1.62	15.0	46.62	1.75
2	CLASS III	13.50	57.03	1.75	15.0	57.03	2.15
3	CLASS IV	13.50	60.91	2.03	14.0	60.91	2.05
4	CLASS V LOW	14.00	84.37	2.88	15.0	84.37	3.01
5	CLASS V	13.50	84.37	2.78	15.0	84.37	3.06
6	CLASS II+L,H	13.50	47.38	1.72	15.0	47.38	1.81
7	CLASS III+H	14.50	54.74	1.92	15.0	54.74	1.96
8	CLASS IV+H	13.00	58.71	2.05	15.0	58.71	2.39
9	CLASS IV+L,H	13.50	73.33	2.32	15.5	73.33	2.72
10	CLASS V+W,H	13.00	85.31	3.24	14.5	85.31	3.07

Note: The fixed costs are based on 8,400 operational hours per year; FC stands for loaded with full 45 foot containers; EC stands for loaded with empty 45 foot containers; and SOG stands for speed over ground.

I contacted two container barge operators to verify the calculations and understood that the bare rent of a Class V (110 x 11.45 meter) barge is now (July 2013) about 1,500 euro per day, but that it should be about 1,800 euro per day to support financial sustainable operations. This tariff is based on a 24/7 operation. It includes the crew costs, but excludes the costs of fuel, port dues, and barge planning. If I would add another 100 euro to cover the fixed fuel costs (for the generator and the bowthruster) and another 5% for the planning of the barge I would obtain a rate of about 2,000 euro per day. This is very much in line with my estimated cost level of 2,025 euro per day (i.e. 24 x 84.37 euro). I also compared the rates of a new Class IV barge and found results quite similar to the numbers indicated by the barge operators.

It should be noted that Rijkswaterstaat (Turpijn, 2013) indicated a default rate of 243.77 euro per hour for a waiting Class V barge. Following a discussion on this issue Rijkswaterstaat requested PANTEIA (former NEA) to develop a new tool for defining the unit costs of inland barges (for which I contributed to the specifications). By applying this tool the average fixed costs for a loaded continuous 24/7 operated Class V container barge can be estimated at 97.14

euro per hour (excluding port dues), which is much closer to my 84.37 euro per hour estimate than the 243.77 euro per hour estimate that was previously used.

10.3.8 The terminal handling costs for rail and barge terminals

The cost model for the rail terminals is mainly based on a Swedish study by Sommar (2010), some additional data from Flodén (2011), and some additional data on ground prices for the Netherlands. As Sommar (2010) reported in Swedish Crowns I applied a conversion rate of 0.10 Euro per Swedish Crown (actual rate in the period 2009-2010) to convert the data into Euros. A number of cost estimates was made for terminals of various sizes including: a small, medium, and large end-station for a block train running between two distinct locations. The average of the cost levels for a large- and medium terminal was applied as default value in the analysis. The following costs per in- or outgoing container were obtained:

- € 37.86 per in- or outgoing container (rail to truck or vice versa).

The cost model for inland barge terminals is based on the same unit rates as applied in the rail terminal model, though a few additional assumptions on the costs of the quay wall were made. The costs of new terminal cranes as well as the fuel and energy consumption of these cranes were based on data obtained from Ligteringen et. al. (2004), www.bromma.com (accessed: 2013), and www.gothwald.com (accessed: 2013). A number of cost estimates was made for different terminal sizes including: a small, medium, and large barge terminal. I used the average of the cost levels for a large- and medium terminal as default value in the model. The following costs per in- or outgoing container were obtained:

- € 41.01 per in- or outgoing container (barge to truck or vice versa).

In case return cargo is available two additional depot moves will be required. The first move is made when the inland depot receives the returning container. The second move occurs when the container is picked up and loaded onto an outgoing truck. The costs for handling a container at an inland depot are lower than those for handling a container from a truck onto a barge or a train at an inland terminal. I applied the following costs for a depot handling:

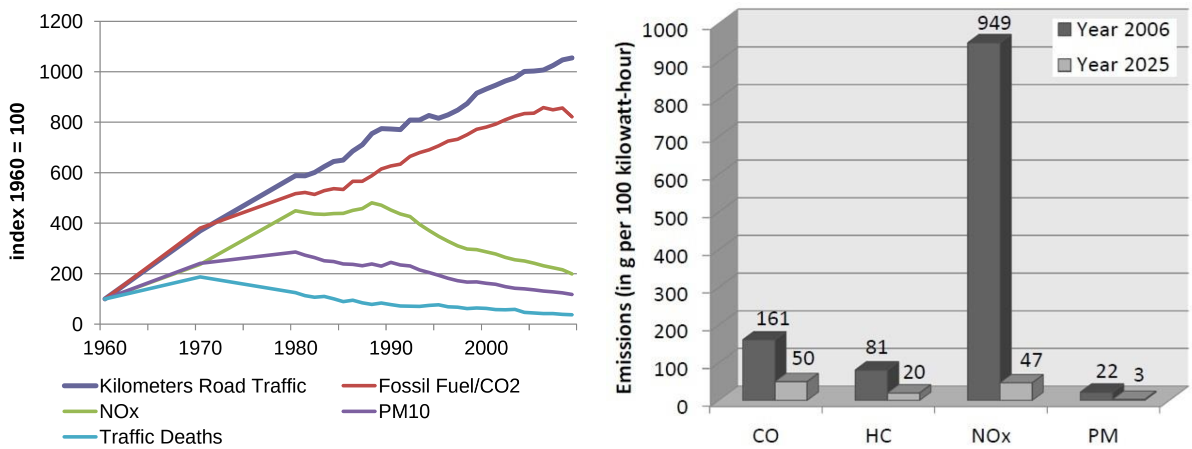
- € 30.22 per round going container (truck to stack, stay in stack, and stack to truck).

10.4 The Carbon Footprint of Inland Transport

The European Commission (2011b, p.3) states that: *"Member States have committed themselves to reducing greenhouse gas emissions (GHG) by 20%, increasing the share of renewables in the EU's energy mix to 20%, and achieving the 20% energy efficiency target by 2020"*; and that: *"In order to keep climate change below 2°C, the European Council reconfirmed in February 2011 the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990, in the context of necessary reductions according to the Intergovernmental Panel on Climate Change by developed countries as a group"*. It is therefore likely that future policies will put more emphasis on the reduction of greenhouse gasses. This section addresses the societal aim to obtain a more sustainable transport system as well as the carbon emissions for each individual step in the inland transport chain.

10.4.1 The societal aim to obtain a more sustainable transport system

The present focus on transport costs is very much related to the mainstream paradigm of the 5th Kondratieff wave, that aims for profit maximisation (see Chapter 4), but the 5th Kondratieff wave is now on its return and it is reasonable to assume that future generations will to behave in a different way than today. In line with the presumed drivers of the next 6th Kondratieff wave I expect an enhanced focus on the implementation of sustainable policies.



Source: Left: Annema (presentation, 2010); Right: Macharis (presentation, 2012), originally reported to be based on Planco Consulting GMBH (2007). Layout of both figures adjusted.

Figure 10-6: Road Traffic and External Effects (left), IWT Emissions (right)

Annema (2010) indicates that road transport already achieved major successes in the reduction of nitrogen (NOx) and particle (PM_{10}) emissions as well as in the number of traffic casualties (see Figure 10-6, left); and Macharis (2012) noticed that a similar trend is expected for IWT in the period up to 2025 (see Figure 10-6, right). In addition new fuel regulations have also resulted in a vast reduction of sulphur (SO_2) emissions (see also Footnote 7). The main challenge for the transport system is to reduce its carbon emissions. Historical data, such as presented in Figure 10-6 (left), show that it is very hard to decouple carbon emissions from transport movements. Some progress was made by applying more efficient engine technologies and more sustainable fuels, but the bottom line is that decoupling of carbon emissions from transport movements is still a major technological challenge.

An effective way to reduce carbon emission is to enhance a shift towards more sustainable modes of transport. This approach is endorsed by the European Commission (2011a), that aims to shift 50% of continental road transport over 300 km to rail and waterborne transport by the year 2050. One can think of several policy options to enhance this shift and reduce the level of carbon emissions from transport. A possible option would be to upgrade the IWT network in order to make it more competitive with road transport, but this alone cannot be expected to be sufficient. A more obvious measure would be to internalise the external costs of carbon emissions by introducing carbon taxes on transport.

To take the possible effects of carbon taxes into account in the model one requires insight in the external costs of emitting carbon, but unfortunately the academic world has not yet reached consensus on this subject. The IMPACT Handbook of the European Commission (Maibach et al., 2008, p.77) summarises shadow prices ranging from €14 per tonne CO_2 on the short term to €280 per tonne CO_2 on the long term. On the basis of the available literature they recommend a shadow price ranging from €7 per tonne CO_2 to €45 per tonne CO_2 in the year 2010 and from €20 per tonne CO_2 to €180 per tonne CO_2 in the year 2050. To avoid a lengthy discussion on the right level of the shadow price for carbon emissions, I decided to analyse the BED in terms of carbon footprint rather than in transport cost that include a tax on carbon emissions. In case high taxes on carbon emissions will be imposed in the future, the BED will tend to move towards the outcome of the footprint analysis.

10.4.2 Fuel and energy consumption for each individual step in the transport chain

For estimating the fuel and energy consumption of each individual step in the transport chain the following assumptions were applied:

- Road Transport: fuel consumption of 0.35 litre per truck km for a large truck as suggested by Grosso (2011) in her average cost model;
- Rail Transport (diesel train): fuel consumption based on 1.51 litre/km plus 0.00424 litre/gross tkm as suggested by Flodén (2011) for a modern diesel train;
- Rail Transport (electric train): energy consumption based on 0.0212 kWh/gross tkm plus an additional 16% energy for transition losses as suggested by Flodén (2011);
- Rail Terminal (average of large and medium size terminal): 3.19 litre/container. Based on fuel consumption of 17 litre/hour for reach stackers; 30 litre/hour for strong shunting locomotives; and 18 litre/hour for small shunting locomotives;
- Barge Transport: fuel consumption based on model discussed in Section 10.3.7;
- Barge Terminal (average of large and medium size terminal): 3.1 litre/container plus 4.4 kWh per container; 36 litre/hour for diesel crane; 100 kW for electric crane;
- Depot Handling: 3.54 litre/container for two handlings including some household moves. Based on a fuel consumption of 15 litre per hour for an empty handler.

The indicated numbers reflect the fuel and energy consumption for the year 2010. Insight in long term effects of possible fuel reductions is provided in Section 10.6.

10.4.3 Carbon emissions per litre diesel and per kWh energy

The next step is to convert the fuel and energy consumption levels into carbon emission levels. For diesel fuels the carbon emissions levels (in kg CO_2) can be derived by multiplying the fuel consumption in litres by a factor 2.7:

- 1 litre diesel ⇨ 2.7 kg CO_2.

The 2.7 kg CO_2 per litre diesel follows directly from the chemical combustion reaction. The exhaust level cannot be reduced, but it is possible to close the carbon cycle by extracting the carbon from the environment when producing the fuels (e.g. use of biofuels).

For electric output the CO_2 production per kWh is strongly affected by the applied fuel. It can be as low as about 4 gram per kWh for clean energy sources like wind or hydroelectric power or as high as 1050 gram per kWh for some adverse types of coal[129]. I defined the emission levels on the basis of the official emission guidelines for the Netherlands (Harmelink et al, 2012). These guidelines distinguish between an integral and a marginal approach. The integral approach is based on the average emissions per kWh. The marginal approach is based on the marginal emissions per extra unit of production. The guidelines recommend the marginal approach for (dis)savings of energy. The marginal emission levels for the base year 2010 were reported to be 0.57 kg CO_2 per kWh.

- 1 kWh ⇨ 0.57 kg CO_2.

Integral emission levels for the year 2010 were reported to be 0.46 kg CO_2 per kWh. In the future the average and marginal emission levels can be expected to be reduced as a result of prevailing policies to shift towards sustainable energy production.

[129] Many different numbers are circling around on the internet. These numbers are just an indication.

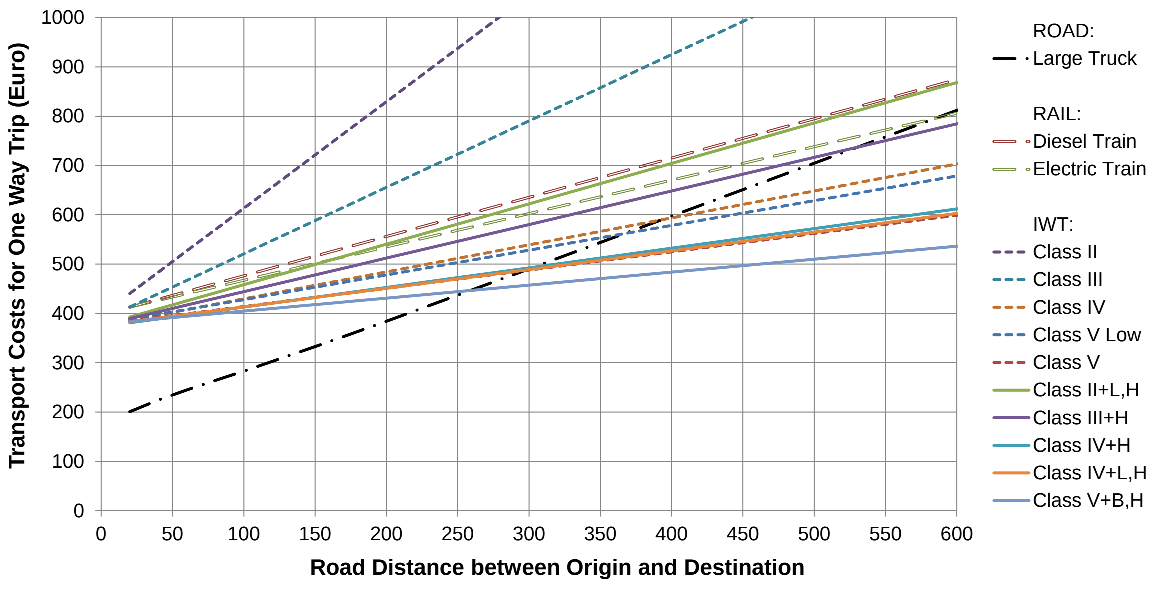
10.5 The Break-Even-Distance for Inland Barge Transport

The base year 2010 cost and emission factors for the various items in the inland transport system that were discussed in the previous two sections allowed me to derive the break-even-distance for continental container barge transport vis-à-vis unimodal road and intermodal rail transport. This section presents the outcome of the break-even-distance analysis in terms of cost and emission levels.

10.5.1 The break-even-distance based on cost levels for the year 2010

I analysed the break-even-distance (BED) for the situation with and without additional road taxes (such as the MAUT in Germany and the eco-tax in France). For both cases an estimate was made of the situation with and without return cargo. In case of unimodal road transport with return cargo a relocation distance of 50 km between the place of unloading and the place of re-loading was assumed. For the corresponding intermodal transport option an average pre- and end-haulage distance of 25 km per trip was assumed (i.e. total of 50 km per haulage roundtrip for delivery and returning to the terminal). The time value of the goods was included in all estimates. The travel distance on the main haulage trip between the intermodal rail- and barge terminals was set at a default value of 1.2 times the road distance between the origin and the destination. This assumption was made to compensate for the fact that in general the alignment of the rail- and IWT infrastructure is longer than for road transport.

The BED for continental transport in 45 foot containers (between two non-seaport locations) was estimated for a roundtrip with and without return cargo. Figure 10-7 shows the estimated transport costs of a one way trip for a continental shipment (in a truck with a semi-trailer or in a continental 45 foot container with a similar loading volume) under the assumption that return cargo is available and no additional road taxes are levied.



Note: The x-axis refers to the distance for unimodal road transport. The corresponding distance for the other modes is longer than for road transport, because a detour factor is applied in the model.

Figure 10-7: Costs for a One Way Trip in case of Return Cargo without Road Tax

Table 10-4 provides the results of the BED calculation for the situation with and without return cargo as well as for the situation with and without the effect of an additional road taxes.

For each situation the costs of rail freight were also calculated to address the cases where rail freight could be even more cost effective. These cases are marked with an asterisk (*).

Table 10-4: Break-Even-Distance based on Cost Levels for the Year 2010

No.	Barge Type	No road tax – with return cargo	No road tax – no return cargo	With road tax – with return cargo	With road tax – no return cargo
1	CLASS II	N/A	N/A	N/A	N/A
2	CLASS III	N/A	N/A	N/A	N/A
3	CLASS IV	393 km	348 km	312 km	280 km
4	CLASS V LOW	367 km	324 km	296 km	265 km
5	CLASS V	297 km	262 km	249 km	223 km
6	CLASS II+L,H	**822 km*	**680 km*	**527 km*	**454 km*
7	CLASS III+H	530 km	468 km	392 km	351 km
8	CLASS IV+H	303 km	267 km	253 km	225 km
9	CLASS IV+L,H	298 km	263 km	250 km	223 km
10	CLASS V+W,H	259 km	228 km	223 km	199 km

***Note: The model estimated rail transport to be the most cost effective mode of transport, the presented numbers indicate the BED compared to road transport in case rail transport is not available.**

For Class II and III barges no break-even-distance was found. This implies that for these barges one cannot expect continental container transport between two inland terminals to be feasible at the present (year 2010) transport cost levels. Please note that this does not imply that there is no work for such barges. They can for instance still be cost effective for the transport of deepsea- and even shortsea containers to/from the hinterland on small waterway routes (see also discussion on shuttle between Rotterdam and Veghel in Section 10.8).

The model indicates that continental container transport can be developed in a cost effective way for standard Class IV and V barges on stretches above 223 – 393 km (under the assumption that sufficient cargo is available to offer a regular service). An interesting finding is that the BED becomes shorter if no return cargo is available. This implies that road transport is more affected by the unavailability of return cargo than intermodal transport. I would consider this an interesting topic for further research.

Increasing the height of the smaller Class III waterways, to allow for two high stacking of containers, will enhance the opportunities for the development of intermodal continental container transport with Class III+H barges on the longer stretches above 351 - 530 km. Upgrading the Class IV and V waterways, for the effective transport of continental 45 foot containers, reduces the BED from about 223 – 393 km to about 199 – 303 km.

Applying the assumed additional road taxes of € 0.15 per km (on all trip distances above 40 km) reduces the BED for standard Class IV and Class V barges from about 262 – 393 km to about 223 – 312 km. This implies that imposing additional road taxes can be a very effective way to enhance intermodal transport. If additional road taxes are combined with an upgrade of the IWT infrastructure the BED is even further reduced to about 199 – 253 km.

10.5.2 The break-even-distance based on emission levels for the year 2010

In the light of the aims of the European Union to reduce 80% to 95% of all carbon emissions by the year 2050 (compared to the year 1990 situation), it is sensible to look not only at the BED in terms of costs, but also in terms of carbon emissions. This section reports on the BEDs for the corresponding year 2010 situation in which no adjustments to the speed of the vehicles is made. The results of this analysis are indicated in Table 10-5.

Table 10-5: Break-Even-Distance based on Emission Levels for the Year 2010

No.	Barge Type	Economic speed – with return cargo	Economic speed – no return cargo
1	CLASS II	N/A	N/A
2	CLASS III	N/A	N/A
3	CLASS IV	**430 km*	**422 km*
4	CLASS V LOW	320 km	**327 km*
5	CLASS V	154 km	154 km
6	CLASS II+L,H	N/A	N/A
7	CLASS III+H	N/A	N/A
8	CLASS IV+H	177 km	186 km
9	CLASS IV+L,H	157 km	162 km
10	CLASS V+W,H	116 km	109 km

***Note: The model estimated rail transport to have lower emission levels, the presented numbers indicate the BED compared to road transport in case rail transport is not available.**

It can be observed that, at the economic speed levels, the BEDs for transport of continental 45 foot containers tend to be higher for the smallest barges and lower for the larger barges (compared to the cost based BEDs). For Class II and III barges loaded with the numbers of containers indicated in Table 10-1, and sailing at the speeds indicated in Table 10-3 the emission levels will be higher than for unimodal road transport at all distances. For larger barges the BED is considerably reduced, in particular when the infrastructure is upgraded.

10.6 Major Changes that affect the Break-Even-Distance

When considering a very long time horizon up to or even beyond the year 2050 one cannot expect the cost and emission structure of the inland transport system to remain the same. This section elaborates on how changes to the primary cost factors (e.g. labour, energy, and capital) as well as a number of other important drivers could affect the cost and emissions levels for inland transport (i.e. for truck-, rail-, barge-, and inland terminal operations).

10.6.1 The assumed composition of transport costs out of primary cost drivers

For each cost item an assumption was made on the relative share of the primary cost drivers *land*, *labour*, *energy*, *materials*, and *infra taxes*. These assumptions are listed in Table 10-6.

Table 10-6: Assumed Composition out of Primary Cost Drivers

Composition of primary drivers	Land	Labour	Energy	Materials	Infra Taxes
VOT goods	0%	0%	0%	100%	0%
Land use	100%	0%	0%	0%	0%
Terminal infrastructure cost	0%	0%	0%	100%	0%
Equipment costs	0%	0%	0%	100%	0%
Direct labour costs	0%	100%	0%	0%	0%
Other labour expenses	10%	50%	20%	20%	0%
Overhead costs - unspecified	10%	50%	20%	20%	0%
Overhead costs - labour	0%	100%	0%	0%	0%
Overhead costs - other	20%	0%	40%	40%	0%
Repair and maintenance costs	10%	50%	20%	20%	0%
Costs of tyres	0%	0%	50%	50%	0%
Road Taxes	0%	0%	0%	0%	100%
Rail Charges	0%	0%	0%	0%	100%
Port and Waterway Dues	0%	0%	0%	0%	100%

Note: Insurance costs are not included as they are defined as a percentage of the capital investment costs; Fuel costs are not included as they are directly related to the price of a barrel of crude oil.

The numbers presented in Table 10-6 were based on my personal judgement. Further research can be conducted to improve these numbers, but I consider them sufficient to obtain an indication of the possible effects that changes to the primary cost drivers can have on the BED for intermodal continental container transport. It goes too far to address the composition of the unit costs that were presented in Section 10.3 out of these cost items, but all these details are made available in the calculation sheet that is referred to in Appendix F.

The energy costs concern the fuel and energy used for buildings and production processes. The fuel and energy consumption of the logistical processes (i.e. running trucks, trains, barges, and inland terminal operations) are implemented in a different way. For these cost items the energy driver is assumed to affect the price of a barrel of Crude Brent Oil from which the diesel and electricity prices are derived for the various modes of transport, taking into account the different excise duties that are presently applied.

10.6.2 The effect of changing oil prices on the fuel and energy price levels

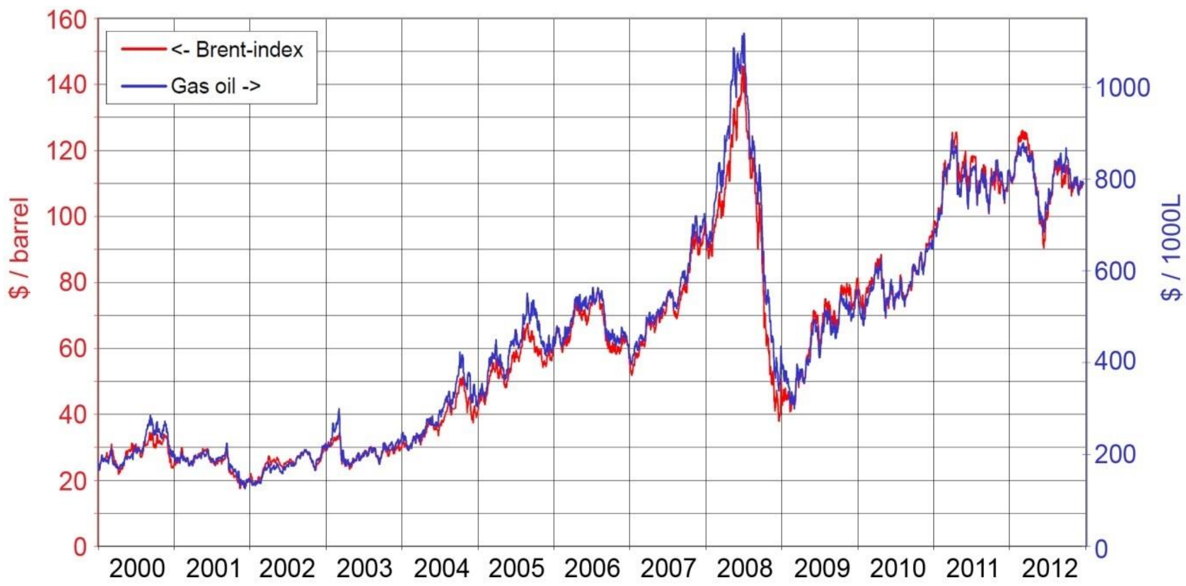
Changes to the fuel and energy cost driver are more complicated than changes to other cost drivers, because different excise duties are applied to different users. For road transport a fair amount of excise duties on diesel is paid while IWT is exempted from excise duties in all Rhine States ever since the Mannheim Act came into force in 1868 (see Chapter 2). For rail diesel a reduced excise duty level was in place for the Netherlands, but since January 1st of 2013 this is no longer the case. Rail transport is now paying the same excise duties on fuel as road transport. For that reason I adjusted the 2010 cost data to match the new situation. Excise duties vary heavily from country to country. A full list of all the excise duties within the EU is provided by the European Commission (2013). From this document it can be concluded that the excise duties on rail diesel are for instance slightly higher in Germany, far lower in Italy, and fully exempted in Belgium. Detailed transport models should take into account all these different excise duty levels, but for obtaining a rough indication of the BEDs I consider it sufficient to base the estimates on the Dutch fuel and energy price levels.

Excise duties also vary a lot for the use of electricity (EC, 2013). Electricity used by the railways is for instance exempted from tax in Belgium and Italy. In Germany rail transport pays € 0.01145 per kWh compared to € 0.01537 for other businesses. In the Netherlands a very progressive system is in place in which large users pay far less excise duties:

- € 0.1165 per kWh for the first 0 – 10.000 kWh;
- € 0.0424 per kWh for the following 10.000 – 50.000 kWh;
- € 0.0113 per kWh for the following 50.000 – 100.000.000 kWh;
- € 0.0005 per kWh for the remaining over 100.000.000 kWh.

The national Dutch railway company (NS) is mainly charged according to the 4th (lowest) tariff. For smaller regional railway companies the 3rd (second lowest) tariff will be applicable. This tariff is very much in line with the tariff applied in Germany. On the basis of the above discussion I conclude that railway companies are either fully exempted from excise duties on electricity, pay less excise duties than other businesses, or pay virtually no excise duties because they are subject to an extraordinary low tax rate that applies to very large electricity users. In this respect it is not surprising that most long haulage freight trains avoid paying excise duties by using electric locomotives instead of diesel locomotives.

The differences in the applied excise duties on fuel and energy use imply that changes in the costs of the primary energy sources (e.g. the oil price) will have a very different effect on the cost levels of the various modes of transport. I took the price of a barrel of Crude Brent Oil as a starting point for the calculations. Figure 10-8 indicates the relation between the excise free gasoil (or diesel)[130] price and the ICE Brent crude oil index. By measuring some points in the figure I was able to derive that the tax exempted gasoil price per litre equals 0.0072 times the price of a barrel crude oil. For the year 2010 the average price of a barrel crude oil was about 80.25 US$ (or € 60.55). This implies that the standard costs for the production of a litre of gasoil were about € 0.44 per litre. On top of these costs one has to add the excise duties, the transport and storage costs, and the margins for the fuel station. All these items were taken into account in the overall cost model. This finally resulted in a base year 2010 price per litre diesel of € 0.47 for IWT, € 0.93 for Road, and € 0.93 for Rail[131]. It should be noted that these numbers are lower than the price levels recommended by oil companies which do not take into account the discount rates that are generally offered by fuel stations.



Source: Backer van Ommeren (2013), adjusted size and layout.

Figure 10-8: ICE – Index for Brent Crude Oil and Price of Gasoil excluding Duties

For electricity prices I also assumed a linear relation to the price of a barrel of crude oil, but I had some difficulties to gain insight in the actual price levels. The website of the national Dutch railway company (NS) reports an annual (no year indicated) energy consumption of about 1.5 billion kWh and a corresponding fuel bill of about 150 million Euro. This implies that the NS pays roughly 10 cents per kWh. Grosso (2011) reported an electricity cost of € 2.9 per km for a train that would elsewise use 6 litre per hour if a diesel locomotive would have been used. I estimated the equivalent energy consumption of this train at 26 kW which

[130] From a technological perspective gasoil is nowadays almost similar to diesel. In the past the technical specifications of gasoil (i.e. red diesel) and diesel fuels used to be slightly different as gasoil used to have a much higher sulphur content than diesel (i.e. 0.1% instead of 0.001%), but since January 1st of 2011 new European regulations prescribe the same maximum amount of 0.001% for both fuels (when applied in inland transport). In that respect the only technical difference is that red-dye is added to the gasoil.

[131] Value based on the new post 2013 excise duty structure; the real year 2010 value was calculated at € 0.75, which is similar to the average value of € 0.75 for rail transport in 2010 as reported by Grosso (2011).

implies that the average electricity costs are in the order of 11 cents per kWh. Assuming the latter value to be correct I defined the costs of a kWh as 0.00184 times the price of a barrel of crude oil for very large users such as rail operators. In line with the progressive Dutch system for electricity users I assumed the rate for inland terminals to be 1 cent higher (apply tariff level 3 instead of 4) at a level of 12 cents.

10.6.3 Effect of changes in the relative costs of the primary cost drivers

In order to get a feeling for the effects of changes to the individual cost drivers I estimated the relative effect of a one percent change of an individual primary cost driver on the relative length of the BED (i.e. the BED elasticities of the primary cost factors). Table 10-7 shows the obtained numbers for a standard trip with return cargo and without additional road taxes.

Table 10-7: Effect of a one percent change of a Primary Cost Driver on the BED

No.	Barge Type	Land Use	Labour	Energy	Materials	Infra Tax	Capital*
1	CLASS II	N/A	N/A	N/A	N/A	N/A	N/A
2	CLASS III	N/A	N/A	N/A	N/A	N/A	N/A
3	CLASS IV	0.04%	-0.07%	-0.04%	0.34%	-0.02	0.39%
4	CLASS V LOW	0.04%	-0.08%	-0.05%	0.33%	-0.01	0.37%
5	CLASS V	0.04%	-0.06%	-0.09%	0.29%	-0.01	0.32%
6	CLASS II+L,H	0.00%	-0.02%	0.19%	0.45%	-0.04	0.66%
7	CLASS III+H	0.02%	-0.06%	0.06%	0.36%	-0.02	0.46%
8	CLASS IV+H	0.04%	-0.05%	-0.08%	0.27%	-0.01	0.32%
9	CLASS IV+L,H	0.04%	-0.03%	-0.09%	0.26%	-0.01	0.31%
10	CLASS V+W,H	0.05%	-0.06%	-0.10%	0.26%	-0.01	0.29%

Note: *For this item the overall required IRR was raised by a factor 1.01 from 6% to 6.06%.

Increasing costs for land use, materials, and capital result in a longer BED. This implies that they will have a negative effect on the competitiveness of intermodal barge transport, which is logical because intermodal transport is relatively land and capital intensive. An increase in labour costs reduces the BED, which can be explained by the fact that labour requirements per container are smaller for an inland barge than for a road truck. The effect of changing energy price levels varies with the size and loading capacity of the barge. Larger barges result in an intermodal transport solution that is more fuel efficient than that of unimodal road transport, while the smallest barges are not necessarily more fuel efficient for the transport of 45 foot containers. Changes to the applied infrastructure taxes (not including additional taxes such as the German MAUT) have a relatively small effect.

10.6.4 Effect of changes to other important intermodal cost drivers

Apart from changes to the primary cost drivers I also investigated the possible effects of a shift of companies back to the waterfront, the possible abolishment of the fuel tax exempt for IWT, and the possible effects of new fuel efficient technologies.

<u>The redevelopment of waterfront business areas:</u>

Chapter 8 indicated that the development of waterfront industrial sites is probably the most effective policy measure that can be taken to reduce the costs of pre- and end-haulage as well as the terminal handling costs. The shift of companies (back to) the waterside will not only reduce the distance between the company and the intermodal barge terminal, but also enhances the clustering of economic activities and the bundling of cargoes near the inland terminals. I assumed a reduction of the average haulage distance from 25 to 2.5 km in the model. To maintain a fair comparison with unimodal road transport the relocation distance for picking up return cargo was also reduced by the same factor from 50 to 5 km.

The effect of the possible abolishment of the fuel tax exempt for IWT:
Following the Mannheim Act of 1868 IWT still benefits from a full tax exempt on gasoil, but it is possible that for some reason this fuel tax exempt will be abolished in the future. Such an event will have a considerable effect on the cost levels for inland shipping and therefore it is also included in the analysis[132].

The possible effects of new fuel efficient technologies:
The following assumptions were applied to address the possible effects of new fuel efficient technologies on the vis-à-vis performance of unimodal road- and intermodal transport flows:

- 30% fuel reduction for road transport;
- 20% fuel reduction for rail transport;
- 30% energy reduction for rail transport;
- 20% fuel reduction for terminal operations;
- 40% energy reduction for terminal operations;
- 20% fuel reduction for barges due to reduced resistance;
- 10% fuel reduction for barges due to improved engine technologies;
- X%[133] fuel reduction for barges due to an improved 75% overall propulsion efficiency.

Road engines leave little room for further efficiency improvements, but a 20% to 40% reduction of the air resistance is still feasible if the aerodynamics of the truck are completely redesigned (C,MM,N: Cargo, accessed: 2013). For rail transport a 23% difference in diesel consumption was reported for an older locomotive compared to a new one (Flodén, 2010). I assumed a further reduction by another 20% in the future. Electric trains can also reduce their energy consumption by feeding back breaking energy into the network. I therefore assumed a higher potential reduction of 30% for electric trains. Feeding back energy into the network is even more interesting for electric terminal cranes. Johanson (2010) indicates that up to 33% of the crane energy can be recovered if smart asynchronous crane operations are adapted. In addition I also expect terminal operations to be organised in a more efficient way. I therefore assumed a 20% reduction in the fuel- and a 40% reduction in the energy consumption of inland terminals. There are plenty of options to reduce the resistance of inland barges (e.g. by applying a more efficient hull shapes, rudder alignments, and better anti-accretion methods). In addition there may still remain some options to improve the fuel consumption of the main engines by means of add on technologies. Finally a completely new propulsion system is now being developed that is referred to as *Whale Tale* or *O-foil* propulsion (www.ofoil.nl). Van Manen and Van Terwisga (1997) indicated that the ideal propulsion efficiency of this system can be over 80% (I therefore assumed a maximum overall efficiency of 75%). This new propulsion system has a great potential to improve the efficiency of in particular the smallest barges. A real scale test aiming for a fuel reduction of 50% is now being performed on a small Class I barge named *'Triade'* (Schuttevaer, 2013) and a larger O-foil driven Class IV barge is now planned to be constructed in 2016 (Klos, 2014). The anticipated effects of the three abovementioned drivers are indicate in Table 10-8.

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[132] The possible abolishment of the fuel tax exempt for IWT can be considered as a Gray Swan (see Chapter 5) that is not in line of present expectations, but could have a potentially large impact when it occurs.

[133] For this item the reduction varies per type of barge, in general the improvement will be larger for the smaller barge types that tend to have a smaller ship propeller with a correspondingly lower propulsion efficiency.

Table 10-8: Effects of Changes to a few other Major Drivers on the BED

No.	Barge Type	Base: No road tax, with return cargo	Reduced haulage distance of 2.5 km	Excise duties on fuel for IWT	Clean technology developments
1	CLASS II	N/A	N/A	N/A	N/A
2	CLASS III	N/A	N/A	N/A	N/A
3	CLASS IV	393 km	256 km	522 km	376 km
4	CLASS V LOW	367 km	240 km	469 km	365 km
5	CLASS V	297 km	193 km	338 km	303 km
6	CLASS II+L,H	**822 km*	**539 km*	N/A	592 km
7	CLASS III+H	530 km	347 km	**871 km*	482 km
8	CLASS IV+H	303 km	195 km	352 km	304 km
9	CLASS IV+L,H	298 km	193 km	339 km	305 km
10	CLASS V+W,H	259 km	168 km	280 km	270 km

Note: *The model estimated rail transport to be the most cost effective mode of transport. The presented numbers indicate the BED compared to road transport in case rail transport is not available.

It can be concluded that spatial developments aiming for the (re)development of waterborne business areas can effectively enhance the development of intermodal (continental) container barge transport. The possible abolishment of the excise duty exempt for gasoil applied in IWT will have a strong negative effect on the BED for continental container barge transport. The effects of new fuel saving technologies are more ambiguous. It turns out that the relative performance of the smaller barges vis-à-vis unimodal road transport is reasonably improved while the performance of the larger barges is slightly lagging behind.

10.7 Development of High- and Low-End Scenarios

I consider it impossible to provide a detailed very long term forecast for the development of the main drivers that affect the BED of continental container barge transport, but it is possible to explore the outer corners of plausible changes to the system by developing a high- and low-end scenario for the competitiveness of continental container barge transport. This section starts with the development of a high- and low-end business as usual scenario that reflects the situation in which transport decisions remain based on minimisation of overall transport costs, and in which no additional policies are implemented to reduce carbon emissions. Thereafter follows a high-end low carbon scenario in which I presume future transport decisions to be based on minimisation of carbon emissions rather than minimisation of transport costs. All scenarios are intended to reflect on the situation in the year 2050.

10.7.1 High- and low-end business as usual scenarios for year 2050

Though I consider it impossible to make very long term forecasts for the development of the primary cost drivers that affect the inland transport system, it is still desirable to get some feeling for the possible direction in which the BED for continental container barge transport can develop. I have therefore prepared a high- and low-end business as usual scenario for the year 2050 in which I assume the primary cost factors to be either half or double the value they were in the year 2010, and for which I selected those combinations of changes that result in highest and lowest BED. In addition I have also added a few other important drivers that can either be included or not included. The applied assumptions are listed in Table 10-9. The effects of fuel saving technologies are included in the low-end scenario, because the large effects on small barges outweigh small effects on large barges. For each scenario two different situations were analysed. The first situation refers to a reduced pre- and end-haulage distance of 2.5 km and a relocation distance of 5 km for unimodal road transport. The second situation refers to the standard model assumption with a pre- and end-haulage distance of 25 km and a relocation distance of 50 km for unimodal road transport.

Table 10-9: Applied Scenario Assumptions for Year 2050

Item	Base Scenario	High-End Scenario	Low-End Scenario
Land use	100% of 2010 value	50% of 2010 value	200% of 2010 value
Labour	100% of 2010 value	200% of 2010 value	50% of 2010 value
Energy	100% of 2010 value	200% of 2010 value	50% of 2010 value
Materials	100% of 2010 value	50% of 2010 value	200% of 2010 value
Intra taxes	100% of 2010 value	200% of 2010 value	50% of 2010 value
Capital (WACC)	6% ROI	3% ROI	12% ROI
Additional road tax	Not Included	Included	Not Included
New clean technologies	Not Included	Included	Not Included
IWT fuel tax exempt	Applicable	Applicable	Not Applicable

Note: The additional road tax relates to the value of €0.15 per taxed km as discussed in Section 10.3.3. The use of new clean technologies relates to the assumptions made in Section 10.6.4. If the IWT fuel tax exempt is not applicable similar fuel costs as for road transport are assumed.

Table 10-10 provides the outcome of the high-end business as usual scenario. In this scenario the BED for continental container barge transport can be as low as 109 – 146 km for Class IV and Class V barges if companies are located close to the terminals at both sides of the route. For these barges the BED can be even further reduced to 98 – 121 km if the corresponding waterway infrastructure is upgraded. For upgraded waterways the BED of Class II+L,H and Class III+H barges reduces from 288 – 380 km to 172 – 232 km when the haulage distance is also reduced. This implies that there may be fair chances to develop continental container services on the smaller waterways – and equally important, that the possibility to start with small container flows may also trigger the development of larger container flows on the larger waterways (for which bundling of cargo is more complicated) by just starting with a relatively small barge and gaining additional volume over time. It should be noted that the BEDs can be further reduced by applying a so called ‘koppelverband’ (see Chapter 2), but I have left this option for further research.

Table 10-10: Outcome of the High-End Business as Usual Scenario for Year 2050

No.	Barge Type	Reduced haulage with return cargo	Reduced haulage no return cargo	Standard haulage with return cargo	Standard haulage no return cargo
1	CLASS II	N/A	N/A	N/A	N/A
2	CLASS III	N/A	N/A	N/A	N/A
3	CLASS IV	146 km	133 km	250 km	230 km
4	CLASS V LOW	142 km	129 km	241 km	221 km
5	CLASS V	120 km	109 km	208 km	191 km
6	CLASS II+L,H	**232 km*	**212 km*	**380 km*	**349 km*
7	CLASS III+H	188 km	172 km	312 km	288 km
8	CLASS IV+H	121 km	109 km	211 km	193 km
9	CLASS IV+L,H	124 km	111 km	213 km	195 km
10	CLASS V+W,H	107 km	98 km	187 km	172 km

Note: *The model estimated rail transport to be the most cost effective mode of transport. The presented numbers indicate the BED compared to road transport in case rail transport is not available.

Table 10-11 shows the outcome of the low-end business as usual scenario. Under these harsh conditions continental container barge transport cannot be developed in a cost effective way, in particular not if no investments are made to upgrade the waterways and if no efforts are made to shift companies (back) to the waterside. The reported break-even-distances are so high that continental container barge transport may not even have a slightest chance to develop on the routes with the thickest cargo volumes. This implies that it is also possible that continental container barge transport will never really develop.

Table 10-11: Outcome of the Low-End Business as Usual Scenario for Year 2050

No.	Barge Type	Reduced haulage with return cargo	Reduced haulage no return cargo	Standard haulage with return cargo	Standard haulage no return cargo
1	CLASS II	N/A	N/A	N/A	N/A
2	CLASS III	N/A	N/A	N/A	N/A
3	CLASS IV	N/A	N/A	N/A	N/A
4	CLASS V LOW	N/A	920 km	N/A	N/A
5	CLASS V	911 km	469 km	N/A	607 km
6	CLASS II+L,H	N/A	N/A	N/A	N/A
7	CLASS III+H	N/A	N/A	N/A	759 km
8	CLASS IV+H	N/A	475 km	N/A	620 km
9	CLASS IV+L,H	862 km	441 km	N/A	574 km
10	CLASS V+W,H	592 km	338 km	744 km	437 km

Note: *The model estimated rail transport to be the most cost effective mode of transport. The presented numbers indicate the BED compared to road transport in case rail transport is not available.

10.7.2 High-end low carbon emission scenario for year 2050

The high- and low-end business as usual scenarios have not yet addressed the possibility that future policies will put much more emphasis on sustainable transport operations in order to reduce carbon emissions. I have therefore included a high-end low carbon emission scenario for the year 2050 that assumes the transport chain to be optimised for the lowest possible carbon emission levels rather than the lowest cost levels. This scenario acts as a limiting case that reflects the future situation in which very high carbon taxes are applied to meet the emission targets of the European Commission (2011b).

In the high-end low carbon emission scenario the barges will no longer sail at their economic speed levels (see Table 10-3). Speed levels will be reduced to save fuel. I estimated that the optimal speed levels from an emission point of view would be in the order of 6 to 7 km per hour, but at such low speed levels the transit time of the barges will become very large and navigational safety can be at stake, in particular in case of strong currents. For this reason a minimum speed of 10 km per hour was assumed in the CO_2 footprint comparison. To keep a fair comparison I also assume the maximum speed for road transport to be reduced from about 90 km/hour to about 80 km/hour, which can be considered the speed with the lowest fuel consumption per km. De Vlieger et al. (2005) estimated that a reduction of the speed of a truck from 90 to 80 km/hour would result in a fuel reduction of about 5% to 10%. To be conservative I assume an overall reduction of 10% for road transport due to lower speed levels (not only on the highways, but for the entire trip). For railway transport I lack such insights and therefore apply the same numbers as for the year 2010.

In line with the objectives of the European Commission (2011b, p.6) to reduce carbon emissions from energy production by 93% to 99% in the year 2050 compared to the year 1990, I could have assumed a substantial decrease in the emission levels for the production of energy, but in that case I should have also included the possible development of other types of liquid fuels (that replace diesel) for which the carbon cycle is closed such as biofuels, hydrogen, and solar fuels (i.e. fuels that are obtained from a process in which carbon and hydrogen are turned into a kind of synthetic diesel by adding sustainable energy). I have not included these changes in the low-end carbon emission scenario, because I consider it impossible to foresee the developments in this field up to the year 2050. In addition I have also not included the possible effects of future fuel and energy reductions because it is unclear if these reductions will eventually be realised. In that respect one could consider this high-end low carbon emission scenario rather hypothetical, but I nevertheless consider it useful for investigating the lower bandwidth of BEDs that can possibly be expected.

Table 10-12: Outcome of High-End Low Carbon Emission Scenario

No.	Barge Type	Reduced haulage with return cargo	Reduced haulage no return cargo	Standard haulage return cargo	Standard haulage no return cargo
1	CLASS II	N/A	N/A	N/A	N/A
2	CLASS III	N/A	N/A	N/A	N/A
3	CLASS IV	95 km	82 km	203 km	188 km
4	CLASS V LOW	81 km	70 km	175 km	161 km
5	CLASS V	59 km	52 km	129 km	120 km
6	CLASS II+L,H	**388 km*	**261 km*	**822 km*	**585 km*
7	CLASS III+H	124 km	**106 km*	263 km	**239 km*
8	CLASS IV+H	65 km	56 km	142 km	130 km
9	CLASS IV+L,H	58 km	51 km	127 km	118 km
10	CLASS V+W,H	49 km	43 km	109 km	100 km

Note: *The model estimated rail transport to have the lowest carbon footprint, the presented numbers indicate the BED compared to road transport in case rail transport is not available.

Table 10-12 shows the BED footprint comparison for a standard trip (assuming a 25 km pre- and end-haulage distance) and a reduced haulage trip (assuming a 2.5 km pre- and end-haulage distance) with and without return cargo. The table clearly reveals a great potential to reduce carbon emissions by using intermodal barge transport. For the smallest Class II and Class III barges the footprint is still higher than that of unimodal road transport, which can be related to the fact that too little continental 45 foot containers can be loaded into these barges. In case the smaller Class II and Class III waterways are upgraded (mainly by raising the height underneath the bridges) they may be able to reduce the footprint of the transport system at distances over 106 km. This conclusion may seem to contradict my earlier findings for Class II+L,H and Class III+H barges in Section 10.7.1, but one should realise that the numbers reported in this section are based on a lower more fuel efficient sailing speed. In general one can conclude that policies aiming for a significant reduction of carbon emissions could enhance the use of the IWT for continental freight. By enforcing such policies the BED for continental transport could, at least in theory, go down to extraordinary low levels of just about 50 km for the larger more efficient barges in combination with a short haulage distance towards the terminal. One should however realise that such policies will also require the sailing speed of the barges to be considerably reduced.

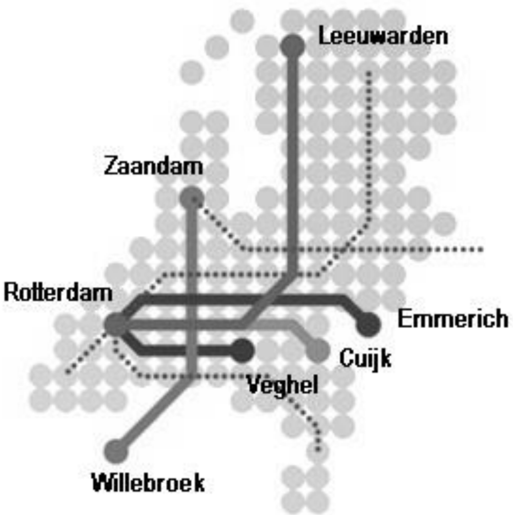
In retrospect it may be worth considering a different approach in which one assumes all fuels to be made out of renewable resources by the year 2050 and in which the main challenge is to reduce the overall energy and fuel consumption in order to enable the entire fuel and electricity demand to be provided by renewable energy sources. In that respect it would have been interesting to define the BED in overall required engine power (i.e. in kWh) rather than in carbon emissions. This suggestion is left for further research.

10.8 Recent Developments and Future Potential

The first part of this section elaborates on a few recent developments that may result in the emergence of the first intermodal continental container barge lines. The second part indicates the perceived potential for the development of continental container transport on the route between Paris and the Ruhr area after the construction of the Canal Seine – Nord Europe.

10.8.1 Recent developments in the Dutch and Belgium Transport Arena

In recent years many efforts have been put into the bundling of (continental) container flows within the Netherlands and between the Netherlands, Germany and Belgium. These efforts amongst others took place within the project *'Maatwerk Binnenvaart'*[134] and the *'Lean Green Barge'* project[135]. The aim of these projects is to bundle cargoes in order to realise new intermodal container lines.



1. Cuijk – Rotterdam
2. Veghel – Rotterdam
3. Willebroek – Zaandam
4. Emmerich – Rotterdam
5. Leeuwarden – Rotterdam

Source: Lean & Green Barge (www.youtube.com/watch?v=VAjnnF_1z9E&feature=youtu.be), adjusted by adding list of liner services and names of places in figure.

Figure 10-9: The development of five new Intermodal Barge Connections

Within these two programs five new intermodal barge connections were initiated of which four of them have already commenced. The five concerned container lines are indicated in Figure 10-9. They can be classified into the following three categories:

1. Connection to deepsea terminals (line 4 and 5);
2. Connection to shortsea terminals (line 1 and 2);
3. Connection between two continental terminals (line 3).

The first category lines are similar to the bulk of the existing container lines that provide a connection between an inland destination and the deepsea terminals. These connections are the easiest to develop and not of any further interest to the issue discussed in this chapter. The second category marks the forefront of the present developments in which continental 45 foot containers are transported to the shortsea terminals, from where they are shipped to other European destinations (e.g. to the UK of Scandinavia). The recent launch of these two liner services marks the first breakthrough in continental inland container barge transport. Finally

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[134] The project *'Maatwerk Binnevaart'* (Dutch for: *'Tailored to Inland Shipping'*) is executed by Dutch promotion council for inland shipping (BVB).

[135] The *'Lean and Green Barge'* project is part of the larger *'Impulse Dynamic Waterway Traffic Management'* (IDVV) project in which various governments, research institutes, waterway controllers, carriers, shippers, harbours and terminals work together in order to improve the utilisation of the waterways. The IDVV project is initiated by RWS and runs from 2010 to 2014.

the last category is the most complicated. The line between Willebroek and Zaandam[136] is intended to bundle truly continental cargo flows of a number of large shippers close to the Dutch – Belgium waterways. The advantage of this connection is that relatively large Class V barges can be applied, but the bundling of sufficient cargo still remains a major challenge. I have understood that this line has not yet commenced. If it eventually does it could well become the first liner service between two continental destinations on the European mainland.

The liner service for continental 45 foot containers between Cuijk and Rotterdam started on the 7th of January 2013. One of the factors contributing to its success is amongst others the fact that the applied Class IV barges are sailing on Class V waterways which makes it possible to stack the containers 3 high. As a result the barges are able to carry a total of up to 36 continental 45 foot containers (i.e. the capacity of a Class IV+H barge).

Most interesting is the success of the liner service between Veghel and Rotterdam that started almost simultaneously with the barge line from Cuijk. On this route a very small Class II+L,H sized barge *'Issaskar'* (length: 67 m, width: 6.60 m) carries up to 12 continental 45 foot containers on a daily basis. The road distance on this route is only 115 km. I have contacted the responsible business developer of the Inland Terminal Veghel and understood that the main factors contributing to the success are amongst others:

- The barge was built in 1961. Despite some new investments to convert the barge the depreciation and capital costs are still relatively low compared to a new barge;
- The capacity of the barges is relatively high because the barge is able to sail with two layers of continental containers on this specific waterway stretch;
- The operator offers a similar transit time as for road transport and is able to realise an almost 100% utilisation of the barges by bundling cargoes of different companies;
- The daily schedule is extremely tight and virtually all waiting times are cut out;
- The applied pre-haulage distance is lower than the 25 km assumed in the model;
- The end point of the trip is located in the seaport. This cuts out the end-haulage costs and reduces the truck waiting times at the shortsea terminal.

Please note that the BED on this route is shorter than the break-even-distances reported in this chapter. The short BED is possible because it concerns a category 2 connection to a shortsea terminal, instead of a category 3 connection between two inland terminals.

10.8.2 Future potential on the route between Paris and the Ruhr area

In addition to the recent developments taking place on the Dutch and Belgium waterways I would like to point out that the planned construction of the new Canal Seine – Nord Europe (if executed) may also offer a great potential for large continental container flows between Paris and the Ruhr area (see Chapter 8). I made a rough cost estimate of the future transport costs by applying the model to the planned infrastructure situation. The analysis applies to intermodal transport between an inland container terminal in Paris and Duisburg.

The road distance between the inland container terminals of Paris and Duisburg is about 520 km, the distance over water via the new connection will be about 750 km and the rail distance

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[136] I understood from a personal conversation with a member of the Dutch promotion counsel for inland shipping that the second location may also be Utrecht instead of Zaandam.

is about 850 km. For road transport I applied an additional road tax of € 0.15 per km on 50% of the route (in France and Germany) the remaining 50% of the trip is assumed to be free of tax. For rail transport the use of an electric train was assumed. The track charges were set at the default value of € 3.75 per km. For IWT no canal duties were included (though there will eventually be some charges for the use of the canal). The current waterway connection for small barges includes 47 locks. The new canal reduces this number to about 32 locks. The canal is planned to be 4.5 m deep and 54 m wide at the surface. I roughly divided the trip into two stretches, a canal stretch of 400 km with a canal dimension of 50 meter wide and 4.5 meter deep, for which I assumed an average speed over ground of 8 km per hour and did not take any currents into account; and a river stretch of 350 km with a waterway dimension of 250 meter wide and a depth of 10 meter, for which I assumed an average speed over ground of 14 km per hour and included a fixed current of 4 km per hour over the entire stretch.

The French government is still planning the canal expansion according to the dimensions of the CEMT 1992 classification (see Chapter 2). The canal is designed for Class V barges with a width of 11.40 meter and a (suboptimal) bridge height of 7.0 meter. The standard dimension of 11.40 meter is sufficient to load four rows of standard ISO containers next to each other, but offers insufficient space for the loading of four rows of pallet wide containers. The 7.0 meter bridge height may be sufficient for the loading of three layers of standard ISO containers (assuming sufficient load per container), but does not allow for the loading of three layers of high cube containers. Continental 45 foot containers are pallet wide and high cube. This implies that the loading conditions for these containers will be very poor. In fact, the new canal will only be accessible for what I refer to as *'Class V LOW'* barges.

I made a comparison between the costs of unimodal road-, intermodal rail-, and intermodal barge transport (with barges of various sizes) on this important route between Paris and the Ruhr area. The analysis includes the total cost levels for: the transport on the main tract; the time value of the goods; the rent of the continental 45 foot container; the terminal handling charges at the inland terminals; and the pre- and end-haulage costs at the beginning and at the end of the intermodal transport chain. The pre- and end-haulage distance between the inland terminal and the sending/receiving companies was set at 25 kilometre (i.e. 50 km per haulage roundtrip). In case no return cargo is available the container is assumed to return empty to the inland terminal at the origin. The details of the calculation are made available in Appendix F. In case return cargo is available the distance from the point of unloading to the point of loading is set at 50 kilometre for unimodal road transport. The results of this analysis are indicated in Table 10-13.

Table 10-13: Continental Container Transport between Paris and the Ruhr Area

Transport Mode	Capacity (45 foot containers)	Trip with return cargo	Trip without return cargo
Unimodal Road Transport	1	€ 765	€ 1288
Rail Transport	80% x 33 = 26	€ 871	€ 1400
Barge Class V Low	80% x 6 x 3 x 2 = 29	€ 841	€ 1313
Barge Class V*	80% x 6 x 3 x 3 = 54	€ 665	€ 965
Barge Class V+W Low*	80% x 6 x 4 x 2 = 38	€ 754	€ 1143
Barge Class V+W*	80% x 6 x 4 x 3 = 58	€ 656	€ 945
Barge Class V+W,H*	80% x 6 x 4 x 4 = 77	€ 611	€ 854

Note: *These barge dimensions are not compatible with the planned infrastructure dimensions. The notation +W stands for additional width. The notation +W,H stands for additional width and height.

Table 10-13 makes clear that the planned *'Class V Low'* waterway dimensions are too tight to enable the development of cost effective intermodal continental container barge transport on this important continental European freight route. I therefore recommend to reconsider the planned infrastructure dimensions. The easiest action that can be taken without imposing any additional investment costs is to increase the allowable width of the barges from 11.40 meter to 11.80 meters. This will allow for the development of new container lines with future Class V+W Low barges, that may be able to attract at least a fraction of the available freight potential. The suggested increase in allowable width should be possible because the design width of the locks is already set at 12.5 meter while the locks on the upper Rhine, that are designed for the same Class V barges, are only 12.0 meter wide.

A further improvement is possible by increasing the available height underneath the bridges. In this respect I would recommend the French government to consider increasing the planned height of the bridges in order to allow for at least three and possibly four layers of high cube 45 foot containers[137]. An additional benefit of raising the bridge height can be that it creates a situation in which the cargo is able to bear the charges for the use of the canal infrastructure, which may generate additional canal revenues.

On the basis of this analysis I conclude that the future potential for the development of continental container transport on the new Canal Seine – Nord Europe connection is still ambiguous and mainly depends on decisions taken by the French government with respect to the allowable width of the barges and the provided bridge clearance. Further research is recommended to study the true potential for continental freight on this important route.

10.9 Concluding Summary

This chapter addresses methodological sub question 2d (MSQ 2d): *"How can insight be obtained in (and what can be expected of) the primary very long term external drivers that act on the IWT system"* of which the fourth driver has been identified as: *"the possible major shifts in the mode of transport stemming from major changes to the cost structure of the inland transport modes?"*. It investigates the effect of major changes to the primary cost drivers (i.e. land, labour, energy, materials, and capital) as well as the effects of a number of other important drivers (being: the possible shift of companies back to the waterfront, the possible abolishment of the fuel tax exempt for IWT, the possible effects of new fuel saving technologies, and the implications of optimising the transport chain for carbon emissions rather than transport costs) on the competitiveness of IWT vis-à-vis road- and rail transport.

10.9.1 Which major shifts can be expected

Major shifts in the mode of transport are not very likely for bulk commodities that tend to be rather captive to IWT. To a lesser extent this also holds for the conventional deepsea container flows on the major routes to/from the hinterland for which barge (and rail) operations are able to gain considerable economies of scale and provide a very cost effective transport solution. I therefore expect the largest possible modal shift effects to relate to the future development of continental container barge transport (i.e. a shift from unimodal road transport in semi-trailers to intermodal transport in continental 45 foot containers), which can

[137] A final conclusion whether the height of these bridges should be increased has to be based on a more detailed analysis in which the additional infrastructure costs and corresponding benefits are taken into account.

be expected to take place during the third stage development of the intermodal IWT network, that I roughly presume to take place in the 25 year period from about 2020 to 2045 (see Chapter 8). In case of the successful development of continental container barge transport one may also expect the development of continental pallet distribution networks on the inland waterways in the subsequent period from 2045 to 2070. These pallet distribution flows are presumably smaller and less certain than the continental container transport flows.

The shift from unimodal towards intermodal transport is in line with the broader societal aim to become more sustainable (i.e. the main driver of the 6^{th} Kondratieff wave). The European Union states in its white book on transport that: *"Thirty per cent of road freight over 300 km should shift to modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors"*. If the European Union succeeds to shift its continental freight flows towards intermodal transport this will have a considerable effect on the use of the inland waterways.

10.9.2 The possible development of continental container transport

I developed an integrated cost model to investigate the future potential for intermodal container transport in continental 45 foot containers, and used this model to investigate the break-even-distance (BED) for intermodal continental rail- and barge transport (assuming that sufficient bundling of continental cargoes can take place). The model output indicates that a modal shift of continental cargoes over 300 kilometre from unimodal road transport towards intermodal barge transport can take place at the present price levels and market conditions, in particular when additional investments in an upgrade of the IWT system are made. The conditions for the development of continental container barge transport may however change over time. I have therefore defined a high- and low-end business as usual scenario for the year 2050 to investigate the possible effects of changing cost factors on the development of continental container barge transport. These two business as usual scenarios reflect the situation in which transport decisions remain based on minimisation of overall transport costs, and in which no additional policies are implemented to reduce carbon emissions.

A strong societal and political focus on sustainable transport may however further enhance the development of intermodal continental container barge transport. For this reason I added a high-end low carbon emission scenario for the year 2050 that assumes the transport chain to be optimised for the lowest possible carbon emission levels rather than the lowest cost levels. This scenario acts as a limiting case that reflects the future situation in which very high taxes on carbon emissions are imposed to meet the objective of the European Union to reduce overall carbon emissions by 80-95%, compared to the base year 1990, in the year 2050.

The high-end business as usual scenario indicates that there is a fair potential for the development of intermodal continental transport flows at relatively short distances (e.g. down to about 100 km) if logistics companies are relocated at waterborne areas; waterways are upgraded to support efficient transport of continental containers; labour and electricity costs are becoming relatively expensive compared to the costs of land use, materials, and capital; and/or additional road taxes are applied to internalise the external costs of transport.

The low-end business as usual scenario indicates that it is also possible to think of conditions in which the development of continental container barge transport will be almost impossible. This is for instance the case if no political efforts are made to shift companies to the waterfront; if investments in the necessary upgrades of the waterways remain absent; if land use, raw materials, and capital become relatively expensive compared to labour and fuel; if road taxes are reduced; and/or if the tax-exempt on gasoil for inland shipping is abolished.

The more hypothetical high-end low carbon scenario indicates the lower bandwidth of the BEDs that can possibly be expected. In this scenario the break-even-distances for intermodal continental container transport may be even further reduced to extraordinary low levels of just about 50 km in case: transport decisions are based on achieving the lowest possible carbon emissions instead of the lowest overall cost levels (e.g. as a result of very high carbon taxes); the transport volumes are sufficient to apply larger barges; and companies are relocated at distances close to the inland terminals.

10.9.3 Recent developments in continental container transport

Recent developments show the first signs that continental container barge transport may now start to develop on the inland waterways, but it is still too early to conclude that these transport flows will really materialise, nor can I tell how large the impact of these flows on the future use of the inland waterways will eventually be. The planned construction of the Canal Seine – Nord Europe (if executed) can offer a great potential for the development of continental container transport between Paris and the Ruhr area (that is routed via the Dutch waterways), but the planned canal dimensions are not compatible with the requirements for efficient transport of continental 45 foot containers. The eventual development of continental container barge transport on this important route is therefore still very uncertain and mainly depends on decisions taken by the French government with respect to the allowable width of the barges and the height of the bridges over the canal.

10.9.4 Answer to Methodological Sub Question 2d

In answer to MSQ 2d, I conclude that major shifts in the mode of transport are not very likely for bulk commodities and to a certain extent also not for conventional deepsea container flows on the major routes to/from the hinterland for which barge- and rail operations are able to gain considerable economies of scale and provide a very cost effective transport solution. Major shifts in the mode of transport can however be expected for continental cargoes, for which the European Union aims to shift 50% of unimodal road transport to intermodal transport solutions by the year 2050. The extent to which a shift of these continental cargoes towards IWT will take place is still very uncertain as continental container barge transport faces difficulties to compete with unimodal road transport. I developed an integrated cost model that enabled me to define the break-even-distance for continental road-, rail-, and barge transport as a function of the main cost drivers (i.e. land, labour, energy, materials, and capital) and a few other important drivers (such as the possible shift of companies back to the waterfront), under the condition that sufficient bundling of cargoes can take place. This model was used to develop a high- and low-end business as usual scenario for the year 2050, that shows the odds for the development of intermodal continental container barge transport in case transport decisions remain based on minimisation of overall transport costs and no environmental transport policies are implemented to reduce carbon emissions. In addition a high-end low carbon scenario was developed for the year 2050, that deals with the possible situation that very high taxes on carbon emissions will be imposed. On the basis of this analysis I conclude that continental container barge transport has either a strong potential to develop in the high-end business as usual and low carbon scenarios (even at very short distances below 100 km), or virtually no potential in the low-end business as usual scenario. This conclusion feeds directly into the development of the shipping scenarios in Chapter 13 and 14.

Literature:

Backer van Ommeren (2011) *Globale schets gasolieverbruik binnenvaartschepen*, http://www.evo.nl/site/binnenvaart-tarieven-kosten/$FILE/Globale_schets_gasolieverbruik_binnenvaartschepen_06.pdf.

Backer van Ommeren (2013) *MEMO: Rapportage gasolieprijzen die relevant zijn voor de binnenvaart t/m december 2012*, http://www.evo.nl/site/binnenvaart-tarieven-kosten/$FILE/Gasolieprijs_ICE_Advies_2012-12%20V2.pdf.

Beelen (2011) *Structuring and modelling decision making in the inland navigation sector*, Universiteit Antwerpen, Belgium.

Blauwens, G., P. De Baere, and E. Van de Voorde (2002) *Transport Economics*, De Boeck nv, Antwerp, Belgium.

Briggs, M.J. (2006) *Ship Squat Predictions for Ship/Tow Simulator*, US Army Corps of Engineers, http://chl.erdc.usace.army.mil/library/publications/chetn/pdf/chetn-i-72.pdf.

De Vlieger, I., L. Schrooten, L. Pelkmans, and L. Int Panis (2005) *80 km/h maatregel voor vrachtwagens, Wetenschappelijke screening van het effect op de uitstoot van* CO_2 *en schadelijke emissies*, VITO, Belgium.

European Commission (2011a) *White Paper on transport, roadmap to a single European transport area – towards a competitive and resource-efficient transport system*, Office for Official Publications of the European Communities, Luxembourg.

European Commission (2011b) *A Roadmap for moving to a competitive low carbon economy in 2050*, COM(2011) 112 final.

European Commission (2013) *Excise Duty Tables, Part II – Energy products and Electricity*, http://ec.europa.eu/taxation_customs/resources/documents/taxation/excise_duties/energy_products/rates/excise_duties-part_ii_energy_products_en.pdf.

Flodén (2011) *Rail freight costs, some basic cost estimates for intermodal transport*, School of Business Economics and Law, Göteborh University and Swedish Intermodal Transport Research Centre.

Grosso (2011) *Improving the competitiveness of intermodal transport applications on European corridors*, University of Antwerp and University of Genoa.

Harmelink, M., L. Bosselaar, J. Gerdes, P. Boonekamp, R. Segers, H. Pouwelse, and M. Verdonk (2012) *Berekening van de CO2-emissies, het primair fossiel energiegebruik en het rendement van elektriciteit in Nederland*, Agentschap NL, CBS, ECN, and PBL.

Hekkenberg (2013) *Inland ships for efficient transport change*, Delft, The Netherlands.

Holtrop, J., G.G.J. Mennen, and T. van Terwisga (1990) *Een empirisch model voor de weerstandspredictie van bakken*, MARIN, Project 49791-1-RD.

Huuska, O. (1976) *On the evaluation of underkeel clearances in Finnish waterways*, Report No. 9., Otaniemi: University of Technology, Ship Hydrodynamics Laboratory.

Johanson, F. (2010) *Efficient use of energy in container cranes*, Port Technology International, vol. 48, pp. 51-54.

Jonkeren, O. E. (2009) *Adaptation to Climate Change in Inland Waterway Transport*, Vrije Universiteit, Amsterdam.

Ligteringen, H., J.C. Rijsenbrij, W.F. Molenaar, B.A. Pielage, M. van Schuylenburg, A.M. Vaes-Van de Hulsbeek (2004) *De Containerterminal van de Toekomst*, Port Reserch Centre, Rotterdam-Delft.

Maibach, M., C. Schreyer, D. Sutter, H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten, C. Doll, B. Pawlowska, and M. Bak (2008) *Handbook on estimation of external costs in the transport sector, Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT)*, CE Delft, Delft.

NEA (2004) *Factorkosten van het goederenvervoer, een analyse van de ontwikkeling in de tijd (tweede druk)*, Rijswijk.

NEA (2007) *Basisbestanden Goederenvervoer 2004, Wegmatrix Totaal*. NEA Transportonderzoek en –opleiding, Rijswijk. Commissioned by Ministerie van Verkeer en Waterstaat, AVV.

NEA (2011) *Kostenbarometer goederenvervoer*, http://www.rws.nl/zakelijk/economische_evaluatie/overzicht_effecten_infrastructuur/kostenbarometer/index.aspx.

Nieuwsblad Transport (2014) *Belgische tol gaat 700 miljoen per jaar opbrengen*, Article in newspaper of 07 May 2014.

Kim, N.S., and B. van Wee (2011) *The relative importance of factors that influence the break-even distance of intermodal freight transport systems***,** Journal of Transport Geography, vol. 19, pp. 859-875.

Klos, S. (2014) *Oude IJsseltak wordt LNG-bunkerpunt en nieuwe overslaglocatie voor Rotra*, Het Magazine voor de ondernemer in de Binnenvaart, juli/augustus 2014, pp. 16-17.

Macharis, C., T. van Lier, E. Pekin, and A. Verbeke (2011) *Intermodaal Binnenvaartvervoer, Economische en ecologische aspecten van het intermodaal binnenvaartvervoer in Vlaanderen*, Uitgeverij VUBPRESS, Brussels, Belgium.

Platz, T.E. (2009) *The Efficient Integration of Inland Shipping into Intermodal continental Transport Chains: Measures and Decisive Factors*, TRAIL Thesis Series Volume T2009/11, Trail Research School, Delft, The Netherlands.

Schuttevear (2013) *Vleugel onder spits Triade gaat zich komende tijd bewijzen*, Schuttevear, 4 mei 2013, p.5.

Significance, VU university Amsterdam, and John Bates Services (2013) *Values of time and reliability in passenger and freight transport in The Netherlands*, on behalf of the Ministry of Infrastructure and the Environment.

Sommar, R. (2010) *Utvärdering av Intermodala Transportkedjor – Kostnadsmodeller*, Swedish Intermodal Transport Research Centre, Göteborg.

Turpijn, B. (2013) *Memo Kostenkengetallen Binnenvaart 2012*, Rijkswaterstaat, Ministerie van Infrastructuur en Milieu.

Van Dorsser (2005) *Amsterdam barge shuttle, Economische haalbaarheid van het AMSbarge project*, TU-Delft, Delft.

Van Hassel (2011) *Developing a Small Barge Convoy System to reactivate the use of the small inland waterway network*, University of Antwerp, Antwerp.

Van Manen, J., and T. van Terwisga (1997) *A New Way of Simulating Whale Tail Propulsion*, Twenty-First Symposium on Naval Hydrodynamics.`

Van Terwisga (1989) *Weerstand en voortstuwing van bakken, een literatuurstudie*, MARIN Rapport No. 49199-1-RD.

Presentations:

Annema, J.A. (19 November 2010) *Transport Innovations, Historical Perspective*, TRAIL course on transport innovations, Delft.

Macharis, C. (11 October 2012) *Sustainable Fleet Management*, Internationaal Congress C-mine Genk, http://www.binnenvaart.be/congres2012cmine/html/presentaties.html.

Websites:

Bromma (accessed: 2013) *Information of electricity consumption of barge terminal cranes,* [http://www.bromma.com/source.php/1187574/Bromma_Report_Spr08_Web.pdf]

C,MM,N: Cargo (accessed: 2013) *Aerodynamic Blue Liner Truck*, [www.cmmncargo.org/project/Details/3]

Gottwald (accessed: 2013) *Information of fuel consumption of barge terminal cranes,* [http://www.gottwald.com/gottwald/site/gottwald/galleries/Brochures/References_Brochure_English.pdf]

Google Maps (accessed: 2014) *Estimation of road distances,* [www.google.nl]

Inland Terminal Veghel (accessed: 2013) *Use Class II barges for shipping 45 foot containers,* [http://www.inlandterminalveghel.eu/nl/inland-terminal-veghel/containerlogistiek/]

O-foil (accessed: 2013) *Information of the O-foil propulsion system*, [www.ofoil.nl]

Transport Online (accessed: 2014) *Information on German MAUT Levels*, [www.transport-online.nl/site/maut/maut_duitsland.php#.VD6ms5ccTiw]

11 Proposed Structure for Transport Model

“All theory depends on assumptions which are not quite true. This is what makes it theory. The art of successful theorizing is to make the inevitable simplifying assumptions in such a way that the final results are not very sensitive.”
- Robert M. Solow (The Quarterly Journal of Economics, 1956, p.65)

11.1 Introduction

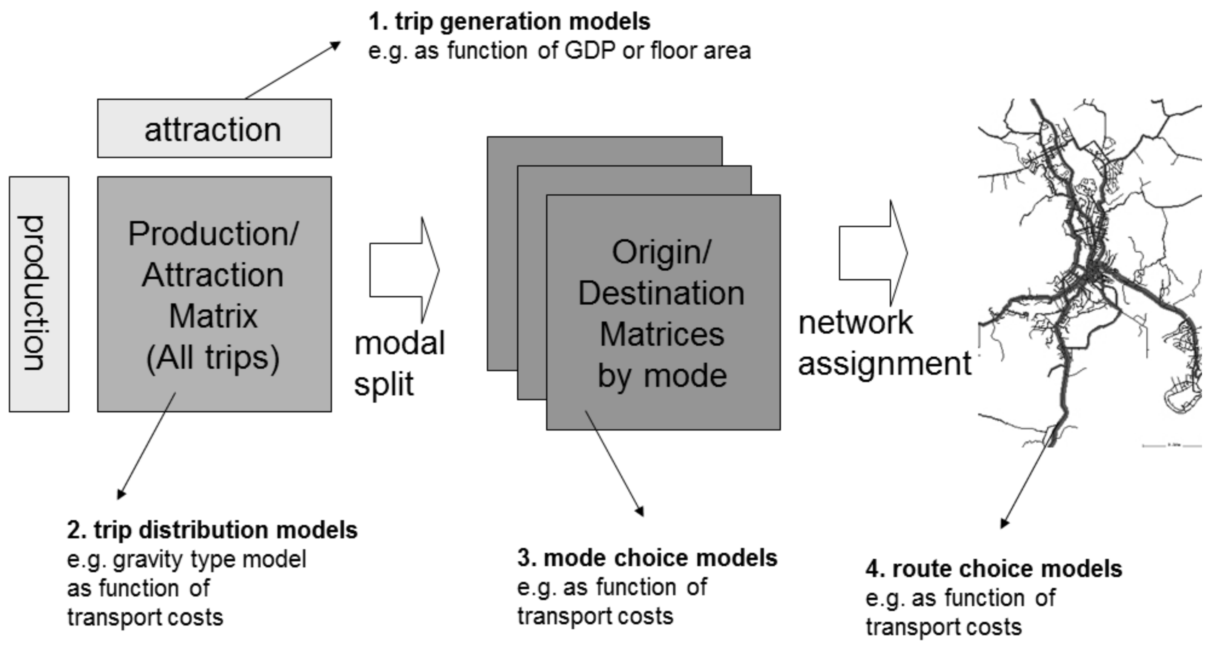
Chapter 6 provided a policy framework that can be applied for the evaluation and valuation of public infrastructure projects with a very long term impact. The central part of this framework consist of a system domain that is described by means of a transport model. Suitable models for the description of very long term transport flows at the network level do however not yet exist. This chapter therefore addresses the third methodological sub question (MSQ 3): *“What would be a sensible structure for modelling effects of external developments and proposed infrastructure policies on the very long term development of the IWT flows at the network level?”*. It proposes a possible structure for the modelling of very long term IWT flows at the network level. The options to implement this structure will be discussed in Chapter 12.

Existing transport models are very well suited for quantifying scenarios up to about 30 years ahead, but they are not intended to deal with very long term developments up to the year 2100. It is still a major challenge to extend the time horizon of existing transport models in such a way that they can be used for the quantification of very long term transport scenarios. The modelling of long term and very long term effects requires a completely different approach. Long term effects can still be quantified by means of forecasting methods, that are able to take a considerable amount of detail into account (e.g. concerning the development at the network level). Very long term effects can only be addressed at a very high level of aggregation, for instance by applying foresight techniques (see Chapter 3 and 5). The main challenge is to combine the strengths of the detailed forecasting and aggregated foresight approach into a single model structure, that can be used to quantify very long term scenarios for the development of the IWT flows at the network level up to the year 2100. This chapter proposes a possible model structure for the preparation of a single scenario quantification on the basis of a single set of given scenario assumptions, that can also be used for the development of a consistent set of scenarios or a number of probabilistic scenarios.

Section 11.2 provides the necessary background on the classic four stage model that is generally applied in transport modelling; Section 11.3 addresses the options to extend the time horizon of existing transport forecast models by applying foresight techniques; Section 11.4 proposes a possible structure for modelling the very long term IWT flows at the network level; Section 11.5 addresses the importance and implications of taking multimodal transport (and in particular intermodal transport)[138] properly into account in the proposed structure of the very long term transport model; Section 11.6 elaborates on the perceived data structure for the proposed modelling approach; and Section 11.7 contains a concluding summary that provides an answer to MSQ 3.

11.2 The Classic Four Stage Transport Model

Over the years many transport modelling techniques have been developed. De Dios Ortúzar and Willumsen (2001, p. 23) indicate that *"Years of experimentation and development have resulted in a general structure which has been called the classic transport model. This structure is, in effect, a result from practice in the 1960s but has remained more or less unaltered despite major improvements in modelling techniques during the last 30 years"*. Tavasszy (1996, p.10) argues that the classic four stage model framework is also applicable to freight transport because: *"1) this framework is fairly adequate to describe a large variety of modelling attempts in this field, including the "behavioural" ones and 2) this framework should be maintained in the design of a model for freight transport within Europe, if one intends to make the maximum possible use of presently available data sources"*. De Jong et al. (2004, p.104) also indicate that: *"Most authors (e.g. Shanker and Pendyala, D'Este) seem to agree that the four-step transport modelling structure from passenger transport can fruitfully be applied to freight transport as well"*. The classic four stage transport model is therefore used as the starting point for the development of the very long term transport model in this chapter. Figure 11-1 provides an outline of the classic transport model.



Source: L. Tavasszy (Presentation for course SPM3610 at the TU-Delft, 2012).

Figure 11-1: Classic Four Stage Transport Model

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[138] Throughout this chapter I will refer to multimodal instead of intermodal transport in cases where the issues discussed also apply to bulk and break bulk commodities, that are not shipped a single loading unit.

The classic four stage transport model consist of the following stages: (1) trip generation, (2) trip distribution, (3) modal choice, and (4) route choice. This section provides a brief discussion of the individual stages. It is not intended to provide a comprehensive overview of all available modelling techniques, for which reference can be made to for instance Tavasszy and De Jong (2014), McNally (2008), Tavasszy (2006), De Jong et al. (2004), De Dios Ortúzar and Willumsen (2004), and Rietveld and Nijkamp (2003).

Trip generation models define the production and attraction volumes of freight flows into and out of a certain region without considering the specific origin or destination of the flow. The output corresponds with the summary axes of the Origin-Destination (OD) matrix and is generally based on input/output analysis and/or regional demand models.

Trip distribution models are used to define the size of the freight flows between the distinct geographic areas of economic activity. The most common models for defining the spatial interaction between different geographic regions are the linear programming (LP) and gravity type models. According to Tavasszy (1996, p.37) the LP-models have the disadvantage that the underlying choice processes relating to the quantities of the goods shipped between the origins and destinations are assumed to be deterministic in nature, which is not the case in reality. He argues that the gravity type models are more realistic.

Mode choice models assign the transport flow to different modes of transport (mainly road, rail, IWT, short sea shipping, and pipeline transport[139]). The modal share can be defined on the basis of the relative competitiveness of the available transport modes (see Chapter 10). It is common to express the competitiveness in terms of generalized transport costs, taking into account a range of aspects relevant to the shipper of the goods (such as transport costs, time, and reliability).

Route choice models assign the transport flows to a certain route on the network. This procedure can for instance be based on shortest- or fastest path algorithms, or on specific algorithms that minimise the overall costs of transport. Problems may arise when the origin and destination locations of each region are projected onto a single location (e.g. the regional capital). When a single optimal route between two OD-locations is selected on the basis of one of the abovementioned optimisation procedures the alternative routes will be neglected. Advanced route choice models have therefore been developed to take the effects stemming from variance in the spread of locations within the origin and destination regions as well as routing preferences of the transport company into account.

In some cases it may be necessary to apply two or more stages simultaneously. This is for instance the case when considering multimodal transport flows, for which the modal split cannot be defined independent of the routing. Combinations of multiple main haulage trips (such as combinations of short sea shipping, IWT, and rail) cannot be addressed by a fixed framework that first assigns the transport flows to a single mode of transport (in stage 3) and then chooses the applied route (in stage 4). The evaluation of multimodal transport flows ideally requires the third and fourth stage to be solved simultaneously.

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[139] For very expensive goods air freight may also be considered, but measured in tonne kilometre air freight accounts for less than 0.1% of the overall transport volume in the EU (refer Chapter 2).

11.3 Extending the Time Horizon of Existing Transport Models

Existing transport models such as TRANS-TOOLS, NODUS, SMILE, and BASGOED apply forecasting techniques to obtain a detailed long term projection of the transport flows at the network level (see also Chapter 12). These projections are still quite suitable for looking up to 30 years ahead, but for longer time horizons a more aggregated less detailed approach will be required. Petersen et al. (2009) for instance applied a different modelling approach for the quantification of long term transport scenarios up to the year 2030, and very long term transport scenarios up to the year 2050 (see Chapter 3). Chapter 7 showed that aggregated very long term probabilistic transport projections can still be made for a large region up the year 2100, but that these projections no longer provide the necessary insights in the development of the transport system at the network level, that are required for the evaluation of infrastructure policies with a very long term impact. One can however still develop quantitative very long term scenarios for the transport flows at the network level by: (1) assuming the total transport flows to develop in line with the aggregated probabilistic projections; and (2) assuming the relative distribution of the transport flows to be similar to those of a certain base year or to the corresponding scenario output of a long term projection. This approach has for instance also been applied by Schade et al. (2008, see Chapter 3).

The easiest way to obtain an order of magnitude estimate for the very long term performance of the transport system at the network level is to assume the future structure of the transport system to remain similar to that of a certain base year (i.e. similar production and attraction areas, similar use of transport means, similar transport cost structure, etc…), and to apply a simple growth factor that represents the difference between the overall transport volumes in the base year and the anticipated transport volumes in the year of the very long term scenario. However, bluntly applying a simple growth factor to the overall transport volume is not very sensible as many insights in the long term and very long term development of the transport system will not be taken into account. I therefore propose a more advanced hybrid approach in which the strengths of the forecasting and foresight approach are combined into a single model structure. The proposed model structure is presented in the next section.

11.4 The Proposed Hybrid Model Structure

The basic idea behind the proposed hybrid model structure is that very long term scenario quantifications for specific developments at the network level can be obtained by ‘projecting’ very long term trends onto the structure of a classic four stage transport model. This can be done by applying a three step approach. The first step concerns the development of a long term transport scenario (e.g. for the year 2040), that is quantified by means of an existing classic four step transport model. This long term scenario functions as a ‘future base year projection’ from which the default input values for the very long term scenario quantification can be inherited. The next step relates to the use of foresight techniques to obtain a corresponding set of aggregated very long term scenarios for the main drivers that act on the transport system, which are amongst others: (1) the development of overall transport demand; (2) the development of the freight transport infrastructure; (3) the effects of climate change on IWT; and (4) the effects of changing cost structures on the modal split of the various transport means. The final step is to ‘project’ the very long term scenarios onto the inherited future base year output of the long term transport model. This final step is complicated by the fact that the different scenario drivers act at different stages of the transport model. It is therefore necessary to re-execute the subsequent stages of the classic transport model in order to obtain the desired very long term transport projection (e.g. for the year 2050 or 2100). The proposed hybrid model structure is indicated in Figure 11-2.

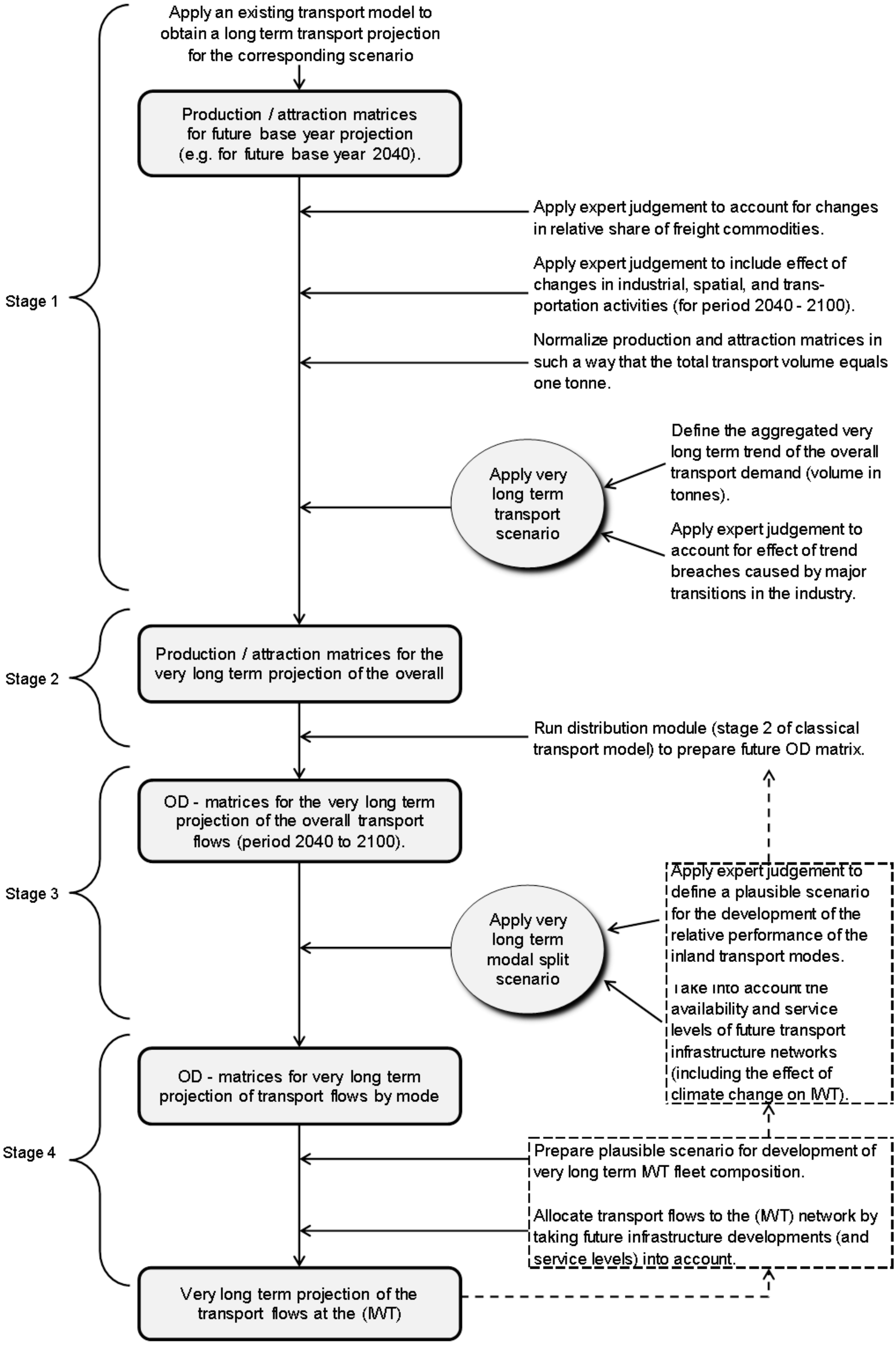

Figure 11-2: Hybrid Structure for quantifying Very Long Term Transport Scenarios

The proposed hybrid model structure has implications for each stage of the classic long term transport model. The main implications are discussed in the remaining of this section. In order to avoid confusion it should be realised that the quantitative output of a scenario can either be referred to as a projection, or as a scenario quantification. All quantitative scenario output can be regarded as projections, but not all projections are scenarios. Projections can for instance also refer to the output of a forecast, which is not a scenario.

Stage 1: Defining the regional production and attraction areas

The first stage of the classic transport model is concerned with the generation of trips in and out of the distinct geographical regions defined by the model. These trips are indicated by the production and attraction matrices in the mathematical description of the transport model (see Figure 11-1). I considered two options to define the relative size of the production and attraction areas in the model. The first option is to develop a sophisticated spatial economic model that is able to take the full development of the production and attraction areas throughout the twenty-first century into account, but the development of such a model will be very complicated and may not even be feasible. The second more practical option is to depart from the geographical spread of activities in the corresponding long term future base year projection (e.g. for the year 2040), and to assume the relative size of the production and attraction areas to remain more or less constant throughout the 21st century. I consider the latter option the most sensible one, because the geographical location of industrial sites and areas of economic activity have shown to remain quite stable over time (see Chapter 2). In addition, the use of a future base year projection also implies that all 'known' future developments, that were identified for the long term future base year projection, are taken into account in the very long term scenario quantification.

One should however be aware that all major transitions in the fields of energy production and transport are likely to become dominant in the upswing period of the next Kondratieff wave. This period is roughly expected from the year 2030 to the year 2055 (see Chapter 4). The use of expert judgement can be considered to account for some identifiable effects of these transitions on the spatial developments towards the end of the century, but it still needs to be investigated how expert judgement can be sensibly applied to deal with these effects. Expert judgement can also be considered for addressing changes in the composition of the types of cargoes that are expected in this period. The use of expert judgement in scenario studies is not uncommon. De Langen et al. (2012) for instance applied a similar approach in the preparation of long term throughput scenarios for the port of Rotterdam.

The use of two different transport models will by definition result in two different sets of outcomes. This implies that the aggregated totals of detailed long term transport models (see also Chapter 12) will differ from the aggregated outcome of transport projections that are based on high level foresight (as developed in Chapter 7). In line with the discussion in Chapter 3 I consider a direct projection that is based on an aggregated trend more reliable than an indirect projection that is based on the summation of disaggregated trends – and in addition I also expect the uncertainty levels of a single aggregated transport projection to be smaller than the combined uncertainty levels of a summation of disaggregated transport projections. I therefore propose to use the future base year projection only to quantify the geographical spread in transport activities throughout the model area and suggest: (1) to normalise the production and attraction matrices of the future base year projection (i.e. total equals 1 tonne); and (2) to multiply the normalised matrices by the overall transport volume (in tonnes) that stem from the very long term transport projection.

Stage 2: Defining the distribution of freight transport flows

The second stage of the model framework deals with obtaining the complete OD-matrices for the very long term projection in the period 2040 to 2100. This can for instance be done by applying a gravity type model. Note that the distribution of the transport flows is a function of the overall freight volume. Larger freight volumes enhance economies of scale that result in lower transport costs and thereby affect the transport structure. I therefore advise to run the distribution module separately for each year of the very long term projection. The output of the second stage consists of a number of OD-matrices that contain the overall transport volumes between the various origins and destinations for all modes of transport combined. For each type of commodity a separate OD-matrix has to be prepared.

Stage 3: Defining the modal split

The third stage defines the OD-matrices per mode of transport (and per commodity type) on the basis of insight in the very long term development of the generalised costs for each transport option (unimodal or multimodal) on each OD-relation. This requires insight in the very long term development of the relative competitiveness of the various modes of transport as well as in the quality of the provided infrastructure. Scenario assumptions for the very long term development of the relative cost levels of the available transport options requires insight in the development of many detailed issues such as: the relative cost levels for the primary cost drivers; the effect of technological developments on the capacity, speed, and fuel consumption of the transport means; the quality of the provided infrastructure; the applied tax levels for the various means of transport; and the distances to/from the multimodal loading points (if applicable). Many of these issues are too detailed to be forecasted at a very long time horizon. It will therefore be challenging to obtain sensible scenario assumptions.

A elegant way to deal with this issue is to define a sensible range (or envelope) of anticipated future outcomes for each of the relevant cost drivers of the transport system – and to simulate the possible outcomes of the transport model by sampling from the assumed envelopes for the distinct variables (see also Chapter 10). This approach generates an envelope of possible scenario outputs that can be presented as probabilistic scenarios (see also Chapter 5).

Stage 4: Allocation of the transport flows to the transport network

The fourth stage relates to the allocation of the transport flows to the transport network. This step requires a plausible scenario for the future composition of the transport fleet as well as a clear method to allocate the flows to the network. Rijkswaterstaat developed its own BIVAS model for the allocation of IWT flows and barge movements to the IWT network. Perhaps is this model also suitable for the allocation of very long term IWT flows.

Improving the model by applying iterations and combining the 3rd and 4th stage assignment

The dotted arrow in Figure 11-2 indicates that the model output can be improved by applying iteration, because: the output of Stage 4 affects the cost structure in Stage 3; and the cost structure in Stage 3 affects the distribution in Stage 2. In line with the discussion in Chapter 7 I suggest to ignore the second order effects of changes to the transport costs on the overall transport volumes. The iteration from Stage 3 and 4 back to Stage 1 is therefore not included, but others may argue differently so one should be aware that this iteration can be added.

Note that the modelling of multimodal (and in particular intermodal) transport should take place at the network level if one intends to include the options for multiple main haulage trips (e.g. road – rail – shortsea – road). Such trips cannot be incorporated in the model if it first assigns a distinct mode of transport and then defines the routing. The inclusion of these flows requires the mode of transport (Stage 3) and the applied transport route (Stage 4) to be assigned simultaneously. Zhang (2013) showed that such a model approach is possible.

11.5 Issues with the Modelling of Multimodal Transport Flows

Chapter 2, 8, and 10 showed that intermodal container transport has already gained a very important share in the overall transport flows on the inland waterways; that there is a great (but still unreleased) potential for the development of continental intermodal container barge transport; and that there remains a future potential for the development of advanced pallet distribution networks on the inland waterways. In line with these conclusions I argue that the applied very long term transport model should be able to deal with all types of intermodal transport in a proper way. In addition I argue that the very long term transport model should ideally also take other multimodal transport options into account. This requires the following conditions to be met: (1) the description of the IWT network should be specific enough to consider the limiting effect of the available infrastructure dimensions on the development of intermodal continental container transport; (2) the classification system of the different commodities should comply with the characteristics of the transport system; and (3) the available data should provide sufficient insight in the true origin and destination of multimodal transport flows.

11.5.1 Description of the IWT infrastructure network

Unlike road and rail transport the dimensions of the inland waterways and the capacity of the inland barges are far from homogeneous. This makes IWT a difficult subject to deal with in transport models. Existing transport models are not developed to take the specific dimensions of the infrastructure network into account, but on the inland waterways each waterway section has its own dimensions. The smallest dimensions on a certain route defines the characteristics of the barge type that can be applied and therefore also the costs of barge transport. To make things even more complicated the allowable draft and height of the barges varies with the height of the water level, which is a function of the river discharge.

IWT generally accounts for a relatively small fraction of the overall transport flows. Transport modellers have therefore put relatively little emphasis on the accurate modelling of the IWT flows[140]. As a consequence they are generally also not as familiar with the IWT system as they are with the road and rail transport system. Existing transport models aim to describe the waterway system by applying a number of different (CEMT 1992) waterway classes for which different transport cost levels are assumed. I think that this approach works out reasonably well for the description of bulk shipments (dry bulk, liquid bulk, and break bulk), but that it still needs to be improved for the accurate modelling of intermodal container transport and in particular for the modelling of intermodal continental container transport.

Let’s for instance consider the hypothetical case of a large rhine barge (110 x 11.45 meter) loaded with empty 40 foot containers. The size of the hold allows for 24 standard 40 foot containers at each layer. For three layers of containers the overall weight of the boxes is about

[140] Limbourg and Jourquin (2009, p.557) for instance report that the applied base data shows a true modal split (measured in tonnes) of 1.73% for IWT, 13.55% for rail, and 84.72% for road. The modal split estimated by their Nodes model was reported to be 1.50% for IWT (87% of real), 14.17% for rail (92% of real), and 84.72% for road transport (100% of real). The least performing fit was therefore related to IWT.

280 tonnes (assuming 3.9 tonnes tare weight). Assuming an additional ballast capacity of about 300 tonnes the average draft of the barge will be about 1.4 meter (see Figure 9-13). The loading floor of the hold is located about 0.5 meter above the bottom of the ship. This implies that the containers are loaded from -0.9 meter below the water line. Taking into account the average height of a standard 8½ foot high (2.6 meter) container the air draft of a large rhine barge carrying three layers of containers is about 6.9 meter. When including a safety margin of about 0.3 meter clearance towards the lower end of the bridge the minimum required bridge height becomes 7.2 meter. Such a barge loaded with three layers of empty containers can for instance not sail on the Albert Canal, that has an available height of just 6.7 meter[141]. However, when the barge is loaded with very heavy full containers (gross weight of 30.5 tonnes) the draft becomes 2.7 meter (without using ballast). This reduces the minimum required bridge height to 5.9 meter. A large rhine barge loaded with three layers of very heavy full containers is therefore well able to sail underneath the bridges of the Albert Canal.

The above example indicates the complication of the draft effect of the barges on the transport system. It shows the importance of taking the weight of the cargo into consideration in the model. This is however not the only complication. Many containers are nowadays higher than the original standard. These higher containers are referred to as high cube containers (which are 9½ foot or 2.90 meter high). If the barge would have been sailing with three layers of high cube containers it would have a required bridge height of 8.0 meter for empty containers and 6.8 meter for heavy full containers (or 6.5 meter when adding ballast). The composition of the type of containers is therefore just as important as the weight effect on the draft.

To make things even more complicated one should also consider the fact that, according to the CEMT 1992 standards for Class VI waterways, the available bridge height can be 7.0 or 9.1 meter[142]. In case the model assumes a height of 9.1 meter for all Class VI waterways it thereby assumes the transport of 3 layers of containers to be possible under all circumstances (and 4 layers in case of loaded standard containers). Despite the fact that the Albert Canal is classified as a Class VI waterway its height is not yet sufficient to allow for such a high load of containers. This may not look important, but it should be realized that a difference between 2 and 3 layers of containers (roughly) implies a 50% difference in transport costs. Likewise a difference between 3 or 4 layers implies a 33% difference in transport costs. These differences may be caused by relatively small differences of a few decimetres in the available bridge height or a few tonnes in the average payload of the containers. Such differences cannot be captured by simply applying a few distinct waterway classes in the transport model. I am therefore of the opinion that, in order to take the future conditions for intermodal container barge transport properly into account, the transport model should be based on the actual infrastructure dimensions (length, width, draft, height), specific barge properties, and realistic loading assumptions. This requires a completely different way of dealing with IWT in transport models than is currently practice.

The above reasoning becomes even more important when considering the characteristics of continental container transport in 45 foot, pallet wide, high cube containers (see Chapter 2).

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[141] Note that the Albert Canal is now being upgraded to a height of 9.1 meter (to be completed by 2020).

[142] As discussed in Chapter 2 the 7.0 meter standard should be applicable to all bridges while the 9.1 meter standard is suggested for new bridges or renovated/upgraded bridges.

The width of the continental 45 foot containers is incompatible with the main dimensions of the Class V waterways. Large rhine barges are unable to load four continental containers properly next to each other in their holds[143]. In addition the continental 45 foot containers are also facing similar height constraints as those for other high cube containers. The extent to which intermodal continental container barge transport will be able to compete with unimodal road transport therefore amongst others depends on the ability to adapt the infrastructure (and the barges), to the needs of the intermodal logistic chain (see Chapter 10).

11.5.2 Commodity classification

The second issue is related to the classification of the available transport data. To the best of my knowledge the transport data in most West European transport models (that will be discussed in Chapter 12) is grouped according to a distinct number of NSTR categories, which are intended to reflect the value of the reported cargoes in customs statistics. An unambiguous link between the NSTR classification and the transported characteristics of the cargoes is however lacking. Cargoes with a similar NSTR number may therefore appear as a combination of bulk products, container loads, and small packages. In particular when a one digit NSTR commodity class is considered, such as: '*Food products and food (NSTR 1)'*.

When defining the modal split for a one digit NSTR commodity class this unfavourable property implies that some very dissimilar commodities are assumed to compete in the same transport market while they in fact belong to different transport markets. This implies that the total transport volume of a certain one digit NSTR commodity class may consist at the same time of *'bulk commodities shipped by large push barge combinations'* and *'small packages transported in distribution vans'*. In such cases the actual cost levels for the various modes of transport will have relatively little explanatory value in the calibrated models – and the model will consequently assign a large fraction of the cargo flows to the various modes of transport (as a fixed location dependant proportion of the flow) without taking the true competition between the various modes of transport properly into account. As a result it may appear from the model that the transport flows are rather inelastic to the mode of transport, while they may in fact be quite elastic when compared in a like for like situation.

I still consider it sensible to apply data categorised by NSTR class in long term transport projections for which only minor changes to the cost structure of the transport system are expected, but I do not consider the NSTR classification suitable for dealing with the major changes that can be expected throughout the 21st century. I would argue that very long term transport projections require the freight transport data to be rearranged into a new set of categories, for which the competition between the various transport means can be properly described (e.g. on the basis of the size and package type of the shipments)[144]. This requires the data to be regrouped into a number of mutually exclusive categories for which the competitive structure of the transport system is completely different. I therefore propose to adopt the following six freight categories:

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[143] It should be noticed that some 11.45 meter wide barges just manage to fit four of the slimmest 2.5 meter wide continental containers next to each other in their hold, but the loading of these containers remains problematic.

[144] It should be noticed that the use of commodity classes that refer to the characteristics of the goods instead of the NSTR classification structure are not uncommon in port throughput forecasts. In this respect reference can be made to for instance: Klein (1996), Veenstra and Haralambides (2001), and De Langen et al. (2012).

- Non-containerised bulk;
- Containerised bulk;
- Continental containers and full truck loads;
- Deepsea containers;
- Parcel loads;
- Packages.

The applied structure behind the selection of these categories is indicated in Figure 11-3. The reasoning behind the selected categories will be discussed in the remaining of this subsection.

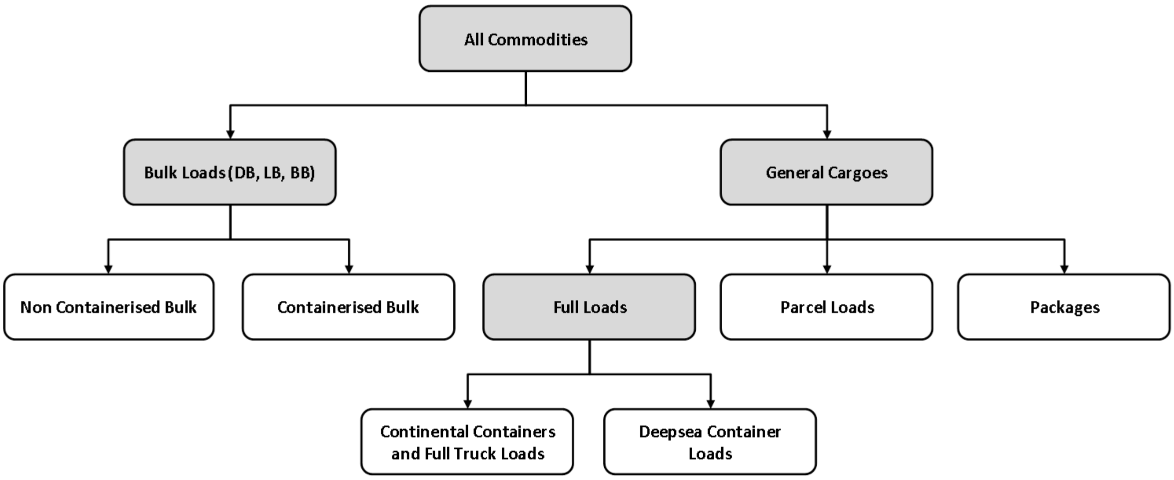


Figure 11-3: Restructuring Commodities into Mutually Exclusive Competitive Classes

First of all I propose to make a distinction between bulk loads and general cargoes. Bulk loads are generally quite heavy and therefore the transport costs are mainly driven by the weight of the cargo. General cargoes are generally much lighter and in contrast to bulk shipments the transport costs are mainly driven by the volume of the cargo.

Bulk loads can be divided into dry bulk (DB), liquid bulk (LB), and break bulk (BB). Each category requires its own type of equipment. The cost structure of for instance motor tank barges, railway tank wagons, and tank trucks differs from the cost structure of dry cargo barges, dry cargo rail wagons, and dry lorry trucks. It may therefore be suggested to subdivide the bulk commodities into the three abovementioned commodity classes. However, the nature of very long term projections also implies that the level of detail should be kept as low as reasonably possible (see Chapter 3 and 5). Considering the fact that the modal split module only requires insight in the relative difference between the generalised transport costs of the applied modes of transport (and not in the absolute cost levels) – and the fact that the relative cost levels of IWT, rail, and road transport are more or less similar for all type of bulk cargoes[145] – I consider it more important to limit the amount of detail in the very long term projections, than to take the precise cost levels into account in the model. I have therefore made no further distinction between the various types of bulk commodities in very long term

[145] Compare for instance the costs presented in the cost barometer (Dutch: *'Kostenbarometer'*) of RWS, http://www.rws.nl/kenniscentrum/economische_evaluatie/Kostenbarometer/; accessed: 2012).

projections. It should however be noted that this argument is only valid for very long term projections. For long term projections up to 30 years ahead I would have proposed to divide the freight flows into the three abovementioned bulk segments.

An increasing share of the bulk freight is nowadays shipped in containers. The nature of containerised bulk shipments is very different from the nature of non-containerised bulk shipments. First off all, the capacity of container barges is constrained by the volume of the containers and the stability of the barge rather than the weight of the shipment. When heavy bulk containers are mixed with standard general cargo containers the displacement can be better utilised, in particular when the stability of the barge is also increased by loading the heavy containers at the lower layers. This implies that bulk containers, that have a high weight to volume ration, can be shipped relatively cost effective compared to standard general cargo containers. On the other hand, bulk products can fit very efficiently into the holds of a barge, which is not necessarily the case for containers. For container barges the size of the waterways needs to be compatible with the size of the containers. This distinction has important implications for IWT policies that aim for an increase in the dimensions of the waterways. A relatively small increase in the width and/or height of the waterways, to allow for barge dimensions that are more compatible with the size of the containers, can for instance cause a relatively large increase in the loading capacity of container barges, while it has only little effect on the loading capacity of barges carrying bulk freight. This is the second reason why I made a distinction between containerised and non-containerised bulk flows.

The way general cargoes are shipped is very much depending on the size of the shipment. I suggest to consider full loads, parcel loads, and packages. Full loads refer to the size of a lorry truck or a container; parcel loads refer to the size of a few pallets; and packages relate to small volumes of a few kilogram. The package size shows a strong relation to the applied mode of transport. Shipments of small packages (e.g. from the distribution centre to the final end consumer) are expected to remain the exclusive domain of road transport. Parcel loads can be shipped by road, IWT, and possibly also by rail.

At present pallet distribution is still almost exclusively the domain of road transport, but a serious attempt to develop a large scale inland waterway pallet distribution network in the Netherlands was undertaken by the Distrivaart project in the period 2002-2004 (see Chapter 8). The concept proved to be technically feasible but failed to become a commercial success (Groothedde, 2005, p.181-182). New initiatives to use the waterways for the transport of pallets are nowadays undertaken in Belgium, but still only a small fraction of the pallets is shipped by IWT (Macharis et al., 2011, p. 22). In addition the present initiatives are mainly related to bulk shipment of pallets (De Lloyd, 2013). They do not concern the distribution of smaller less than truck load (LTL) volumes, that were once targeted by the Distrivaart project. In that respect I consider the new Belgium pallet initiatives as break-bulk shipments.

Taking the above into account it can be concluded that parcel loads are still almost completely shipped by road. It is however possible that cost effective inland waterway pallet distribution networks will be developed in the second half of the 21st century (see Chapter 8). Similar pallet distribution networks may also be developed on the railways (Vogel, 2002), but given the fact that the break-even distance for rail transport is much longer than for IWT I consider the development of rail pallet distribution networks less likely.

Full loads can be classified into ‘deepsea container loads’, and ‘continental containers and full truck loads’. In general deepsea container flows are almost exclusively shipped in standard

ISO containers, for which the outer dimensions were developed in line with the legislation for road transport in the USA (see Chapter 8). Continental transport takes place on a regional scale (e.g. on the European continent). The European transport system is developed in line with the dimensions of the euro-pallet, that is 1.2 meter wide. The allowable width of a road vehicle is defined in such a way that two euro-pallets can be placed next to each other in truck trailer. Standard ISO containers do not support the efficient loading of two euro-pallets. This is a major disadvantage for intermodal continental container transport. To solve this problem the transport system has now eventually adopted the continental 45 foot container. This container is longer, wider, and higher than the standard ISO container and has become the standard intermodal loading unit for Europe (see Chapter 2, 8, and 10). The different cost levels for the transport of standard 20 and 40 foot deepsea containers, and continental 45 foot containers (for which IWT is substantially less competitive) requires a clear distinction between continental and deepsea loads.

The notion that adjustments to the commodity classification system are necessary to improve the performance of transport models is not new. De Jong et al. (2004, p.119) indicated that: *"Transport activities increasingly take place within a larger context of logistic choices (including inventory policy, warehouse location, consolidation of flows to distribution centres). Such considerations can be added to the freight transport model [...]. The increased awareness of the logistic context should also have repercussions on the commodity classification. Ideally, this should be based on the handling characteristics of the goods being transported and on the fact that different commodity groups have different values of time. The categories that are created when using attributes with regards to logistic processes are sometimes called 'logistic families'. In some cases, it has proved possible to translate a detailed classic commodity classification (NSTR) into logistic families"*.

The SMILE+ model provides a good example of a successful attempt to reclassify the NSTR commodities into a distinct number of 50 logistic families (De Jong et al, 2013). The reason for proposing a smaller number of commodity classes is that I find it important to reduce, as much as possible, the amount of detail in very long term projections. This is necessary because detailed aspects cannot be foreseen at a very long time horizon. In addition my new classification system is also intended to take the specific characteristics of IWT properly into account into the very long term transport model. This perspective differs from that of the SMILE+ model that is intended to cover the entire logistic system.

11.5.3 Insufficient data on multimodal transport flows

The development of an advanced modal split module, that is able to take the full range of possible multimodal transport solutions (or even full logistic solutions) into account, requires a good understanding of the true origins and destinations of the multimodal transport flows within the study area (i.e. the locations where the goods are originally produced and finally consumed). However, in practice the true origins and destinations are not very well known as the transport data tends to be gathered in a unimodal way that results in virtual production and attraction of commodities at the distinct regions in the transport model. I think that the production and attraction matrices should clearly reflect the true production and attraction activities in the distinct regions of the very long transport model. The reason why I find this so important is explained by the following example. Consider a hypothetical case for shipping agricultural products from Kassel in the centre of Germany to the port of Rotterdam. Suppose that the presently applied transport solution is to first truck them to the port of Duisburg and then ship them by barge to the port of Rotterdam. To recognise the alternative options the model should at least understand that agricultural products are initially coming from Kassel and have a final destination in the port of Rotterdam. This is not the case when the data is gathered in a unimodal way by mode of transport. In that case the base year data (that is used for the calibration of the transport model) is likely to indicate a fictive production of agricultural products near Duisburg, while it in fact concerns a flow of goods that are produced near Kassel. By ignoring the fact that this concerns a multimodal transport flow with an origin outside the model region, the available options to route the flows via other regions (for instance by direct rail transport from Kassel to Rotterdam) will be ignored by the model. This implies that the calibrated parameters of the model are likely to show high fixed location dependant factors that stem from not taking the true origins and destinations of the freight flows properly into account (i.e. assuming a higher volume and a higher fixed share of agricultural products shipped by means of IWT from Duisburg to Rotterdam). Such a model is not expected to be very suitable for dealing with the effects of major changes to the cost structure of transport, that may take place throughout the 21st century.

11.6 Outline for the Very Long Term Transport Model

The previous sections discussed the perceived issues with the modelling of very long term transport flows. They showed that the existing long term transport models are not suitable for the preparation of very long term transport projections. To extend the time horizon of existing transport models towards the end of the century a hybrid three step approach was proposed, in which aggregated very long term trends (that are based on foresight) are 'projected' onto the output of a classic four stage transport model for a certain future base year (e.g. the year 2040). This approach is however complicated by the fact that the very long term trends that describe the different external developments act at different stages of the classic transport model. It is therefore not possible to multiply the output of the future base year projection by a simple growth factor. The very long term trends need to be successively imposed at the intermediate stages of the classic transport model while executing the model.

A more fundamental problem occurs when the existing transport models are unable to deal with multimodal (and in particular continental intermodal) transport flows in an appropriate way. Such models will be unable to deal with modal shifts stemming from major changes to the cost structure of transport that may occur during the 21st century.

Figure 11-4 proposes a possible outline for the structure of the new very long term transport model. It shows how I think a very long term transport model can be developed as an extension of an existing long term transport model, for which the base year data and the long term future base year 2040 model results are available.

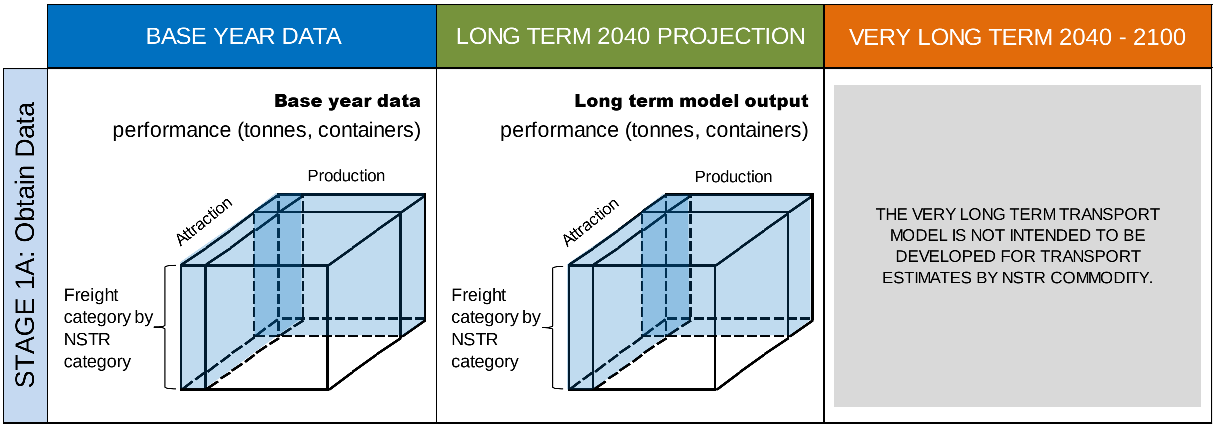


Figure 11-4a: Possible Outline for a Very Long Term Transport Model

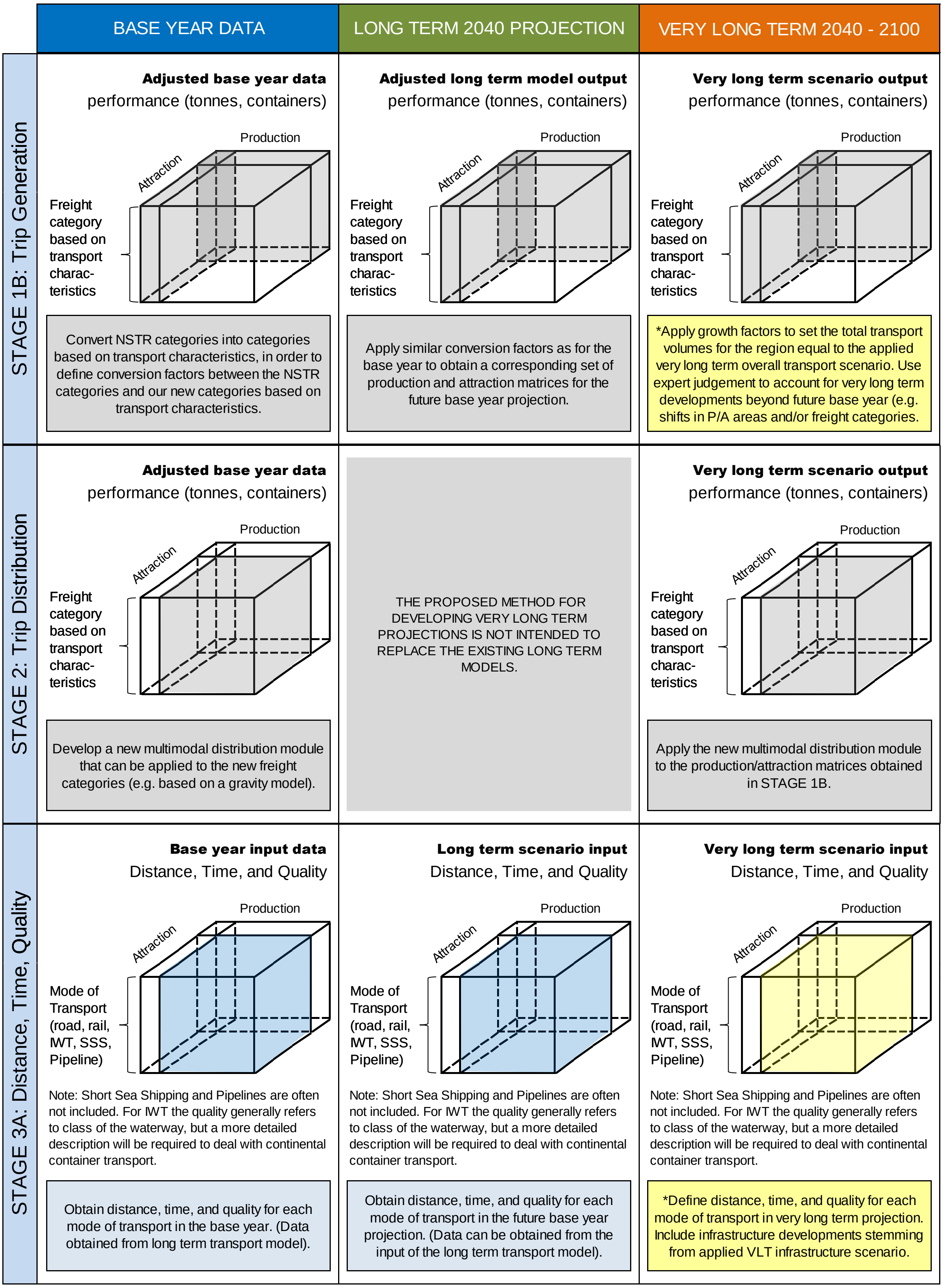


Figure 11-4b: Possible Outline for a Very Long Term Transport Model

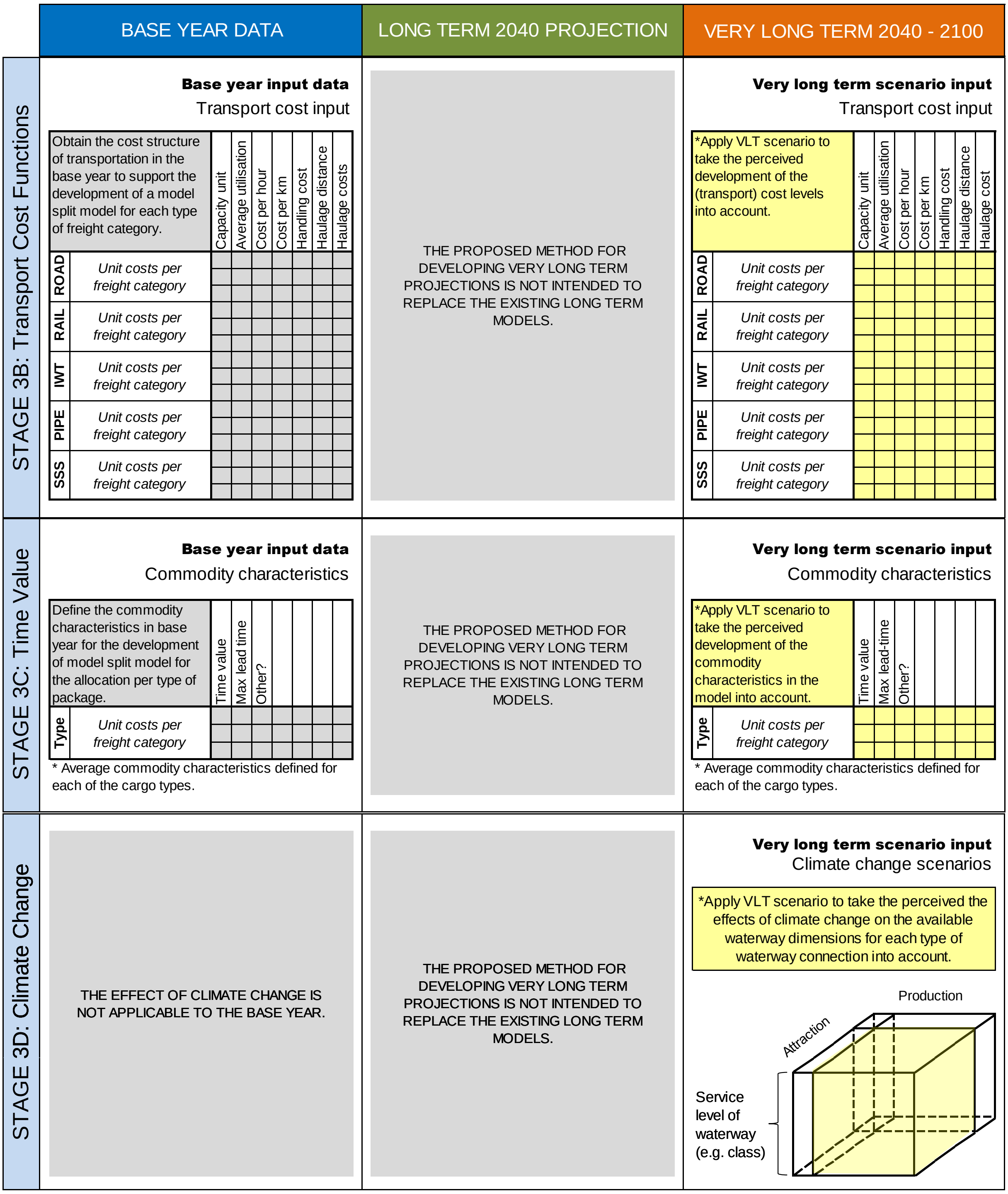
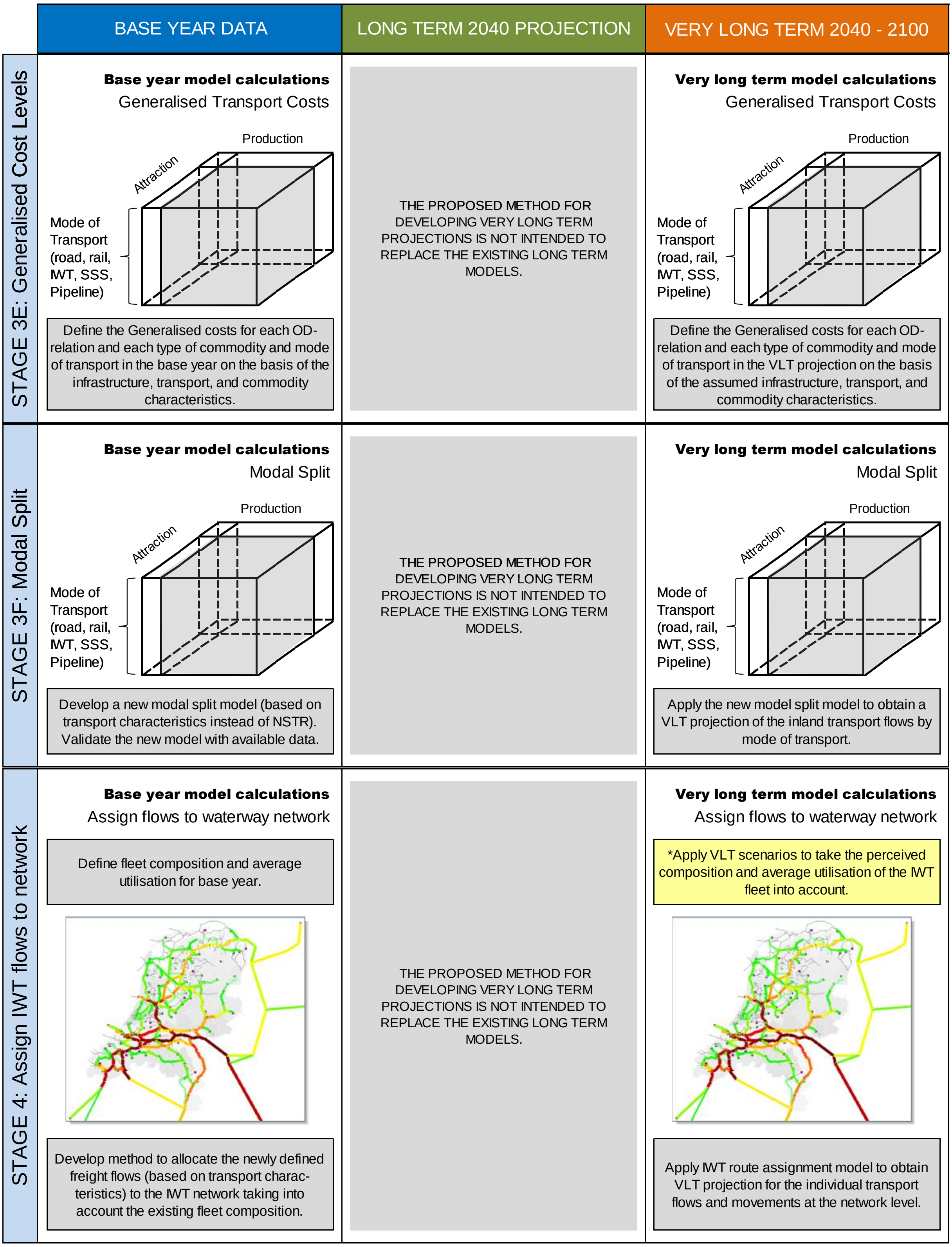


Figure 11-4c: Possible Outline for a Very Long Term Transport Model



***Note: the image in stage 4 is obtained from: http://bivas.chartasoftware.com/Article/431.**

Figure 11-4d: Possible Outline for a Very Long Term Transport Model

The left side column shows the base year data, that is required for the development and calibration of the very long term model extension. This data can be similar to the input data of an existing classic four stage transport model, but differs to the extent that: a different description of the IWT infrastructure is used, and a different commodity classification is applied. The middle column refers to the future base year projection that has been obtained from running an existing four stage transport model. The future base year projection is intended to provide insight in the long term development of the geographical spread of freight production and attraction throughout the model area – as well as in the expected long term infrastructure developments that have been taken into account in the corresponding long term transport scenario. The right side column addresses the required input and proposed output data of the proposed very long term transport model up to the year 2100.

The cubicles presented in the figure represent the data structure of the model. The edges of the cubicles relate to the summary totals of the matrices. The inner box contains the transport data for each OD-relation, each type of commodity, and each mode of transport. The various colours applied in the model indicate that the data is: obtained from available models and/or data sources (blue), obtained from newly developed or adjusted transport models (grey), or related to the very long term scenario input based on foresight (yellow). For clarity the scenario input is indicated with an asterisk (*).

The presented model stages are similar to the four stages of the classical transport network and need to be executed in a subsequent order. In case preparatory works for a certain stage are required the necessary preparatory works are addressed in separate sub stages. This is why Stage 3 (i.e. defining the modal split) for instance consists of the sub stages 3A to 3F.

For the development of the model I suggest to step by step work through the subsequent sub stages. For each sub stage one should work from left to right (i.e. first addressing the base year data, than addressing the long term projection, and finally addressing the modelling approach and output of the very long term projection up to the year 2100).

The **first stage** of the transport model is intended to provide insight in the very long term development of the geographical spread of freight production and attraction throughout the model area up to the year 2100. This stage consists of four steps. The first step provides insight in the long term development of the geographic spread of activities throughout the region. These insights can be obtained by running an existing four step transport model for a certain future base year (e.g. the year 2040). The in- and output data of the existing transport models is however generally structured according to the NSTR classification, while I apply a different commodity classification based on the loading characteristics of the transported cargoes. The second step therefore aims to convert the NSTR categories into the six newly proposed commodity classes (i.e. non-containerised dry bulk, containerised dry bulk, deepsea containers, continental containers, parcel loads, and packages). The third step concerns the use of expert judgement to take the anticipated very long term effects of fundamental changes to the composition and geographical spread of the freight flows beyond the time horizon of the future base year into account. The fourth step applies a growth factor to scale the transport volumes in such a way that the total matches the outcome of the very long term projection for the development of the overall transport demand based on foresight.

The **second stage** deals with the regional distribution of the freight transport flows between the various production and attraction areas in the model. This stage requires the development of a new multimodal distribution module that supports my new commodity classification system. This new module will first have to be calibrated against the base year data and can then be applied to estimate the OD-flows in the very long term projection.

The **third stage** consists of six steps that need to be undertaken to define the modal split. The first step (3A) describes the characteristics of the transport infrastructure for each mode of transport. This step is intended to inherit the basic information on the distance, travel time, and quality of the network from the applied existing long term transport model. The inherited data is adjusted to comply with the scenario assumptions on the very long term development of the IWT infrastructure. Step 3B deals with the relative costs of the various transport means applied in the model (including the assumptions on the relative haulage distance to/from the multimodal transfer points). Step 3C deals with the main properties of the cargo itself, such as the time value of the shipped goods and the maximum lead time. Step 3D deals with the effect of climate change on the relative performance of the IWT system. Step 3E defines the generalised costs for each OD-relation, type of commodity, and mode of transport. Step 3F concerns the development of a new modal split module that is able to deal with the improved description of the inland waterway system and the adjusted commodity classification system. Once this module is calibrated for the base year it can be used to derive the desired very long term transport projections up to the year 2100.

The **fourth stage** assigns the IWT flows to the network. This stage requires an allocation model that is able to deal with the adjusted commodity classification. It may for instance be possible to adjust the existing BIVAS model that is owned by Rijkswaterstaat. This will however require insight in the size and composition of the IWT fleet for the base year. Once the model is adjusted and calibrated it can be used to assign the IWT flows to the network. The next step is to obtain a very long term scenario for the composition of the IWT fleet[146]. This scenario is then finally used as input for the allocation model to obtain the desired very long term projections for the specific barge movements on the inland waterways. Note that the transport model should ideally be able to execute the third and fourth stage simultaneously. This will still require some further adjustments to the proposed model structure.

Though the proposed model extension may appear rather straight forward there still remain a number of important issues with the modelling of very long term IWT flows that need to be resolved (see Section 11.5). In my opinion the desired very long term transport model should at least be able to deal with the expected development of intermodal continental container barge transport, but preferably the model should also be able to deal with the possible development of intermodal pallet distribution networks, and with possible changes to the multimodal bulk flows. Chapter 12 will therefore investigate the extent to which existing transport models are able to comply with these requirements.

Once developed there are two sensible options to use the very long term transport model. The first option is to define a number of plausible very long term scenarios that explore the corners of possible future developments. The advantage of this option is that it is relatively simple and requires only a few distinct model runs (i.e. one for each scenario). The downside is that much of the scenario input concerns issues that are too detailed to be forecasted at a

[146] Insight in the development of the size and characteristics of the inland barges is hard to obtain, but it may still be possible to define a number of alternative scenario that take into account the physical and legal limitations to inland shipping as well as the required hold sizes for efficient transport of continental containers.

very long term time horizon. This implies that it will not be easy to make sensible very long term scenario assumptions for the various cost drivers. The second option concerns use of probabilistic scenarios (see Chapter 5). This option also involves the development of a few storyline scenarios along the dimensions of a few major uncertainties, but the main advantage is that it will no longer be necessary to make specific assumptions for many aspects that are too detailed to be forecasted at a very long term horizon (e.g. those related to the relative cost structure of inland transport). Instead, an envelope of possible outcomes is defined from which data is sampled in the simulation process (e.g. similar to the envelopes applied in Chapter 10). The second option is more sophisticated but also harder to conduct as it involves hundreds or even thousands of computational model simulations.

11.7 Concluding Summary

This chapter addresses the third methodological sub question (MSQ 3): *“What would be a sensible structure for modelling effects of external developments and proposed infrastructure policies on the very long term development of the IWT flows at the network level?”*. It proposes a possible model structure for the quantification of very long term transport flows at the network level, and elaborates on the issues that need to be resolved for the proper modelling of very long term transport flows.

11.7.1 The proposed structure for the very long term transport model

Existing long term transport models generally apply forecasting techniques for the quantification of scenarios with a 20 to 30 year time horizon, but I consider the level of detail applied in these models too high for the quantification of scenarios with a much longer time horizon (see Chapter 3 and 5). Insight in very long term trends can only be obtained at a more aggregated level, for instance by applying foresight techniques. In order to obtain insight in the transport flows at the network level I propose a hybrid approach that combines the strengths of forecasting and foresight methodology into a single model structure. This approach comprises of the following three steps:

1. Develop a detailed long term scenario (e.g. for the year 2040) and quantify this scenario at the network level by means of an existing transport model;
2. Develop an aggregated set of corresponding very long term scenario quantifications for the main drivers that act on the transport system up to the year 2100 (e.g. by applying foresight methodology);
3. Project the aggregated very long term scenario drivers onto the output of the long term scenario (that I refer to as ‘future base year scenario’).

Though the principles of the proposed hybrid approach are simple, there still remain a number of issues that need to be resolved. The first issue concerns the structure of the transport model. Long term transport models are generally developed in line with the classic four stage transport model that covers the following stages: (1) trip generation, (2) trip distribution, (3) modal choice, and (4) route choice. The staged structure of this model implies that aggregated very long term projections for the different external developments up to the year 2100 act at different stages of the transport model. This implies that the hybrid very long term model approach cannot simply apply a growth factor to the output of the long term transport model. It needs to interact with the long term transport model and impose the very long term trends at the intermediate stages during the execution of the model. The proposed hybrid very long term model structure is indicated in Figure 11-2.

The second issue has a more fundamental nature. It starts with the notion that intermodal transport has already gained a very important share in the overall transport flows on the inland waterways – and that there is also a great (but still unused) potential for the development of intermodal continental container and pallet flows by barge. The minimum requirement for a very long term transport model is therefore that it covers the anticipated development of intermodal continental container flows, but preferably the model should also be able to deal with the possible development of intermodal pallet distribution networks, and the possible changes to the multimodal bulk flows.

11.7.2 Main concerns with the modelling of very long term transport flows

I think that the proper modelling of the very long term effects of intermodal and multimodal transport requires the following three conditions to be met: (1) the description of the IWT network should be specific enough to consider the limiting effect of the available infrastructure dimensions on the development of intermodal continental container transport; (2) the applied commodity classification system should comply with the characteristics of the transport system; and (3) the available data should provide sufficient insight in the true origin and destination of multimodal transport flows. This raises the following concerns:

Concern 1: About the modelling of IWT infrastructures

Existing transport models aim to describe the IWT system by applying a number of different (CEMT 1992) waterway classes to which different transport cost are applied. I consider this approach sufficient for the modelling of bulk shipments (dry bulk, liquid bulk, and break bulk), but insufficient for the proper modelling of intermodal container transport. The proper modelling of in particular continental container transport requires a more advanced approach that takes the actual IWT infrastructure dimensions (length, width, draft, height), specific barge properties, and realistic barge loading conditions into account. This results in a completely different way of dealing with IWT in very long term transport models.

Concern 2: About the applied freight classification system

Existing transport models are generally developed in line with the standard NSTR freight classification system that is intended to reflect on the value of the goods in customs statistics. An unambiguous link between the NSTR classification and the transport characteristics of the goods is lacking. Commodities with a similar NSTR code may (at least in theory) appear as a combination of bulk products, container loads, and small packages. This implies that very dissimilar commodities are assumed to compete in the same transport market, while they in fact belong to different transport markets. In such cases the relative cost levels of the various transport modes will have little explanatory value – and the model may wrongly assign an unnecessary large fraction of the freight flows directly to the various modes of transport (as a fixed proportion of the flow) without taking the true competitiveness of the transport modes properly into account. I therefore propose to convert the NSTR categories into six new commodity classes (based on the transport characteristics of goods) that can be applied in very long term transport projections. This new commodity classification system contains the following mutually exclusive categories: non-containerised dry bulk, containerised dry bulk, deepsea containers, continental containers, parcel loads, and packages.

Concern 3: About the quality of the origin and destination data

Transport data is often collected by mode of transport (i.e. unimodal data collection). As a result of this practice the true origins and destinations of the shipments are often unknown. To deal with this issue the freight volumes are often treated as if they are produced and consumed in the model region itself. This implies that the calibration of the parameters in the model will result in high fixed location dependant factors that stem from not taking the true origins and destinations of the freight commodities properly into account (e.g. assuming a high volume and fixed share of IWT at the transhipment location). This approach cannot be expected to take the very long term effects of major changes to the transport system properly into account. I think that very long term effects of major changes to the cost structure of transport on the modal split up to the year 2100 should be modelled with historical data that reflects the true origins and destinations of the multimodal transport flows. This implies that the transport data should ideally be obtained in such a way that virtual production and attraction in the origin and destination regions of the model is avoided.

11.7.3 Answer to Methodological Sub Question 3

In answer to MSQ 3, I conclude that a sensible structure for modelling the very long term development of the IWT flows at the network level can be obtained by combining the strengths of the forecasting and foresight methodologies into a hybrid model structure that consists of the following three steps: (1) develop a long term scenario (e.g. for the year 2040) and quantify this scenario at the network level by means of an existing transport model; (2) apply foresight techniques to obtain an aggregated set of corresponding very long term scenario quantifications for the main drivers that act on the transport system up to the year 2100; and (3) project the very long term scenario quantifications onto the output of the long term scenario to obtain a detailed very long term scenario quantification at the network level. This approach may look simple, but there still remain a few complicated issues that need to be resolved. First of all, the aggregated very long term scenario quantifications for the main drivers of the transport system act at different stages of the classical four stage transport model (that is generally applied for the modelling of long term transport flows). This implies that the proposed hybrid model approach needs to interact with the long term transport model and has to impose the very long term trends at the intermediate stages during the execution of the long term transport model. In addition, the modelling of very long term transport flows requires an advanced transport model that is able to cover the possible development of intermodal continental container transport flows, the possible development of advanced pallet distribution networks, and the possible changes in the multimodal continental bulk transport flows. The proper modelling of these flows requires, amongst others, a completely different way of dealing with IWT in transport models, a completely new commodity classification system, and quite some additional efforts to improve the available transport data.

Literature:

De Dios Ortúzar, J. and L.G. Willumsen (2001) *Modelling Transport*, John Wiley & Sons, LTD, Chichester, UK.

De Jong, G., H. Gunn, and W. Walker (2004) *National and International Freight Transport Models: An Overview and Ideas for Future Development*, Transport Reviews, vol. 24, no. 1, pp. 103-124.

De Jong, G., I. Vierth, L. Tavasszy, and M. Ben-Akiva (2013) *Recent Developments in national and international freight transport models within Europe*, Transportation, vol. 40, no. 2, pp. 347-371.

De Langen, P.W., J. van Meijeren, L.A. Tavasszy (2012) *Combining Models and Commodity Chain Research for Making Long-Term Projections of Port Throughput: an Application to the Hamburg- Le Havre Range*, European Journal of Transport and Infrastructure Research, vol. 12, no. 3, pp. 310-331.

De Lloyd (14 January 2013) *Zes bedrijven krijgen Vlaamse steun voor palletvervoer met binnenvaart*, http://www.delloyd.be/Article/tabid/231/ArticleID/32485/ArticleName/ZesbedrijvenkrijgenVlaamsesteunvoorpalletvervoermetbinnenvaart/Default.aspx#.

Groothedde, B. (2005) *Collaborative logistics and transportation networks, a modelling approach to hub network design*, Trail Research School, Delft.

Klein, A. (1996) *Forecasting the Antwerp Maritime Traffic Flows Using Transformations and Intervention Models*, Journal of Forecasting, vol. 15., no. 5, pp. 395-412.

Limbourg, S., and B. Jourquin (2009) *Optimal rail-road container terminal locations on the European network*, Transportation Research Part E, vol. 45, no. 4, pp. 551-563.

Macharis, C., T. van Lier, E. Pekin, A. Verbeke (2011) *Intermodaal Binnenvaartvervoer, Economische en ecologische aspecten van het intermodaal binnenvaartvervoer in Vlaanderen*, Uitgeverij VUBPRESS, Brussels, Belgium.

McNally, M.G. (2008) *The four-step model*. In: Henscher, D.A., K.J. Button (Eds.), *Handbook of Transport Modelling*, Elsevier, Amsterdam, pp. 35-53.

Petersen, M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, A. Ulied (2009) *TRANSvisions: Report on Transport Scenarios with a 20 and 40 year Horizon, Final Report*, Funded by DG TREN, Copenhagen, Denmark.

Rietveld, P., and P. Nijkamp (2003) *Spatial interaction models*. In: Hall, R.W. (Ed.) *Handbook of Transportation Science*. Kluwer, Dordrecht, The Netherlands, pp. 661-668.

Schade W, D. Fiorello, J. Köhler, M. Krail, A. Martino, B. Schade, T. Wiesenthal (2008) *Final Report of the TRIAS Project: SIA of Strategies Integrating Transport, Technology and Energy Scenarios*. Deliverable 5of TRIAS (Sustainable Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

Solow, R. M. (1956) *A Contribution to the Theory of Economic Growth*, The Quarterly Journal of Economics, vol. 70, no. 1, pp. 65-94.

Tavasszy, L.A. (1996) *Modelling European Freight Transport Flows*, TU-Delft, Delft, The Netherlands.

Tavasszy, L.A. (2006) *Freight Modelling: an overview of international experiences*, TRB Conference on Freight Demand Modelling: Tools for Public Sector Decision Making, September 25-27, 2006, Washington DC.

Tavasszy, L.A. and G. De Jong (2014) *Modelling Freight Transport*, Elsevier, London.

Veenstra, A.W., and H.E. Haralambides (2001) *Multivariate autoregressive models for forecasting seaborne trade flows*, Transportation Research Part E, vol. 37, no. 4, pp. 311-319.

Vogel, B. (2002) *Distrirail, Vervoerslogistieke Werkdagen proceedings*, Corsendonk, pp. 1-8.

Zhang, M. (2013) *A Freight Transport Model for Integrated Network Service, and Policy Design*, TRAIL, Delft, The Netherlands.

Presentations:

L. Tavasszy (2012) *Modellen Goederenvervoer*, Course SPM3610 at the TU-Delft, Delft.

Websites:

RWS (2012) *Cost barometer (Dutch: Kostenbarometer)*, [www.rws.nl/kenniscentrum/economische_evaluatie/Kostenbarometer/]

12 Towards Implementation of Transport Model

“Fools ignore complexity. Pragmatists suffer it. Some can avoid it. Geniuses remove it.”
- Alan Perlis (1922-1990)

12.1 Introduction

The previous chapter proposed a possible structure for the modelling of very long term IWT flows at the network level in which the strengths of the long term forecasting and very long term foresight approach are combined. This chapter examines the options to develop the proposed very long term transport model on the basis of an existing transport model. It thereby addresses the fourth methodological sub-question (MSQ 4): *“What are the options to make efficient use of an existing long term transport model for the implementation of the proposed model structure – and where will additional modelling and/or research efforts be required to obtain a workable model?”*. As the development of a workable very long term transport model will still require a considerable amount of additional research efforts this chapter concludes with a comprehensive research agenda.

I initially aimed to develop the desired very long term transport model by undertaking the following steps: (1) start with the conversion of the base year data into a new commodity classification system that reflects the characteristics of the transported goods; (2) apply this dataset to an adjusted version of an existing long term transport model; and (3) make the transport model suitable for taking the aggregated very long term trends, that are based on foresight, into account. Prior to the execution of these steps an existing long term transport model had to be selected on which the very long term transport model could be based. Because this PhD project is executed on behalf of Rijkswaterstaat I considered it desirable to base the very long term model on the in-house BASGOED model of Rijkswaterstaat.

The use of the BASGOED model as a starting point for the intended modelling exercise was expected to have the following benefits: (1) the model is owned by Rijkswaterstaat which implies that it is freely available in the development stage, as well as in the period thereafter when the model is used by Rijkswaterstaat; (2) use can be made of the expertise on the BASGOED model that is available within the Rijkswaterstaat organisation[147]; (3) it is easier for Rijkswaterstaat employees to work with a model that they are already somewhat familiar

[147] Please note that I had several meetings with the following experts of Rijkswaterstaat: Bolt, Mitte, Schmorak, and Turpijn (see also Annex V).

with; and (4) once developed there exists a close link between the present long term transport model and the new very long term transport model. For these reasons I initially attempted to develop the proposed very long term transport model on the basis of the BASGOED model, but it soon turned out that an alternative modelling approach would be required. This chapter therefore assesses the options to develop a very long term transport model on the basis of an alternative existing transport model.

Section 12.2 covers the first step of the intended model development by showing that it is possible to convert the base year 2004 data of the BASGOED model into the new commodity classification system that was proposed in Chapter 11; Section 12.3 describes why it turned out that the BASGOED model does not provide a suitable starting point for the development of a very long term transport model; Section 12.4 continues with the identification of a number of alternative transport models, that also cover the Dutch IWT network; Section 12.5 assesses the compliance of these models with a predefined set of criteria, that I consider relevant for the development of the very long term transport model; Section 12.6 presents a research agenda for the further development of the very long term transport model; and Section 12.7 contains a concluding summary that provides an answer to MSG 4.

12.2 The Conversion of the Base Year 2004 Data

The first step in the development of the very long term transport model is the conversion of the base year data. I successfully converted the *'2004 base year files for freight transport'*[148] (as applied in the Dutch BASGOED model) into the new commodity classification system that was proposed in Chapter 11. For each mode of transport (i.e. road, rail, and IWT) and for each commodity class (i.e. non-containerised bulk, containerised bulk, continental containers and full truck loads, deepsea containers, parcel loads, and packages) an OD-matrix was prepared that contains the transport volumes in gross load, payload, and payload tonne kilometres. The payload data was included because it provides the best indication of the true transport volumes, as the gross load data also includes the weight of the equipment, such as the weight of the container or combi-load (i.e. including trailer) in case of rail transport.

The 2004 base year data consists of an undisclosed file for road-, rail- and IWT. The content of these files is discussed in the covering documents of NEA (2007abc). The files contain data on disaggregated freight flows for which a broad range of aspects is listed, but the fields are not always properly reported and one has to be very careful with the interpretation of the data. In particular the data on containerised cargoes is often incomplete and it is not always clear what is exactly measured (e.g. gross weight or payload). The content of the containers is also reported in dissimilar ways. The rail file reports all container and combi-loads as NSTR2 class 98 and 99, while other files report the data according to the NSTR2 class of the content inside the container. In addition it seems that the content of the containers is also not always properly reported for IWT. The data gathering therefore needs to be improved. The aggregated results of the conversion exercise are summarised in Table 12-1 to 12-3 and Figure 12-1; the details on the conversion of the base year data are provided in Appendix D; and the files that contain the obtained OD-matrices are listed in Appendix F.

[148] In Dutch: Basisbestanden Goederenvervoer 2004.

Table 12-1: Gross Load Data

Gross Load Tonnes (volume x 1 million tonnes)

Total PL	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	45.4				12.5	3.4	87.6
NSTR 1	47.5				32.8	3.0	129.2
NSTR 2	38.1				0.0	0.0	38.3
NSTR 3	69.5				0.0	0.0	72.3
NSTR 4	53.0	No Data Available			0.0	0.0	53.4
NSTR 5	38.4				0.0	0.0	40.6
NSTR 6	210.5				9.3	2.5	249.8
NSTR 7	27.6				0.0	0.0	27.8
NSTR 8	48.6				16.1	0.6	124.5
NSTR 9	34.7				51.7	47.0	311.9
Total	613.2	32.4	42.2	268.7	122.5	56.4	1,135.3
% of Total	54.0%	2.9%	3.7%	23.7%	10.8%	5.0%	100.0%

Road PL	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	35.3	0.7	1.0	24.2	12.5	3.4	77.0
NSTR 1	28.3	0.8	4.2	38.8	32.8	3.0	108.0
NSTR 2	3.4	0.0	0.0	0.0	0.0	0.0	3.4
NSTR 3	14.9	0.3	0.0	0.0	0.0	0.0	15.2
NSTR 4	7.5	0.4	0.0	0.0	0.0	0.0	7.9
NSTR 5	23.5	1.6	0.0	0.0	0.0	0.0	25.1
NSTR 6	125.4	0.7	0.2	25.6	9.3	2.5	163.7
NSTR 7	20.9	0.1	0.0	0.0	0.0	0.0	21.0
NSTR 8	24.1	3.2	2.4	46.7	16.1	0.6	93.1
NSTR 9	16.6	2.4	9.3	131.9	51.7	47.0	258.9
Total	300.0	10.2	17.2	267.1	122.5	56.4	773.4
% of Total	26.4%	0.9%	1.5%	23.5%	10.8%	5.0%	68.1%

Rail PL	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	0.3				0.0	0.0	0.7
NSTR 1	0.6				0.0	0.0	2.2
NSTR 2	4.3				0.0	0.0	4.4
NSTR 3	0.6				0.0	0.0	0.9
NSTR 4	6.3	No Data Available			0.0	0.0	6.4
NSTR 5	2.8				0.0	0.0	3.1
NSTR 6	1.8				0.0	0.0	2.2
NSTR 7	0.1				0.0	0.0	0.2
NSTR 8	3.3				0.0	0.0	5.1
NSTR 9	1.5				0.0	0.0	8.4
Total	21.7	4.2	6.8	0.8	0.0	0.0	33.5
% of Total	1.9%	0.4%	0.6%	0.1%	0.0%	0.0%	3.0%

IWT PL	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	9.7	0.1	0.0	0.0	0.0	0.0	9.8
NSTR 1	18.6	0.2	0.2	0.0	0.0	0.0	19.1
NSTR 2	30.4	0.1	0.0	0.0	0.0	0.0	30.5
NSTR 3	54.0	2.1	0.0	0.0	0.0	0.0	56.1
NSTR 4	39.1	0.0	0.0	0.0	0.0	0.0	39.2
NSTR 5	12.0	0.3	0.0	0.0	0.0	0.0	12.4
NSTR 6	83.3	0.7	0.0	0.0	0.0	0.0	84.0
NSTR 7	6.5	0.0	0.0	0.0	0.0	0.0	6.6
NSTR 8	21.1	5.0	0.2	0.0	0.0	0.0	26.3
NSTR 9	16.6	9.3	17.8	0.7	0.0	0.0	44.5
Total	291.6	17.9	18.3	0.7	0.0	0.0	328.4
% of Total	25.7%	1.6%	1.6%	0.1%	0.0%	0.0%	28.9%

LEGEND:

NCB: Non Containerised Bulk
CB: Containerised Bulk
DC: Deepsea Containers
CL: Continental Full Load (FTL, FCL)
CP: Continental Parcels (LTL, LCL)
CS: Continental Packages

In which:
FTL: Full Truck Load
FCL: Full Container Load
LTL: Less than Truck Load
LCL: Less than Container Load

NSTR:

0: Agricultural products; live animals
1: Food products and food
2: Solid mineral fuels
3: Petroleum and petrochemical products
4: Ores and metal residues
5: Metals, metal semi manufactures
6: Crude minerals, building materials
7: Fertilizers
8: Chemical products
9: Other goods and manufactures

Note: Data relates to the year 2004. It includes all shipments via Dutch territory (loaded and or unloaded in the Netherlands as well as transit cargo).

Table 12-2: Payload Data

Payload Tonnes (volume x 1 million tonnes)

Total	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	45.4				12.5	3.4	87.1
NSTR 1	47.5				32.8	3.0	127.9
NSTR 2	38.1				0.0	0.0	38.3
NSTR 3	69.5				0.0	0.0	71.8
NSTR 4	53.0		No Data Available		0.0	0.0	53.4
NSTR 5	38.4				0.0	0.0	40.2
NSTR 6	210.5				9.3	2.5	249.5
NSTR 7	27.6				0.0	0.0	27.7
NSTR 8	48.6				16.1	0.6	122.1
NSTR 9	34.6				51.7	47.0	285.8
Total	613.2	26.9	27.6	257.2	122.5	56.4	1,103.8
% of Total	55.6%	2.4%	2.5%	23.3%	11.1%	5.1%	100.0%

Road	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	35.3	0.6	0.8	24.0	12.5	3.4	76.6
NSTR 1	28.3	0.7	3.6	38.5	32.8	3.0	106.9
NSTR 2	3.4	0.0	0.0	0.0	0.0	0.0	3.4
NSTR 3	14.9	0.3	0.0	0.0	0.0	0.0	15.2
NSTR 4	7.5	0.3	0.0	0.0	0.0	0.0	7.8
NSTR 5	23.5	1.4	0.0	0.0	0.0	0.0	24.9
NSTR 6	125.4	0.6	0.2	25.5	9.3	2.5	163.5
NSTR 7	20.9	0.1	0.0	0.0	0.0	0.0	21.0
NSTR 8	24.1	2.7	2.1	46.2	16.1	0.6	91.7
NSTR 9	16.6	1.8	7.3	122.1	51.7	47.0	246.5
Total	300.0	8.5	13.9	256.4	122.5	56.4	757.7
% of Total	27.2%	0.8%	1.3%	23.2%	11.1%	5.1%	68.6%

Rail	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	0.3				0.0	0.0	0.7
NSTR 1	0.6				0.0	0.0	1.9
NSTR 2	4.3				0.0	0.0	4.4
NSTR 3	0.6				0.0	0.0	0.9
NSTR 4	6.3		No Data Available		0.0	0.0	6.4
NSTR 5	2.8				0.0	0.0	3.0
NSTR 6	1.8				0.0	0.0	2.1
NSTR 7	0.1				0.0	0.0	0.1
NSTR 8	3.3				0.0	0.0	4.8
NSTR 9	1.4				0.0	0.0	7.1
Total	21.6	3.6	5.5	0.7	0.0	0.0	31.4
% of Total	2.0%	0.3%	0.5%	0.1%	0.0%	0.0%	2.8%

IWT	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	9.7	0.1	0.0	0.0	0.0	0.0	9.8
NSTR 1	18.6	0.2	0.2	0.0	0.0	0.0	19.0
NSTR 2	30.4	0.1	0.0	0.0	0.0	0.0	30.5
NSTR 3	54.0	1.8	0.0	0.0	0.0	0.0	55.8
NSTR 4	39.1	0.0	0.0	0.0	0.0	0.0	39.2
NSTR 5	12.0	0.3	0.0	0.0	0.0	0.0	12.3
NSTR 6	83.3	0.6	0.0	0.0	0.0	0.0	83.9
NSTR 7	6.5	0.0	0.0	0.0	0.0	0.0	6.6
NSTR 8	21.1	4.2	0.1	0.0	0.0	0.0	25.5
NSTR 9	16.6	7.6	7.8	0.2	0.0	0.0	32.2
Total	291.6	14.8	8.1	0.2	0.0	0.0	314.7
% of Total	26.4%	1.3%	0.7%	0.0%	0.0%	0.0%	28.5%

LEGEND:

NCB: Non Containerised Bulk
CB: Containerised Bulk
DC: Deepsea Containers
CL: Continental Full Load (FTL, FCL)
CP: Continental Parcels (LTL, LCL)
CS: Continental Packages

In which:
FTL: Full Truck Load
FCL: Full Container Load
LTL: Less than Truck Load
LCL: Less than Container Load

NSTR:

0: Agricultural products; live animals
1: Food products and food
2: Solid mineral fuels
3: Petroleum and petrochemical products
4: Ores and metal residues
5: Metals, metal semi manufactures
6: Crude minerals, building materials
7: Fertilizers
8: Chemical products
9: Other goods and manufactures

Note: Data relates to the year 2004. It includes all shipments via Dutch territory (loaded and or unloaded in the Netherlands as well as transit cargo).

Table 12-3: Payload Tonne Kilometres Data

Payload Tonne Kilometres (volume x 1 billion)

Total	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	11.8				2.7	0.1	24.0
NSTR 1	10.7				5.2	0.1	29.4
NSTR 2	13.5				0.0	0.0	13.5
NSTR 3	16.2				0.0	0.0	17.0
NSTR 4	14.6		No Data Available		0.0	0.0	14.7
NSTR 5	13.4				0.0	0.0	13.9
NSTR 6	24.2				1.1	0.1	29.3
NSTR 7	5.1				0.0	0.0	5.1
NSTR 8	14.8				1.4	0.0	29.1
NSTR 9	8.0				10.8	1.5	76.5
Total	132.3	8.9	7.4	80.9	21.2	1.8	252.5
% of Total	52.4%	3.5%	2.9%	32.0%	8.4%	0.7%	100.0%

Road	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	7.3	0.1	0.1	8.9	2.7	0.1	19.3
NSTR 1	4.4	0.1	0.9	11.4	5.2	0.1	22.1
NSTR 2	0.5	0.0	0.0	0.0	0.0	0.0	0.5
NSTR 3	1.3	0.1	0.0	0.0	0.0	0.0	1.4
NSTR 4	1.0	0.0	0.0	0.0	0.0	0.0	1.1
NSTR 5	6.9	0.2	0.0	0.0	0.0	0.0	7.1
NSTR 6	7.0	0.1	0.0	3.5	1.1	0.1	11.7
NSTR 7	2.0	0.0	0.0	0.0	0.0	0.0	2.0
NSTR 8	6.1	0.6	0.3	9.6	1.4	0.0	18.0
NSTR 9	3.7	0.5	1.3	46.8	10.8	1.5	64.7
Total	40.2	1.8	2.8	80.2	21.2	1.8	148.0
% of Total	15.9%	0.7%	1.1%	31.7%	8.4%	0.7%	58.6%

Rail	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	0.2				0.0	0.0	0.4
NSTR 1	0.3				0.0	0.0	1.2
NSTR 2	1.7				0.0	0.0	1.7
NSTR 3	0.3				0.0	0.0	0.5
NSTR 4	3.2		No Data Available		0.0	0.0	3.2
NSTR 5	1.6				0.0	0.0	1.7
NSTR 6	0.7				0.0	0.0	0.8
NSTR 7	0.1				0.0	0.0	0.1
NSTR 8	1.9				0.0	0.0	2.7
NSTR 9	0.7				0.0	0.0	3.8
Total	10.7	1.9	2.8	0.6	0.0	0.0	16.1
% of Total	4.2%	0.8%	1.1%	0.3%	0.0%	0.0%	6.4%

IWT	**NCB**	**CB**	**DC**	**CL**	**CP**	**CS**	**Total**
NSTR 0	4.3	0.1	0.0	0.0	0.0	0.0	4.3
NSTR 1	6.0	0.1	0.0	0.0	0.0	0.0	6.1
NSTR 2	11.2	0.0	0.0	0.0	0.0	0.0	11.3
NSTR 3	14.5	0.6	0.0	0.0	0.0	0.0	15.1
NSTR 4	10.5	0.0	0.0	0.0	0.0	0.0	10.5
NSTR 5	4.9	0.2	0.0	0.0	0.0	0.0	5.1
NSTR 6	16.6	0.1	0.0	0.0	0.0	0.0	16.7
NSTR 7	3.1	0.0	0.0	0.0	0.0	0.0	3.1
NSTR 8	6.8	1.4	0.1	0.0	0.0	0.0	8.4
NSTR 9	3.6	2.7	1.7	0.0	0.0	0.0	8.0
Total	81.4	5.2	1.8	0.0	0.0	0.0	88.4
% of Total	32.2%	2.0%	0.7%	0.0%	0.0%	0.0%	35.0%

LEGEND:

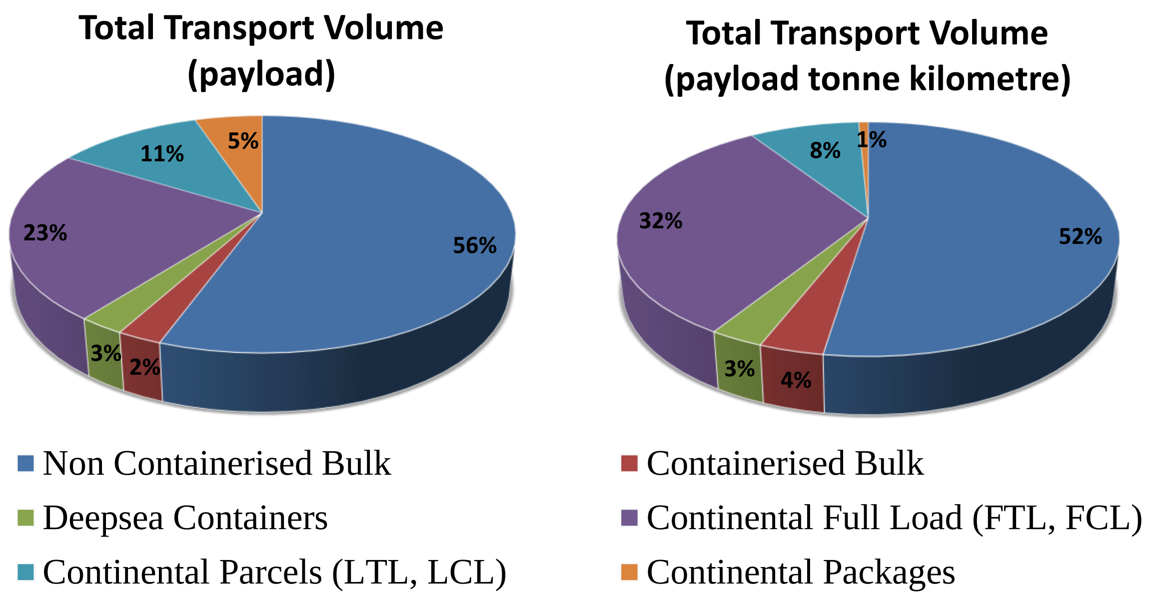
NCB: Non Containerised Bulk
CB: Containerised Bulk
DC: Deepsea Containers
CL: Continental Full Load (FTL, FCL)
CP: Continental Parcels (LTL, LCL)
CS: Continental Packages

In which:
FTL: Full Truck Load
FCL: Full Container Load
LTL: Less than Truck Load
LCL: Less than Container Load

NSTR:

0: Agricultural products; live animals
1: Food products and food
2: Solid mineral fuels
3: Petroleum and petrochemical products
4: Ores and metal residues
5: Metals, metal semi manufactures
6: Crude minerals, building materials
7: Fertilizers
8: Chemical products
9: Other goods and manufactures

Note: Data relates to the year 2004. It includes all shipments via Dutch territory (loaded and or unloaded in the Netherlands as well as transit cargo). Tonne kilometres measured over entire trip (not only NL).



Note 1: Data relates to year 2004. It includes all shipments via Dutch territory (loaded and or unloaded in the Netherlands as well as transit cargo). Tonne kilometres measured over entire trip (not only NL).
Note 2: The terms FTL and FCL refer to *'full truck load'* and *'full container load'*. The terms LTL and LCL stand for *'less than truck load'* and *'less than container load'*.

Figure 12-1: Aggregated Results of Conversion Exercise

It is interesting to observe that 58% of the Dutch transport volume (measured in payload tonnes) relates to bulk products, of which only 4% is shipped in containers. This volume represents 2.4% of the total transport volume. Deepsea containers accounted for 2.5% of the total volume. The total share of containerised cargoes is therefore about 5%.

The container flows are still relatively small compared to the continental full load shipments and the continental parcel load shipments, that are almost completely transported by road and cover about 34% of the total inland transport volume. This implies that even a moderate shift from continental road transport towards intermodal barge transport could already have a considerable effect on the total container volumes that are shipped by IWT. To gain insight in the possible effects of a major modal shift from continental road transport towards intermodal barge transport, I investigated the impact of a successful modal shift policy of the European Commission (2011, p.9), for which the aimed 50% modal shift of continental road cargoes over 300 km to multimodal transport has been fully realised by the year 2050.

For the quantification of the possible effects of a major shift from continental road transport towards intermodal transport a hypothetical scenario was considered in which: (1) the overall transport volumes in the year 2050 are similar to those in the base year 2004; (2) the modal shift of road cargoes over 300 km is precisely 50% for each of the six individual commodity classes defined in Chapter 11 (i.e. NCB, CB, DC, CL, CP, and CS); and (3) IWT has obtained a share of precisely 30% in the intermodal transport volumes. For this hypothetical scenario the effects can be defined by comparing the road transport volumes over 300 km that have been shifted to IWT with the container transport volumes that were already shipped by IWT. This comparison does however require additional insight in the road transport volumes over 300 km. I therefore prepared an additional OD-matrix for the road transport volumes over 300 km in the base year 2004. The aggregated output of this matrix is listed in Table 12-4.

Table 12-4: Converted Payload Data for Road Transport over 300 kilometres

Payload Tonnes (volume x 1 million tonnes)

Road 300+	NCB	CB	DC	CL	CP	CS	Total
NSTR 0	5.7	0.0	0.1	7.9	2.4	0.0	16.1
NSTR 1	3.3	0.1	0.7	9.8	2.8	0.0	16.7
NSTR 2	0.4	0.0	0.0	0.0	0.0	0.0	0.4
NSTR 3	0.5	0.1	0.0	0.0	0.0	0.0	0.5
NSTR 4	0.8	0.0	0.0	0.0	0.0	0.0	0.8
NSTR 5	7.4	0.2	0.0	0.0	0.0	0.0	7.5
NSTR 6	3.7	0.1	0.0	1.8	0.4	0.0	6.0
NSTR 7	1.0	0.0	0.0	0.0	0.0	0.0	1.0
NSTR 8	5.6	0.5	0.3	8.7	0.9	0.0	16.0
NSTR 9	2.9	0.4	1.1	46.8	8.3	0.3	59.8
Total	31.3	1.5	2.2	74.9	14.8	0.3	125.0
% of Total	2.8%	0.1%	0.2%	6.8%	1.3%	0.0%	11.3%
% Road 300+	25.0%	1.2%	1.8%	60.0%	11.8%	0.3%	100.0%

LEGEND:

NCB: Non Containerised Bulk
CB: Containerised Bulk
DC: Deepsea Containers
CL: Continental Full Load (FTL, FCL)
CP: Continental Parcels (LTL, LCL)
CS: Continental Packages

In which:
FTL: Full Truck Load
FCL: Full Container Load
LTL: Less than Truck Load
LCL: Less than Container Load

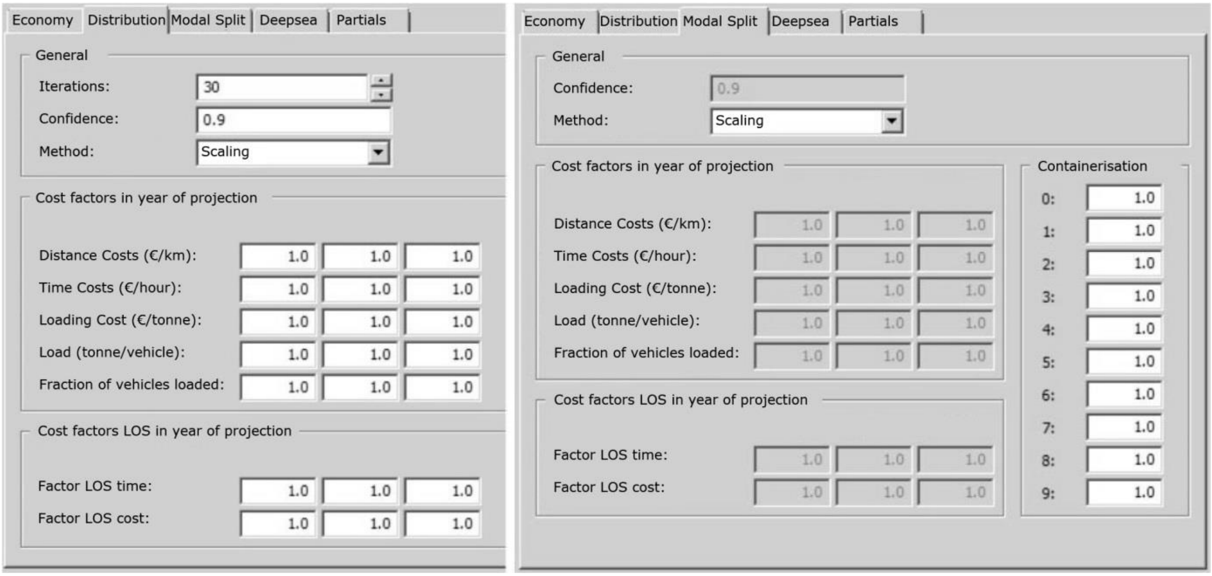
Note: Data relates to the year 2004. It includes all shipments via Dutch territory (loaded and or unloaded in the Netherlands as well as transit cargo).

The overall size of the continental full load road cargoes over 300 km equals 74.9 million payload tonnes. When assuming that precisely 50% of these cargoes are shifted to intermodal transport of which precisely 30% is transported by IWT, this results in an additional IWT volume of 11.2 million payload tonnes. If this volume is compared to the 22.9 million payload tonnes of deepsea- and bulk container freight that are already shipped by IWT (see Table 12.2), it can be concluded that this shift would imply an almost 50% increase in the total container transport volumes that are shipped by IWT. This hypothetical scenario shows that the potential shift of continental road transport towards intermodal barge transport can have a very substantial effect on the overall container volumes that are shipped by IWT. In addition a smaller but similar effect can also be expected in case intermodal pallet distribution networks are developed on the inland waterways in the subsequent period that follows the development of continental container transport (see Chapter 8). The outcome of this hypothetical scenario therefore underlines why it is so important that the very long term transport model is able to take the very long term effects of potential shifts from continental full load- and parcel load shipments into account. This is in fact not only important for assessing the possible effects of proposed policies with a very long term impact by Rijkswaterstaat, but also for assessing the effects of proposed modal split policies at the European level.

12.3 Approach based on BASGOED model

I initially intended to develop the desired very long term transport model on the basis of the in-house BASGOED model of Rijkswaterstaat, but unfortunately it turned out that the structure of the BASGOED model is too rigid to serve as a basis for the development the very long term transport model. This section indicates why the BASGOED model is not suitable for the development of a very long term transport model.

My first objection is that the model structure assumes the costs of all the transport means for a certain mode of transport to move along in a similar way. The model starts with a base level for the transport costs of the individual modes of transport and then allows the user to vary the unit rates for the various modes of transport by multiplication with certain primary cost factors. The default value for these cost factors is set to 1.0 (no changes). The primary cost factors that can be adjusted in the BASGOED model are indicated in Figure 12-2.



Source: Screenshots from BASGOED model Version 1.0.3, translated.

Figure 12-2: Input Parameters available in BASGOED model

The assumption that the costs of the various transport means move along together is already undesirable for very long term road- and rail transport projections (assuming large changes to the cost structure), but even less appropriate for the IWT system. The IWT system consists of many different waterways, each restricting the maximum size and loading conditions of the barges that can be used. This implies that a change to a primary cost factor (such as fuel, labour, or capital) will have a different effect on the relative cost levels for IWT, depending on the applied waterway route (see Chapter 10). This issue becomes even more problematic when specific changes to certain waterways or waterway classes are considered. Suppose that for instance, as a result of a proposed new policy, all Class IV waterways will be upgraded to allow for an extra layer of containers. This considerably improves the performance of Class IV container barges but has no effect on barges of other waterway classes nor on Class IV bulk shipments. Due to the homogeneous model structure there are no ways to take these kind of differences properly into account. I therefore think that a far more sophisticated modelling approach will be required to deal with the aspect of IWT in a proper way. Such an approach would ideally be able to take the main properties (length, width, draft, and air-draft) of the individual waterway routes into account when defining the costs levels for IWT.

My second objection is that the rather basic BASGOED model is developed as a unimodal transport model that does not allow for the modelling of multimodal transport flows, which I consider a prerequisite for the modelling of very long term IWT flows.

In light of the above it is sensible to question why Rijkswaterstaat has decided to replace its previous SMILE model by the new BASGOED model. According to De Jong et al. (2013): *"The SMILE model (later SMILE+, see Tavasszy et al. 1998 and Bovenkerk 2005) has been the Dutch national freight model system for over a decade. SMILE was the first national freight transport model that took into account the effect of logistics choices on freight flows. In 2009, the Dutch MoT chose to invest in a more simple and straightforward freight transport model that would also be easier to maintain. A basic freight transport model was developed, called BASGOED (where BAS comes from basic and GOED from good). This model was developed in about a year, and should be able to answer the most pressing policy* *questions of the MoT (Significance et al. 2010). BASGOED is a conventional four-step transport model, with only a limited number of zones and commodity types. Its distribution and modal choice model coefficients were estimated successfully on aggregate data, leading to reasonable elasticity values. It uses inputs (row and column totals: generation and attraction) from the economy model of SMILE+. Also for assignment, existing unimodal transport models are used. In addition to this basic model, a roadmap was built for the inclusion of logistics choices (Tavasszy 2011; Tavasszy et al. 2012) on the basis of, amongst others, the SMILE+ logistic model"*[149].

From the above citation it can be concluded that the present BASGOED model is developed as a unimodal transport model that is intended to be far more basic than its SMILE+ predecessor. It is therefore not surprising that the BASGOED model is too rigid to be applied as a basis for the development of the desired very long term transport model. In this respect it may be worth considering the reuse of the old SMILE+ model, but alternatively the use of another West European transport model can also be considered.

12.4 Identifying Alternative Transport Models

As the BASGOED model turned out to be too rigid to serve as a basis for the development of the desired very long term transport model, I searched for alternative transport models that can also be used for this purpose. This section identifies a number of alternative options for the modelling of very long term transport flows on the Dutch IWT network. The starting point for the identification of the relevant transport models is the publication of De Jong et al. (2013) on *"Recent developments in national and international freight transport models within Europe"*. This paper provides a summary of freight transport models recently developed for national or state authorities and for the European Commission. It reports on four models that cover the Dutch IWT network. These are the BASGOED, SMILE+, TRANS-TOOLS, and NODUS model. A list of the basic characteristics of these four models is provided in Table 12-5. I have included the BASGOED model in the table to allow for a comparison with the other transport models, but I do not consider it a sensible modelling option.

An earlier review of De Jong et al. (2004) on *"European freight transport modelling developments from 1990 onwards"* also referred to the ASTRA (Assessment of Transport Strategies); SCENES (Scenarios for European Transport); STREAMS (Strategic Environmental Assessment; a predecessor of the SCENES model); NEAC (European freight transport model); EXPEDITE (EXpert-system based PrEdictions of Demand for International Transport in Europe); and STEMM (Strategic European Multi-modal Modelling) models. These models are not included in the discussion because:

- The ASTRA, SCENES, and NEAC models are already incorporated in the TRANS-TOOLS model (De Jong et al., 2013; De Ceuster et al., 2010);
- The EXPEDITE model belongs to a special category of meta-models that integrates the results of several models into a single framework (De Jong and Gunn, 2003);
- The STEMM model appears to be dealing with mode-choice only and pays no attention to the IWT mode (Fowkes and Toner, 1998).

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[149] Note that the former MoT (Ministry of Transport; Dutch: Ministerie van Verkeer en Waterstaat) is now part of the Ministry of I&M (Infrastructure and Environment; Dutch: Infrastructuur en Milieu).

Table 12-5: Freight Transport Models developed for Public Authorities

Model	BASGOED	SMILE+	NODUS	TRANS-TOOLS
Client	Dutch MoT	Dutch MoT	Several, including Walloon region	EU
Sources	Tavasszy (2011), Significance et al. (2010a, 2010b)	Tavasszy et al. (1998), Bovenkerk (2005)	Pekin et al. (2007), Jourquin and Beuthe (1996)	Chen (2011), TNO (2008), Hansen (2011), Tetraplan (2009)
Year of development	2010-2011	1998-2005	2006, building on earlier work	2005-2009
Study area	Netherlands	Netherlands	Belgium or Europe	Europe
Number of zones: internal + external used for modelling freight transport	40 (NUTS 3) + 30	40 (NUTS3) + 60	Almost 600 in Belgium (NUTS5), more than 250 in Europe (NUTS2)	277 (NUTS2) + 19
Number of commodities	10 NSTR1	50 logistical families	10 NSTR1	10 NSTR1 + Crude oil as separate item
Choices included	Generation, Distribution, Modal Split, and Assignment	Generation, Distribution, Modal Split, Logistics, and Assignment	Modal Split and Assignment	Generation, Distribution, Modal Split, (Logistics) and Assignment
Modes	Road, Rail, IWT	Road, Rail, IWT, Sea, Air, Pipeline	Road, Rail, IWT	Road, Rail, IWT, Sea

Source: Based on De Jong et al. (2013, Table 1), minor adjustments.

The further discussion in this chapter concerns an assessment of the four transport models that were developed for public authorities as listed in Table 12-4, as well as two other models that were developed in a more scientific context (i.e. not on behalf of public authorities), which are: (no. 5) the intermodal freight transport model of Zhang (2013), and (no. 6) the intermodal distribution network model of Groothedde (2005).

12.5 Assessment of Alternative Transport Models

Having identified a number of alternative transport models I continued this study with an assessment of the most appropriate transport models. For this assessment I first listed the requirements, that I consider necessary for the development of an advanced very long term transport model, and then assessed the compliance with these requirements by means of literature research and discussions with two experts, being: Tavasszy and Zhang. This section first defines the necessary requirements for the development of an advanced very long term transport model, and then assesses the compliance of the identified transport models with these requirements. In order to show how well the assessed items comply with the very long term model requirements the non-complying items are highlighted in *'italic'* writing.

12.5.1 Requirements for modelling of very long term IWT flows

Chapter 11 indicated that the desired very long term transport model should at least cover the possible development of intermodal continental container barge transport, but preferably it should also address the possible development of intermodal pallet distribution networks, and the possible effects of major changes to the cost structure of transport on the modal split for multimodal bulk cargoes. The relevance of taking the possible development of intermodal continental container- and pallet transport properly into account has been confirmed by the hypothetical scenario in Section 12.2, for which I concluded that the possible impact of a major modal shift of continental road cargoes to intermodal IWT can be very substantial.

Chapter 11 further indicated that the development of a very long term transport model requires: (1) the description of the IWT network to be specific enough to consider the limiting effect of the available infrastructure dimensions on the development of intermodal container transport; (2) the classification system of the different commodities to comply with the characteristics of the transport system; and (3) the available data to provide sufficient insight in the true origin and destination of multimodal transport flows. These are however are not the only requirements that the very long term transport model should meet. I identified a total of fourteen requirements that should preferably be met for the development of an advanced very long term transport model, which are:

1. The geographical description of the model should not only cover the geographical area of the Dutch IWT system but also that of the surrounding IWT networks.
2. The geographical description of the model areas in and around the Netherlands should have a sufficient high resolution to enable the proper assignment of the IWT flows to the network (i.e. minimal at the NUTS 2 and preferably at the NUTS3 level).
3. The data that is applied in the model should not only address the transport flows that are presently shipped on or via Dutch territory, but also the potential transit flows that could be routed via Dutch territory if transport conditions change.
4. The model should be able to address all four stages of the classical transport model (alone, or in combination with other models).
5. The model should be able to deal with all kinds of freight commodities (i.e. the model is not solely developed for a single commodity such as containers).
6. The model should be subject to ongoing support and modelling efforts in order to allow new insights to be taken into account in new versions of the model and to free ride on funding of other research projects.
7. The model should allow for the modelling of intermodal transport (considering both deepsea and continental container flows).
8. The model should allow for the modelling of the future development of intermodal parcel loads (e.g. pallet distribution networks).
9. The model should allow for the modelling of integrated multimodal bulk flows (no longer dealing with bulk commodities as unimodal transport flows).
10. The model should allow for the modelling of changes in the geographic spread of logistic activities.
11. The model should allow for the modelling of changes in the geographic spread of production and consumption activities.
12. The network description should be sufficient to consider the effects of changing IWT infrastructure dimensions on continental transport flows (i.e. based on real waterway dimensions, realistic water levels, and realistic barge- and cargo characteristics).
13. The commodity classification system should comply with the requirements of the transport system (e.g. by applying the commodity classification proposed in Chapter 11, or by applying an alternative set of logistical families).
14. The available data should be sufficient to provide clear insight in the true origins and destinations of the multimodal freight transport flows.

It should be noted that the above requirements are very rigorous and therefore none of the identified models will fully comply with the requirements, but the list at least indicates what additional efforts may be required for the development of a very long term transport model.

12.5.2 Discussion on the compliance of the BASGOED model

As discussed in Section 12.3, the BASGOED model is developed to provide the Dutch Ministry of Infrastructure and Environment with a basic modelling tool for the most pressing policy questions. For a description of the model I refer to OmniTRANS (website, accessed: 2012), Rijkswaterstaat (website, accessed: 2012), Significance et al. (2010a, 2010b), Tavasszy (2011), and de Jong et al. (2013). On the basis of the available studies, consulted experts, and my personal experience with the model I concluded that:

1) The geographical model description covers the Dutch national territory as well as the regions to and from which goods are shipped.
2) The geographical model description includes 40 zones (at NUTS 3) that are located within the Netherlands as well as 30 zones outside the Netherlands. This is sufficient for the proper allocation of the transport flows to the IWT network.
3) *The applied transport data only includes flows that are shipped on or via the Dutch territory. Potential new transit cargo flows are therefore not taken into account.*
4) The broader model framework includes all four stages of the transport model, though the trip generation step is based on input from the economic module of the SMILE+ model and additional models are applied to assign the flows at the network level (such LMS for road transport and BIVAS for IWT).
5) The model is suitable of taking all freight commodities into account (NSTR 1 to 9).
6) The model is now being developed by Rijkswaterstaat with the intention to step-by-step improve and add functionality to the model.
7) *BASGOED is developed as a unimodal transport model that does not support the modelling of intermodal freight flows.*
8) *The model does not allow for the modelling of intermodal parcel loads.*
9) *The model does not allow for the modelling of multimodal bulk flows.*
10) *The model does not allow for the modelling of changes in the geographic spread of logistic activities (though changes in logistic activities may be covered after the future development of a logistics module).*
11) *The model does not allow for the modelling of changes in the geographic spread of production and consumption activities.*
12) *The description of the IWT system is insufficient to take changes to the IWT system into account, in fact the model does not even allow the user to consider changes to the cost structure of the individual barge types.*
13) *The applied NSTR1 commodity classification does not comply with the requirements of the transport system.*
14) *The available data is obtained from unimodal transport flows and provides no insight in the true origins and destinations of the multimodal transport flows.*

From this analysis I conclude that only the 1st, 2nd, 4th, 5th and 6th requirement of the model are sufficiently met. This confirms that the BASGOED model is not a very suitable starting point for the development of a very long term transport model.

12.5.3 Assessment of the compliances of the SMILE+ model

The SMILE (Strategic Model for Integrated Logistic Evaluations) model was developed in an attempt to provide a sophisticated integrated theory based transport modelling solution for the Netherlands. A functional outline of the model is provided by Tavasszy et al. (1998). Further discussion on the capability of the model can be found in De Jong et al. (2004, 2013). The SMILE (later SMILE+) model was the first national freight transport model that took into account the effect of logistic choices on freight flows in an endogenous way. The model was not only able to deal with multimodal freight flows, for which the third and fourth stage of the model were solved simultaneously, but it also included the modelling of logistic processes (i.e. supply logistics via distribution centres). This made the model suitable for dealing with structural changes in the logistic system that can be expected over time. Quite interesting is that the model has been reported to allow for the evaluation of structural effects of major infrastructure improvements such as the construction of the Canal Tunnel. In addition the SMILE model is also reported to be able to deal with changes in the geographic structure, that affect the optimal points where logistics activities take place (Tavasszy et al., 1998). In order to model the various logistical activities, the SMILE model uses input data from 50 different logistical families instead of a distinct number of NSTR categories. Unfortunately the SMILE model is no longer supported by the Dutch government. On the basis of the available literature and consulted experts I conclude that:

1) The geographical model description covers the Dutch national territory as well as the regions to and from which the goods are shipped.
2) The geographical model description includes 40 zones (at NUTS 3) that are located within the Netherlands as well as 60 zones outside the Netherlands. This is sufficient for the proper allocation of the transport flows to the IWT network.
3) *The applied transport data only includes flows that are shipped on or via the Dutch territory. Potential new transit cargo flows are therefore not taken into account.*
4) The model framework does not only allow for the execution of all four stages of the classical transport model, but it also includes a fifth layer that deals with supply side logistics. Additional models were used for the assignment of the freight flows at the network level, such as the BIVAS model for the assignment of the IWT flows.
5) The model is suitable of taking all freight commodities into account by means of 50 logistical families. These commodities relate to the value density, package density, perishability, delivery time, shipment size, and demand frequency of the goods.
6) *The model is no longer supported by Rijkswaterstaat and now being replaced by the simpler and more robust model called BASGOED.*
7) The model was developed as a multimodal transport model that allows for the modelling of intermodal (deepsea) container transport flows, but the modelling takes place in tonnes and the differences in the types and weights of the containers are therefore not included. *The modelling of intermodal continental container flows is as such not supported, but the structure of the model should, at least in theory, be considered flexible enough to take these flows into account.*
8) *The smile model is not able to deal with economies of scale and scope stemming from consolidated parcel loads such as for instance modelled by Groothedde (2005).*
9) The model is developed as a multimodal transport model, that is intended to support the modelling of multimodal bulk flows.
10) The model is able to take changes in the geographical spread of logistics activities into account by applying the logistics module.
11) *The model does not allow for the modelling of changes in the geographic spread of production and consumption activities.*
12) *The network description of the model applies three distinct barge classes, namely: small, medium, and large. This description is insufficient to allow for the proper evaluation of the effects of infrastructural changes on the IWT system.*
13) The applied commodity classification (consisting of 50 logistical families) is designed to take into account the logistical properties of the transported goods. In this respect the model complies with the requirements of the transport system, *but it should be noted that the specific characteristics of intermodal continental container barge transport (in 45 foot containers) have not been taken into account specifically.*
14) The requirement of the model to include the logistic processes implies that the model is at least intended to relate the freight flows to their true origins and destinations, *but this aim is not fully realised due to issues with the available data.*

From the above I conclude that the SMILE model could have been an interesting candidate for the development of a very long term transport model. The main problem with this model is however the fact that it is no longer supported by the Dutch government.

12.5.4 Assessment of the compliances of the NODUS model

The NODUS model is developed for long-term planning of freight transport on an intermodal network. It was originally developed to model the Walloon region in Belgium, as an enclave in the European one. For a description of the model reference can be made to Jourquin and Beute (1996), and Geerts and Jourquin (2001). Applications of the model are reported by Beute et al. (2001), Pekin et al. (2007), Limbourg and Jourquin (2008), and Jonkeren et al. (2011). The latter concerns a study of the effects of low water levels stemming from climate change on the competitive position of IWT in the Rhine market, of which the results have already been discussed in Chapter 9.

NODUS is developed as a GIS based software application focussed on the transport of goods (Jourquin and Beute., 1996). It is a tool for the detailed analysis of freight transport over extensive multimodal networks. It contains the networks of road- (including ferry lines), rail-, and IWT. The model covers the whole of Europe. For each transport mode a network was constructed that consists of links and nodes. Horizontal movement of freight takes place on the links (i.e. the roads and ferry lines, railways, and inland waterways). The nodes refer to the vertical movement of cargo (i.e. loading, unloading, and transhipment). Costs are attributed to each individual operation on the network (Jonkeren et al., 2011).

The nodes and links are joined in a virtual network that allows the transport options to be defined in an intermodal way. The NODUS model does not produce the OD-matrices and cost functions required for the analysis. In case of Jonkeren et al. (2011) the base year OD-matrix as well as the applied cost functions were kindly provided by NEA. The model input is based on transport data obtained at the one digit NSTR classification. Intermodal transport is only applied to the NSTR 9 class of *'diverse products'* (Beute et al., 2001). The model therefore supports the modelling of intermodal container transport, but does not take the more complex multimodal bulk and intermodal pallet flows into account. The model distinguishes between inland barges of 300, 600, 1350, and 2000+ tonnes. Based on the above I conclude that:

1) The geographical model description covers the Dutch national territory as well as the regions to and from which goods are shipped.
2) The geographical description of the model includes 600 zones (NUTS 5) that are located within Belgium as well as 250 zones in Europe (NUTS 2). *The resolution of the areas within the Netherlands is therefore sufficient but not optimal.*
3) The data for the model is obtained from other sources which implies that the model should be able to address the flows within the Netherlands as well as within a broader region if data can be obtained from external sources.
4) The model deals with the third and fourth stage of the classical transport model simultaneously. The distribution OD-matrices are obtained from external sources.
5) The model is suitable of taking all freight commodities into account (NSTR 1 to 9).
6) The model is still applied for policy analysis inside and outside Belgium. Use of the model has latest been reported by Jonkeren et al. (2011).
7) The model is developed as an intermodal transport model. It should therefore be able to deal with intermodal transport flows. *However in practice only the NSTR9 'diverse products' category is treated in an intermodal way. In addition, the modelling of intermodal continental container transport is not as such included.*
8) *The model is not able to deal with the distribution of intermodal parcel loads.*

9) *The model deals with bulk commodities in a unimodal way. It is therefore not able to deal with multimodal bulk flows.*
10) *The model deals with the assignment of predefined OD-flows. It cannot take changes in the geographic spread of logistic activities into account.*
11) *The model does not allow for the modelling of changes in the geographic spread of production and consumption activities.*
12) *The model differentiates between a number of different barge types (300, 600, 1350, and 2000+ tonnes) that are assigned to the waterways. This provides some options to account for changes in the cost structure of IWT, but I consider it insufficient for the proper modelling of intermodal (continental) container transport flows.*
13) *The applied NSTR1 commodity classification does not comply with the requirements of the transport system.*
14) Since the data is obtained from other sources it should be possible to import data from a source that refers to the true origins and destinations of the freight flows.

On the basis of the above, I think that the NODUS model could serve as a reasonable starting point for the modelling of very long term IWT flows at the network level, provided that a number of adjustments is made. First off all, I think that a different classification system should be applied, that reflects the transport characteristics of the freight flows, such as the new classification system discussed in Chapter 11. In addition I think that the model should allow for the modelling of all relevant intermodal freight flows, instead of only the NSTR9 goods category. Finally the proper modelling of continental full cargo loads (i.e. full truck or container loads) will also require a different description of the IWT network. The NODUS model only covers a small number of different barge types. I think that this approach is still reasonable for the modelling of unimodal bulk flows, but I consider it insufficient for the proper modelling of intermodal container transport flows. I therefore argue that, in order to take the loading conditions, capacity, and cost levels of in particular continental intermodal container transport properly into account, it will be necessary to base the model on real waterway dimensions, realistic water levels, and realistic barge- and cargo characteristics. This requires a completely different structure of the applied IWT module, but I think that such a structure can be developed in a GIS based model environment.

I consider it possible to adjust the NODUS model in such a way that it is able to support the modelling of intermodal container transport flows (for deepsea and continental containers) as well as the modelling of multimodal bulk shipments (no longer applying a unimodal assignment). However, for the modelling of advanced intermodal pallet distribution networks, that may also evolve in the future, an alternative model approach will be required.

12.5.5 Assessment of the compliances of the TRANS-TOOLS model

The TRANS-TOOLS model is developed on behalf of the European Commission and free of intellectual property rights (IPR). The first version of the model (TT1), that covers the EU transport network, is addressed by Burgess et al. (2008). The second version of the model (TT2), that was developed by a different team in the course of the TEN-Connect project for the European Commission, is addressed by Rich et al. (2009). The main objective of the second version was to extend the geographic study area beyond the EU. The EU is presently funding the development of a third version (TT3) that improves the usability of the model, as well as the level of detail with respect to the rail, maritime (sea), and air transport modules. The new model should have already been completed, but there remain some issue that still need to be solved (TRANS-TOOLS 3 website, last accessed: 2014).

A brief discussion on the development of the TRANS-TOOLS model is provided by De Jong et al. (2013). A clear overview of the development of the TRANS-TOOLS model in relation to other European transport models is provided by De Ceuster et al. (2010). Applications of the TRANS-TOOLS model can be found in various EU policy documents such as Petersen et al. (2009) as discussed in Chapter 3.

The TRANS-TOOLS model is developed in ArcGIS to allow the user to edit, operate, and illustrate the results from the same common GIS-based platform. The model covers both passenger and freight transport and deals with unimodal as well as multimodal transport. The distribution of freight transport takes place at the NUTS2 level, but TT2 allows a NUTS2 zone to have more than one fixed port in order to enable disaggregation from NUTS2 to NUTS3 for assignment (Rich et al., 2009). The freight module includes road, rail, IWT, and sea transport. Commodities are classified according the NSTR1 classification, but with crude oil treated as a separate 11th commodity class.

The data for the TRANS-TOOLS 1 and 2 model was collected, prepared and emitted by the ETIS database project. The ETIS project collects all required data and fills in the required data gaps, such as gaps in the OD-matrix of the transport chain (Burgess et al., 2008). The ETIS freight database contains the following items:

- Origin, first transhipment, second transhipment, and destination region;
- Transport mode at origin, between transhipments, and at destination;
- Commodity group;
- Tonnes.

The level of service is defined for unimodal transport links. The results are presented in matrices for each year of the very long term projection. These matrices contain the:

- Origin and destination region;
- Mode of transport (road, rail, IWT, sea);
- Distance per mode;
- Time per mode;
- Cost per mode;
- Existence of service per mode.

The TRANS-TOOLS model is based on a conventional four stage model approach with unimodal allocation of goods, that allows the user to apply the logistics module as a post-processor on the freight distribution model. De Jong et al. (2013) indicate that: *"The logistics module in TT1 is similar to the Dutch SMILE+ model (Bovenkerk, 2005) and the logistics model within SCENES (SLAM; SCENES consortium 2000) and explains the location and use of distribution centres, leading to the formation of transport chains"*. The modelling of logistics processes is only possible for the NSTR classes 0, 1, 5, 8, and 9, because the distribution logistics mainly takes place in these commodity classes (Burgess et al., 2008). With respect to the modelling of IWT a different approach is applied in the distribution and allocation stage. In the distribution stage the modal split is defined on the basis of calibrated parameters for costs and time per NSTR category and per OD-relation. In the allocation stage a distinction is made between the CEMT II to VI waterway classes.

On the basis of the above the following can be concluded:

1) The geographical model description covers the Dutch national territory as well as the regions to and from which goods are shipped.

2) The geographical description of the model includes 277 zones in Europe that are defined at the NUTS 2 level. *The resolution of the areas within the Netherlands is therefore sufficient but not optimal.*
3) The transport data covers the larger European region, which implies that it covers the entire hinterland of the West European waterways including the Netherlands.
4) The model framework considers all four stages of the classical transport model and includes a fifth optional layer that deals with logistic processes.
5) The model is suitable of taking all freight commodities into account (NSTR 1 to 9, with chemicals of NSTR Class 3 split into crude oil and other chemicals).
6) The model functions as the main transport model of the European Commission. A new version TRANS-TOOLS 3 is now being developed*, though the completion of the new model has been delayed (it is unclear when the outstanding issues will be solved).*
7) *The TRANS-TOOLS model applies a unimodal allocation of the freight flows and does not contain a virtual network description such as in NODUS. This implies that the model is not very suitable for the modelling of intermodal container transport flows (let alone for continental containers). The inclusion of intermodal container transport will therefore still require a very substantial amount of modelling efforts.*
8) *The model is not able to deal with the distribution of intermodal parcel loads.*
9) *The unimodal assignment of the TRANS-TOOLS model implies that changes in the multimodal transport of bulk commodities cannot be taken into account.*
10) The logistics module of TRANS-TOOLS is able to take changes in the geographical spread of logistics activities into account for at least some commodities.
11) *The model does not allow for the modelling of changes in the geographic spread of production and consumption activities.*
12) *The distribution and modal choice modules do not consider the real variance in the cost structure of the different waterways. The distribution module applies parameters describing the cost structure for inland shipping calibrated for each commodity class and OD regardless of the available waterway characteristics. The assignment module differentiates between a number of different barge types (Class II to VI) that can be applied on the waterways. This allows for some differentiation in the cost structure of IWT, but complies mainly with the cost structure for unimodal bulk transport.*
13) *The applied NSTR1 commodity classification does not comply with the requirements of the transport system.*
14) The OD data from the ETIS database is intended to comply with the requirement to include the real origin and destination of the supply chain*, but the applied methods are not documented and therefore the quality of the database cannot be judged. In addition there still seem to be some issues with the data that need to be resolved*[150].

From the above considerations I conclude that the TRANS-TOOLS model is probably not the best starting point for the desired very long term IWT model, because it does not contain a network structure for the modelling of multimodal transport flows. The benefits of using the TRANS-TOOLS model are however: (1) that it is supported by the European Union; (2) that it is free of intellectual property rights; and (3) that it covers the broader West-European region. It is therefore still sensible to consider the use of this model as a starting point for the development of the desired very long term transport model, but the use of this model will

[150] Reference should also be made to the issues with the new ETIS+ database, that provides the input data for the new TRANS-TOOLS 3 model (see TRANS-TOOLS 3 website, www.transtools3.eu, attended 2014).

require substantial modelling efforts to overcome the shortcomings. First off all, it will be necessary to change the data structure from the present arrangement by NSTR commodity class to a structure that complies with the characteristics of the transport system, such as for instance the classification system discussed in Chapter 11. In addition, substantial efforts will be required to enable the modelling of intermodal deepsea and continental container flows as well as preferably also the modelling of multimodal bulk flows. In line with the discussion for the NODUS model I also consider it necessary to base the modelling of the cost levels for IWT on real waterway dimensions, realistic water levels, and realistic barge- and cargo characteristics. And finally an alternative model approach will be required to deal with the possible development of advanced intermodal pallet distribution networks in the future.

I am not the only one who advocates a more advanced modelling approach for IWT. The notion that IWT models should be based on more specific waterway characteristics is for instance also addressed by De Ceuster et al. (2010, p.57 – p.58) who argues that: *"In the information available at the European level which is incorporated in ETIS and TRANS-TOOLS no proper information is available about locks and bridges. Information is available about the depth and so called CEMT classification which defines which maximum ship sizes can navigate on a river. The assignment that can be made with TRANS-TOOLS and which has also been applied in for instance TENSTAC the inland navigation flows are assigned by an all-or-nothing assignment without capacity restrictions.*

Although insight can be obtained on where the flows will grow there is no proper analysis possible on the bottlenecks. In national inland navigation models this type of information is available and models are designed to analyse the delays at locks. Generally the national territory is most detailed and up to date where the links across the borders are of lesser quality. In future exercises it might be worthwhile to create a European Network that can be used for modelling.

In commercial software like for instance PC-Navigo all required information is available. With this software individual shippers plan their routes taking into account the waiting times at locks and other capacity constraints for a certain ship size. With this software one could create travel time OD's based on current average waiting times at locks. This time matrix then can be used in the assignment module to be used and would add to the quality".

I share the opinion that it is important to take the allowable dimensions of the waterways (length, width, draft, and air-draft) into account, and I agree that the PC-Navigo approach can provide a reasonable starting point. I further agree that a different description of the network will be required to improve the quality of IWT modelling, in particular when it concerns the modelling of possible future intermodal IWT flows. I therefore support the idea to create a GIS based European IWT Network that can be used for transport modelling. The benefit of such a GIS based system would be that it provides actual data on the properties of the inland waterways (such as the allowed infrastructure dimensions). This implies that, by means of the link to the GIS database, the model is also automatically updated when changes to the infrastructure occur (assuming that the database is of course held up to date).

The notion that IWT is not taken properly into account in TRANS-TOOLS is also addressed by Burgess et al. (2008, p.135) who indicates that: *"Also flows in inland waterways seem to have a wrong representation".* This provides a clear indication that adjustments to the model will be required to deal with IWT in a proper way. In that respect it is a pity that the new TT3 model does not focus on improving the model for IWT flows. I would recommend to put this issue on the agenda for the development of the TT4 model.

12.5.6 Assessment of the compliances of the ZHANG model

Zhang (2013) developed a European GIS based intermodal freight transport model based on transport data for the Netherlands. The model includes road, rail, and IWT transport as well as the pre- and end-haulage for intermodal transport. It is able to deal with economies of scope and density. The model optimises the performance of terminals and freight services on the basis of a service network model. The base year transport data for the model were obtained from the raw 2006 CBS (i.e. the Dutch statistical agency) data files. These are presumably similar to the files from which the 2004 base year data files of the BASGOED model were derived. The model defines the mode and route choice of the freight flows by simultaneously running the infrastructure and service network assignment modules. The model is developed for containers, though the cost data are defined on the basis of tonnes instead of container boxes of a specific size. Other commodities have not been included, but they can be included by adding the locations of the multimodal transfer points (i.e. the barge and rail terminals for bulk and break-bulk commodities) as well as the corresponding cost functions. From personal conversations with Zhang and Tavasszy the following was concluded on the compliance with the very long term transport model requirements:

1) The description of the geographic zones in the model covers the Netherlands as well as the broader European continent.
2) The description of the model areas takes place at the NUTS 3 level. This is sufficient for the proper allocation of the transport flows to the IWT network.
3) *The applied transport data only includes flows that are shipped on or via the Dutch territory. Potential new transit cargo flows are therefore not taken into account.*
4) The model covers the last two steps of the classical transport model including the assignment of IWT flows to the network. The trip distribution data was obtained from the raw CBS data files for the year 2006.
5) *The model is solely developed for the modelling of intermodal container transport flows,* but it was understood that the model structure can be further developed to include other commodities as well.
6) The model is owned by the TU-Delft and intended to be further develop over time.
7) The model is developed for intermodal container transport, but the modelling takes place on the basis of tonnes instead of container boxes of a specific size. *The model can therefore not be expected to take transport cost differences between for instance deepsea 20 and 40 foot containers as well as continental 45 foot containers into account. It will require additional efforts to adjust the model in such a way that this topic is properly covered, but it was understood that this would not be a major issue.*
8) *The model is developed for intermodal container transport and cannot readily take the development of advanced pallet distribution networks into account.* However, the service network description of the model is likely to support the development of a module that enables the modelling of advanced intermodal pallet distribution networks on the basis of aggregated OD data.
9) *The model has only been developed to deal with intermodal container transport,* but it is possible to upgrade the model in such a way that it can also include multimodal bulk transport. Upgrading the model requires insight in the locations of the multimodal bulk terminals as well as in the cost functions for multimodal bulk transport.
10) *The model does not allow for the modelling of changes in the geographic spread of logistic activities.*

11) *The model does not allow for the modelling of changes in the geographic spread of production and consumption activities.*
12) *The model contains only a few distinct waterway classes for which a different cost structure is applied.* The GIS based structure should however be able to support the development of a more advanced modelling approach, that takes the actual size and properties of the waterway system into account.
13) *The model deals only with containers, other commodities have not yet been included in the model.* However, the fact that the base year data stems from the same CBS data source as the base year 2004 data that has been applied in the BASGOED model, implies that it should be possible to convert the base year data into the classification system proposed in Chapter 11 (e.g. by applying similar conversion rules as discussed in Appendix D).
14) The intermodal transport data is intended to reflect on the true origins and destination of the freight flows. *However, given the fact that the data stems from the same source as the data applied in the BASGOED model, it cannot be expected to fully reflect the true origins and destinations of the multimodal transport flows.*

On the basis of this discussion, I conclude that the ZHANG model provides an interesting starting point for the development of a very long term transport model. The main advantages of the model are: (1) the fact that the data conversion into my new classification system is likely to be feasible; (2) the fact that the model contains a description of the transport network, that supports the modelling of intermodal transport flows; and (3) the fact that it should be possible to adjust the model in such a way that it enables the modelling of advanced pallet distribution networks on the inland waterways. The main disadvantages of the ZHANG model are: (1) the fact that the applied data sources only cover the Netherlands; and (2) the fact that the bulk flows have not yet been included in the model.

12.5.7 Discussion on the possible use of the GROOTHEDDE model

Groothedde (2005) modelled the possible development of various types of multimodal pallet distribution networks (see Chapter 8). A detailed description of the model approach is given by Groothedde et al. (2005). According to De Jong et al. (2013), the model is especially meant to investigate "*how economies of scale and scope can be obtained in multimodal hub networks. The authors show how the total logistics costs can be reduced (and services levels maintained) by shifting consolidated flows from road to rail, inland waterway or coastal shipping, that are better suited for handling large volumes. The total logistics costs are formulated taking into account the density of the flows and the location of the hubs. The approach is described through presenting the results of the design and implementation of collaborative networks for distribution of fast moving consumer goods in the Netherlands using road and inland waterway transport".* The work of Groothedde (2005) is based on a specific dataset that contains actual data of some 26 million pallet shipments stemming from a distinct number of companies (i.e. at the micro-level). This implies that additional modelling efforts will be required to make this approach suitable for the modelling of intermodal pallet distribution flows at the macro-level (i.e. on the basis of an OD-matrix containing aggregated 'parcel load' shipments), but in my opinion this should be possible.

I expect the GROOTHEDDE model to offer a possible solution for the modelling of advanced intermodal pallet distribution networks. By using the GROOTHEDDE model in addition to one of the previously described models, one should be able to obtain a complete picture of the development of the very long term IWT flows at the network level.

12.5.8 Conclusions with respect to compliance of existing transport models

The assessment of the existing transport models indicates that none of the assessed models meet all the requirements for the development of an advanced very long term IWT model. The assessment confirms that the BASGOED model is not suitable for the development of a very long term transport model. The SMILE+ model could have been an interesting candidate, but is no longer supported by the Dutch government. The TRANS-TOOLS model is presumably not the most suitable option, because it applies unimodal assignment and does not contain a network description for the modelling of intermodal transport flows. However, the fact that it is supported by the European Union, free of intellectual property rights, and covers the broader West European region still makes it worth considering as a possible option. The NODUS model is considered a reasonable candidate, because it supports the modelling of intermodal transport flows and has a relatively clear model structure, for which it is still possible to oversee the complications that can occur during the modelling exercise. The ZHANG model presumably offers the best starting point, as it does not only contain a network description for the available infrastructures, but also a model of the available service networks. The downside of the ZHANG model is however that it has only been developed for containers. It was however understood that it should be possible to upgrade the model in order to include also the modelling of multimodal bulk and break-bulk flows. The structure of the ZHANG model can further be expected to support the development of a module that deals with the possible development of advanced intermodal pallet distribution networks on the inland waterways, which is not the case for the other models. In case the TRANS-TOOLS or NODUS model is applied, an additional model will be required to incorporate the intermodal pallet flows. Such a model can be based on the GROOTHEDDE model.

Despite the fact that I was able to identify a few of possible candidates, there still remain some major challenges that need to be addressed before an advanced very long term transport model can be developed. These challenges relate to the following issues:

- *The availability and quality of the transport data:* There are quite some issues related to the data available for freight transport modelling (see also De Jong et al., 2004[151], and Appendix A). It is for instance of major importance that the base year data provides insight in the real origins and destinations of the freight flows and not only in a single leg of the transport chain. Some issues may have been solved by the ETIS database, but there still remain a number of issues that need to be addressed.
- *The classification of transport data:* I consider the NSTR (customs) classification system insufficient to address the transport characteristics of the freight flows, because it does not allow for a real comparison of the available logistic supply chain options. This problem was addressed in the SMILE+ model by applying 50 logistical families instead of a distinct number of NSTR1 classes. I have also proposed an alternative classification system that can be used in very long term transport models. This system divides the freight flows into: non-containerised bulk, containerised bulk, continental containers and full truck loads, deepsea containers, parcel loads, and packages. Despite the fact that I have been able to convert the input data of the BASGOED model into my new classification system, it is still uncertain if this can also be done with the data that has been applied in other transport models.

[151] De Jong et al. (2004, p.104) indicates that there are problems with the limited availability of data, especially when considering disaggregated data (e.g. due to issues with the confidentiality of the individual flows).

- *The modelling of the IWT infrastructure:* The present approach for modelling IWT flows does not take the limiting effects of the real infrastructure dimensions on the capacity of the inland barges into account. Whereas a simple division into a number of waterway classes and corresponding barge types still provides reasonable results for unimodal bulk flows, I consider it inappropriate for the modelling of container flows and, in particular, for the modelling of continental container flows. I think that, in order to define the cost levels for IWT properly, the transport model should be based on real waterway dimensions, realistic water levels, and realistic barge- and cargo characteristics. It should be possible to developed such a model in the GIS based environments of the NODUS, TRANS-TOOLS, and ZHANG models.
- *The applied barge characteristics:* When a new GIS based system is implemented it makes sense to consider the use of efficient barges for each individual commodity type on each individual waterway route. Efficient barges can be obtained from parametric barge models, that define the capacity and operational cost levels on the basis of parametric input concerning the length, width, height, draft, and speed of the barges. Parametric barge models have recently been developed by Hekkenberg (2013) and were further improved in the cost model of Chapter 10. Parametric barge models allow the user to select a cost effective barge for each waterway route and to define the true cost levels for cost effective barge operations.
- *The modelling of intermodal distribution networks:* The structure of the NODUS and TRANS-TOOLS models does not support the modelling of advanced intermodal pallet distribution networks. The modelling of these flows requires the development of an additional module (or model) on the basis of, for instance, the GROOTHEDDE model. The structure of the ZHANG model is expected to support the modelling of advanced intermodal pallet distribution networks, but still requires a new module to be developed in order to deal with these transport flows.
- *The geographic spread of logistic activities:* The NODUS and ZHANG models only cover the last two steps of the classical transport model. In order to take changes in the geographic spread of logistic activities into account, they should obtain their data from a model that covers the supply side logistics, such as for instance the logistics modules applied in the SMILE+ and TRANS-TOOLS models.
- *The geographic spread of production and consumption areas:* none of the evaluated models is able to take changes in the geographical spread of production and consumption areas into account. New approaches will have to be developed to deal with this aspect in the trip generation stage of the model.

I conclude that there still remain many outstanding issues with the development of an advanced very long term transport model. The most important issues that need to be addressed in order to obtain a workable transport model are presumably: (1) the conversion of the OD-data into a new classification system that reflects the transport characteristics of the freight flows; (2) the development of an improved IWT infrastructure model description; and (3) the development of a new module that covers the expected development of intermodal continental container transport flows, which are mainly shipped in continental 45 foot containers. A fourth issue that can also be addressed in a later stage concerns the development of a module (or model) that covers the possible development of advanced intermodal pallet distribution networks. The development of a workable very long term transport model does however still require a substantial amount of additional research and modelling efforts, that is well beyond the scope of this thesis. I therefore conclude this chapter with a comprehensive research agenda for the further development of the desired very long term transport model.

12.6 Research Agenda

The previous section indicated that the TRANS-TOOLS, NODUS, and ZHANG models may provide a possible starting point for the development of a very long term transport model, but that for each of these models there still remain a substantial number of issues that need to be resolved. This section proposes a comprehensive research agenda for the development of an advanced very long term transport model, as well as for a basic model solution (for which the text is written in *'italics'*) in which only the most critical modelling issues are addressed to obtain a workable very long term transport model. The research agenda starts with a general section that does not relate to any of the existing transport models on which the very long term model solution can be based and continues with three specific model approaches.

General Research (independent of the applied transport model)

- Develop a new GIS based IWT module that can replace the IWT modules in existing transport models such as NODUS, TRANS-TOOLS or ZHANG. This module should take into account the real waterway dimensions (length, width, draft, and air-draft), water levels, effective barge dimensions, cargo characteristics, and preferably also the infrastructure bottlenecks (speed restrictions and waiting as well as service times at bridges and ship locks). *For the basic model solution one can alternatively extend the number of different waterway (sub)classes that are used in the model (e.g. in a similar way as applied in Table 10.1, but then for all relevant types of cargo).*
- Develop a new parametric barge module, that can be used in combination with the GIS based IWT module to define the actual cost levels for cost effective barge operations. *In the basic model solution one can alternatively define a different cost level for each individual waterway subclass and type of commodity (e.g. similar to the approach applied in Table 10.2).*

Option 1: TRANS-TOOLS based approach

- Convert the base year OD-data into my new commodity classification system that has been defined in Chapter 11 and consists of: non-containerised bulk, containerised bulk, deepsea container loads, continental full container and truck loads, continental parcel loads, and small packages.
- Make the trip generation and distribution modules (stage 1 and 2 of the classical four stage transport model) compatible with my new commodity classification system.
- Make the logistical module (that is placed between stage 2 and 3 of the classical four stage transport model) compatible with my new commodity classification system. *This module can be omitted in the basic model solution.*
- Incorporate the new GIS based IWT module in TRANS-TOOLS, to obtain an improved structure for modelling the very long term developments on the inland waterways. *For the basic model solution one can alternatively extend the number of waterway subclasses.*
- Incorporate the new parametric barge module in TRANS-TOOLS, to obtain the actual cost levels for cost effective IWT operations. *In the basic model solution one can also apply a different cost structure for each individual waterway subclass and type of commodity.*
- Make the TRANS-TOOLS model suitable for the modelling of intermodal container transport flows on the inland waterways (including continental container flows).
- Develop an additional module that is able to deal with the possible development of intermodal pallet distribution networks (e.g. based on the GROOTHEDDE model). *In the basic model solution one can consider not to include these flows.*

- Extend the time horizon of the adjusted TRANS-TOOLS model to deal with the very long term developments on the IWT system (following the outline that has been proposed in Chapter 11).

Option 2: NODUS based approach

- Select or develop a trip generation and distribution model from which the OD-input for the NODUS model can be obtained – and adjust this model in such a way that the obtained OD-input data complies with my new commodity classification system (e.g. by adopting the first three steps of the TRANS-TOOLS based approach).
- Incorporate the new OD-input data and GIS based IWT module in NODUS to obtain an improved structure for modelling the very long term transport developments on the inland waterways. *In the basic model solution one can instead of developing a new GIS based IWT module also extend the number of waterway subclasses.*
- Incorporate the new parametric barge module in NODUS, to obtain the actual cost levels for cost effective IWT operations. *In the basic model solution one can also apply a different cost structure for each individual waterway subclass and type of commodity.*
- Make the NODUS model suitable for the modelling of intermodal continental container transport flows on the inland waterways.
- Develop an additional module that is able to deal with the possible development of intermodal pallet distribution networks (e.g. based on the GROOTHEDDE model). *In the basic model solution one can consider not to include these flows.*
- Extend the time horizon of the adjusted NODUS model to deal with the very long term developments on the IWT system (following the outline proposed in Chapter 11).

Option 3: ZHANG based approach

- Select or develop a trip generation and distribution model from which the OD-input for the ZHANG model can be obtained – and adjust this model in such a way that the obtained OD-input data complies with my new commodity classification system (e.g. by adopting the first three steps of the TRANS-TOOLS based approach, or by developing an alternative approach on the basis of, for instance, the 2006 base year data for the Netherlands, for which I expect the data conversion to be possible).
- Incorporate the new OD-input data and GIS based IWT module in the ZHANG model to obtain an improved structure for modelling very long term transport developments on the inland waterways. *In the basic model solution one can instead of developing a new GIS based IWT module also extend the number of waterway subclasses.*
- Incorporate the new parametric barge module in the ZHANG model, to obtain the actual cost levels for cost effective IWT operations. *In the basic model solution one can also apply a different cost structure for each individual waterway subclass and type of commodity.*
- Make the ZHANG model suitable for the multimodal modelling of non-containerised bulk flows (amongst others by adding the terminal locations and required cost data).
- Make the ZHANG model suitable for the modelling of intermodal continental container transport flows on the inland waterways.
- Make the ZHANG model suitable for the modelling of the possible development of intermodal pallet distribution networks on the inland waterways. *In the basic model solution one can consider not to include these flows.*
- Extend the time horizon of the adjusted ZHANG model to deal with the very long term developments on the IWT system (following the outline proposed in Chapter 11).

In addition to the modelling options presented in the research agenda it is of course also possible to develop a completely new model, for instance by combining various parts of existing transport models into a model that is intended to comply as much as possible with the requirements for the modelling of very long term transport developments.

12.7 Concluding Summary

This chapter addresses the fourth methodological sub question (MSQ 4): *"What are the options to make efficient use of an existing long term transport model for the implementation of the proposed model structure – and where will additional modelling and/or research efforts be required to obtain a workable model?"*. It first examines the options to develop the proposed very long term transport model on the basis of an existing transport model, and then continues with a research agenda for the further development of the desired model approach.

12.7.1 Options to make efficient use of an existing long term transport model

I initially aimed to develop the desired very long term transport model by undertaking the following steps: (1) start with the conversion of the base year data into a new commodity classification that reflects the characteristics of the transported goods; (2) apply this dataset to an adjusted version of an existing long term transport model; and (3) make the transport model suitable for taking the aggregated very long term trends, that are based on foresight, into account. Prior to the execution of these steps I had to select an existing transport model on which the very long term transport model could be based. Because this PhD project is executed on behalf of Rijkswaterstaat I considered it desirable to base the very long term model on the in-house BASGOED model of Rijkswaterstaat.

I managed to address the first step by converting the 'base year 2004 data files' (i.e. those applied in the BASGOED model) into the new classification system that was proposed in Chapter 11. However, in the second step I had to conclude that the BASGOED model is not suitable to serve as a basis for the development of a very long term transport model. I therefore studied the alternative options to develop a very long term transport model on the basis of an existing transport model, that also covers the transport flows on the Dutch national territory. To this end I assessed the compliance of the SMILE+, NODUS, TRANS-TOOLS, ZHANG, and GROOTHEDDE models with a predefined set of requirements for the development of an advanced very long term transport model.

On the basis of this assessment I conclude that none of the existing transport models meet all the requirements that I consider necessary for the development of a very long term transport model. Even for a basic model approach, in which only the most critical modelling issues are solved to obtain a workable very long term transport model, still a considerable amount of additional research and modelling efforts will be required. The most relevant issues that need to be addressed in order to obtain a workable model are: (1) the conversion of the OD-data into a new classification system that reflects the transport characteristics of the freight flows; (2) the development of an improved IWT infrastructure model description; and (3) the development of a new module that covers the expected development of intermodal continental container transport flows, which are mainly shipped in continental 45 foot containers. A fourth issue that can also be addressed in a later stage concerns the development of a module (or model) that covers the possible development of advanced intermodal pallet distribution networks. The development of a workable very long term transport model does still require a substantial amount of additional research and modelling efforts, that is well beyond the scope of this thesis. I have therefore concluded this chapter with a research agenda for the further development of the desired very long term transport model.

12.7.2 Research agenda for development of a very long term transport model

The development of a very long term transport model is still a major challenge. There are many outstanding modelling issues that need to be addressed. I have therefore proposed a comprehensive research agenda for the further development of an advanced very long term transport model, as well as for a basic model solution in which only the most critical modelling issues are solved. This research agenda starts with a general section, that does not relate to any of the existing transport models on which the very long term model solution can be based and continues with three specific options that relate to the use of the TRANS-TOOLS, NODUS, and ZHANG models.

The general research section concerns the development of: (1) a new GIS based module, that defines the characteristics of the selected waterway route by taking into account the real waterway dimensions (length, width, draft, and air-draft), water levels, effective barge dimensions, cargo characteristics, and preferably also the infrastructure bottlenecks (speed restrictions and waiting as well as service times at bridges and ship locks); and (2) a new parametric barge model, that can be used in combination with the new GIS based IWT module to define the actual cost levels for cost effective IWT operations. Once developed these two new modules can replace the present modelling approach that is used in for instance the TRANS-TOOLS, NODUS, and ZHANG models.

The first model option relates to the use of the TRANS-TOOLS model. This option has the benefit that the model covers all four stages of the classical transport model, covers the entire European continent, and is free of intellectual property rights. The downside is however that it applies unimodal assignment of freight flows and is therefore not suitable for dealing with intermodal transport flows, while these flows need to be taken into account. The TRANS-TOOLS model is also unable to cover the possible development of intermodal pallet distribution networks. To include these potential flows an additional transport model (or module) will be required, that can be based on the GROOTHEDDE model.

The second option relates to the use of the NODUS model. The NODUS model has the benefit that the structure of the model is able to deal with intermodal container transport. The downside of the NODUS model is that it covers only the last two stages of the classical four stage transport model, and that it is unable to cover the possible development of intermodal pallet distribution networks. To include these potential flows an additional transport model (or module) will be required, that can be based on the GROOTHEDDE model.

The third option relates to the use of the ZHANG model. The benefit of this model is that it does not only contain a module that describes the available infrastructures, but also a module that defines the service network. This implies that the ZHANG model can also be used for the modelling of advanced intermodal pallet distribution networks on the inland waterways. The downside is however that the model covers only the last two stages of the classical four stage transport model and that it has only been developed for containers.

Though not explicitly stated the above options require substantial changes to the applied model structure, including: the conversion of the OD-data and projections into a new classification system that reflects the transport characteristics of the freight transport flows; the development of a new module that deals with the development of intermodal continental container transport flows; and possibly also the development of an new module that covers the development of advanced intermodal pallet distribution networks.

12.7.3 Answer to Methodological Sub Question 4

In answer to MSQ 4, I conclude that a workable very long term transport model can be developed by applying the following steps: (1) start with the conversion of the base year data into a new commodity classification system that reflects the characteristics of the transported goods; (2) apply this dataset to an adjusted version of an existing long term transport model; and (3) make the transport model suitable for taking the aggregated very long term trends, that are based on foresight, into account.

I initially intended to apply this approach to the BASGOED model that is owned by Rijkswaterstaat, but I had to conclude that the BASGOED model does not provide a suitable starting point for the development of a very long term transport model. I therefore studied the alternative options to develop a very long term transport model on the basis of an existing transport model, that also covers the transport flows on the Dutch national territory. A few alternative modelling options were identified, but none of the existing transport models seems to comply with the basic requirements for the development of a very long term transport model. For this reason I concluded the modelling section with a comprehensive research agenda that indicates how the desired very long term transport model can be developed on the basis of the TRANS-TOOLS, NODUS, or ZHANG models in combination with the GROOTHEDDE model. The development of a workable very long term transport model does however still require a considerable amount of additional research and modelling efforts that is well beyond the scope of this thesis.

Literature:

Beuthe, M., B. Jourquin, J. -F. Geerts, and C. Koul à Ndjang'Ha (2001) Freight transportation demand elasticities: a geographic multimodal transportation network analysis, Transportation Research Part E, vol. 37, no. 4, pp. 253-266.

Bovenkerk, M. (2005) *SMILE+: the new and improved Dutch national freight model system*, Abstract of paper presented at the European transport conference, Strasbourg.

Burgess, A., T.M. Chen, M. Snelder, N. Schneekloth, A. Korzhenvych, E. Szimba, M. Kraft, M. Krail, O. Nielsen, C. Hansen, A. Martino, D. Fiorello, and P. Christidis (2008) *Final Report TRANS-TOLLS (TOOLS for TRansport forecasting ANd Scenario testing) Deliverable 6. Funded by 6th Framework RTD Programme. TNO Inro, Delft, The Netherlands.*

Chen, M. (2011) *ETIS and TRANS-TOOLS v1 freight demand.* Presentation at the CTS-seminar on European and national freight demand models, Stockholm.

De Ceuster, G., T. Voge, M. Chen, M. de Kievit, J. Laird, A. Koh, C. Sessa, R. Enei, and R. Mascellaro (2010) *Trans-European transport network planning methodology*, Transport & Mobility Leuven, commissioned by European Commission, DG MOVE.

De Jong, G., H. Gunn, and W. Walker (2004) *National and International Freight Transport Models: An Overview and Ideas for Future Development*, Transport Reviews, vol. 24, no. 1, pp. 103-124.

De Jong, G., H. Gunn, and RAND Europe (2003) *A Meta-Model for Passenger Transport in Europe, Integrating Existing Models*, European Transport Conference 2003.

De Jong, G., M. de Bok, K. Ruijs, D. Wentink, A. Burgers, M. de Gier, R. Versteegh, P. Grashoff (2010a) *Schatting BASGOED, rapportage DP1*, Significance, Den Haag.

De Jong, G., M. de Bok, J. Baak, A. Burgess, M. De Gier, P. Grashoff (2010b) Systeem- en gebruiks documentatie MS en DM BasGoed, rapportage DP2, Significance, Den Haag.

De Jong, G., I. Vierth, L. Tavasszy, and M. Ben-Akiva (2013) *Recent Developments in national and international freight transport models within Europe*, Transportation, vol. 40, no. 2, pp. 347-371.

European Commission (2011) White Paper on transport, roadmap to a single European transport area – towards a competitive and resource-efficient transport system, Office for Official Publications of the European Communities, Luxembourg.

Fowkes, T., and J. Toner (1998) *Freight Mode/Route Choice Modelling with Limited Data*, in Transportation Planning Methods Vol. II, European Transport Conference 1998.

Geerts, J., and B. Jourquin (2001) *Freight Transportation Planning on the European Multimodal Network, The case of the Walloon region*, European Journal of Transport Infrastructure Research, vol. 1, no. 1, pp. 91-106.

Groothedde, B. (2005) *Collaborative logistics and transportation networks, a modelling approach to hub network design*, Trail Research School, Delft.

Groothedde, B., C. Ruijgrok, and L. Tavasszy (2005) *Towards collaborative, intermodal hub networks. A case study in the fast moving consumer goods market*. Transportation Research Part E, vol. 41, no. 6, pp. 567-583.

Hansen, C.O. (2011) *Trans-tools version 2.* Presentation at the CTS-seminar on European and national freight demand models, Stockholm, Sweden.

Jonkeren, O., B. Jourquin, P. Rietveld (2011) *Modal-split effects on climate change: The effect of low water levels on the competitive position of inland waterway transport in the river Rhine area*. Transportation Research Part A, vol. 45, no. 10, pp. 1007-1019.

Jourquin, B., and M. Beute (1996) *Transportation policy analysis with a geographic information system: The virtual network of freight transportation in Europe*, Transportation Research Part C, vol. 4, no. 6, pp. 359-371.

Limbourg, S., and B. Jourquin (2009) *Optimal rail-road container terminal locations on the European network*, Transportation Research Part E, vol. 45, no. 4, pp. 551-563.

NEA (2007a) *Basisbestanden Goederenvervoer 2004, Binnenvaartmatrix*. NEA, Rijswijk. Commissioned by Ministerie van Verkeer en Waterstaat, AVV.

NEA (2007b) *Basisbestanden Goederenvervoer 2004, Spoormatrix*. NEA, Rijswijk. Commissioned by Ministerie van Verkeer en Waterstaat, AVV.

NEA (2007c) *Basisbestanden Goederenvervoer 2004, Wegmatrix Totaal*. NEA, Rijswijk. Commissioned by Ministerie van Verkeer en Waterstaat, AVV.

Pekin, E., C. Macharis, A. Caris, G.K. Janssens, T. Crépin, and B. Jourquin (2007) *Integrated Decision Support Tool for Intermodal Freight Transport*, Vrije Universiteit Brussel, Universiteit Hasselt and Les Faculte´s Universitaires Catholiques de Mons, Brussels.

Petersen, M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, A. Ulied (2009) *TRANSvisions: Report on Transport Scenarios with a 20 and 40 year Horizon, Final Report,* Funded by DG TREN, Copenhagen, Denmark.

Rich J., J. Bröker, C.O. Hansen, A. Korchenwych, O.A. Nielsen, and G. Vuk (2009) *Report on Scenario, Traffic Forecast and Analysis of Traffic on the TEN-T, taking into Consideration* *the External Dimension of the Union – TRANS-TOOLS version 2; Model and Data Improvements, Funded by DG TREN, Copenhagen, Denmark.*

Significance, NEA, and DEMIS (2010) *Schatting BASGOED, Rapportage DP1*, A Report for DVS-Rijkswaterstaat, Significance, The Hague.

Tavasszy, L.A. , B. Smeenk, and C.J. Ruijgrok (1998) *A DSS For Modelling Logistic Chains in Freight Transport Policy Analysis*, International Transactions in Operational Research, vol. 5, no. 6, pp. 447-459.

Tavasszy, L.A. (2011) *Freight modelling and policy analysis in the Netherlands*. Presentation at the CTS-seminar on European and national freight demand models, Stockholm.

Tavasszy, L.A., K. Ruijgrok, and I. Davydenko (2012) Incorporating logistics in freight transportation models: state of the art and research opportunities. Transport Reviews, DOI:10.1080/01441647.2011.644640, pp. 1-17.

Tetraplan (2009) *TENCONNECT*, Tetraplan A/S, Copenhagen.

TNO (2008) *TRANS-TOOLS, Deliverable 6: TRANS-TOOLS Final Report, WP 6*, TNO Inro, Delft, The Netherlands.

Zhang, M. (2013) *A Freight Transport Model for Integrated Network Service, and Policy Design*, TRAIL, Delft, The Netherlands.

Websites:

OmniTRANS (accessed: 2012) *BASGOED model*, [www.omnitrans-international.com/en/products/omnitrans/recent-studies/basgoed-the-dutch-national-freight-model]

Rijkswaterstaat (accessed: 2012) *BASGOED model*, [www.rijkswaterstaat.nl/kenniscentrum/economische_evaluatie/nieuwsbrieven/december_2011/basgoed.aspx]

TRANS-TOOLS 3 (accessed: 2014) *TRANS-TOOLS 3 model*, [www.transtools3.eu]

13 Shipping Scenarios for Delta Programme

"A living land builds for its future."
- Delta Committee (2008)

13.1 Introduction

The evaluation of policies with a very long term impact on the IWT system requires insight in the possible development of the system itself. These insights can be obtained from a deductive set of storyline scenarios (see Chapter 5). This chapter addresses the fifth methodological sub-question (MSQ 5): *"What would be a plausible set of qualitative storyline scenarios for the very long term development of freight transport on the inland waterways?"*. It shows how I developed a plausible set of story line scenarios on the basis of the insights that were obtained in the previous chapters of this thesis.

The story line scenarios that are presented in this chapter were not only developed to address the primary objective of this thesis (see Chapter 1), but also served as input for the official very long term Delta Scenarios of the Dutch government up to the year 2100 (Bruggeman et al., 2013). In September 2012 I received a request to contribute to the development of the shipping section of the Delta Scenarios, for which hardly anything had been put on paper at that time. I responded with a comprehensive background document (Van Dorsser, 2012), of which the primary objective was to make the insights of this thesis available to the Delta Programme. This document contained a discussion on the main drivers as well as a full set of qualitative and quantitative scenarios, that reflect the possible development of the transport volumes in the sea ports and on the inland waterways from my perspective.

By providing the background documentation for the shipping section of the Delta Scenarios my work became part of a larger scenario study that was conducted by Deltares on behalf the Ministry of Infrastructure and Environment, and Rijkswaterstaat. Within this project experts from various organisations provided input for the development of four Delta Scenarios that are named BUSY, STEAM, REST, and WARM. To ensure that the individual contributions resulted in a consistent storyline several meetings and bilateral discussions were held between the experts of the various organisations. I also participated in some of these meetings and had several conversations with Mr. Bruggeman and Mr. Van der Wekken (responsible project managers at Deltares and Rijkswaterstaat), as well as with a number of other experts within Rijkswaterstaat, the Ministry of Infrastructure and Environment, the PBL Netherlands Environmental Assessment Agency, and the Port of Rotterdam Authority. The list of consulted experts is provided in Appendix E.

Parts of my work were already reviewed and/or commented on during the execution of the assignment. In addition a specific review session was held after the completion of the draft report (Van Dorsser, 2012); in which experts of Deltares, Rijkswaterstaat, the Ministry of Infrastructure and Environment, and the Port of Rotterdam Authority commented on the results. Some further comments were also obtained by e-mail from experts that were unable to attend the meeting. After addressing the comments my contribution was fully incorporated into the shipping section of the broader Delta Scenario report of Bruggeman et al. (2013).

The aim of the broader Delta Scenario study was to explore the outer corners of plausible future developments on the requirements of the water system from the perspective of the various stakeholders. To this end it mainly took into account the combined effects of socio-economic developments and climate change on: the natural and built environment; the river discharge volumes, sea level rise, and safety against flooding; the availability of sufficient clean fresh water for consumption and agricultural purposes; the availability of sufficient fresh water for industrial production and cooling of power plants; and the effects on seagoing- and inland shipping (Bruggeman et al., 2013). My contribution only concerned the shipping part of the broader Delta Scenario study.

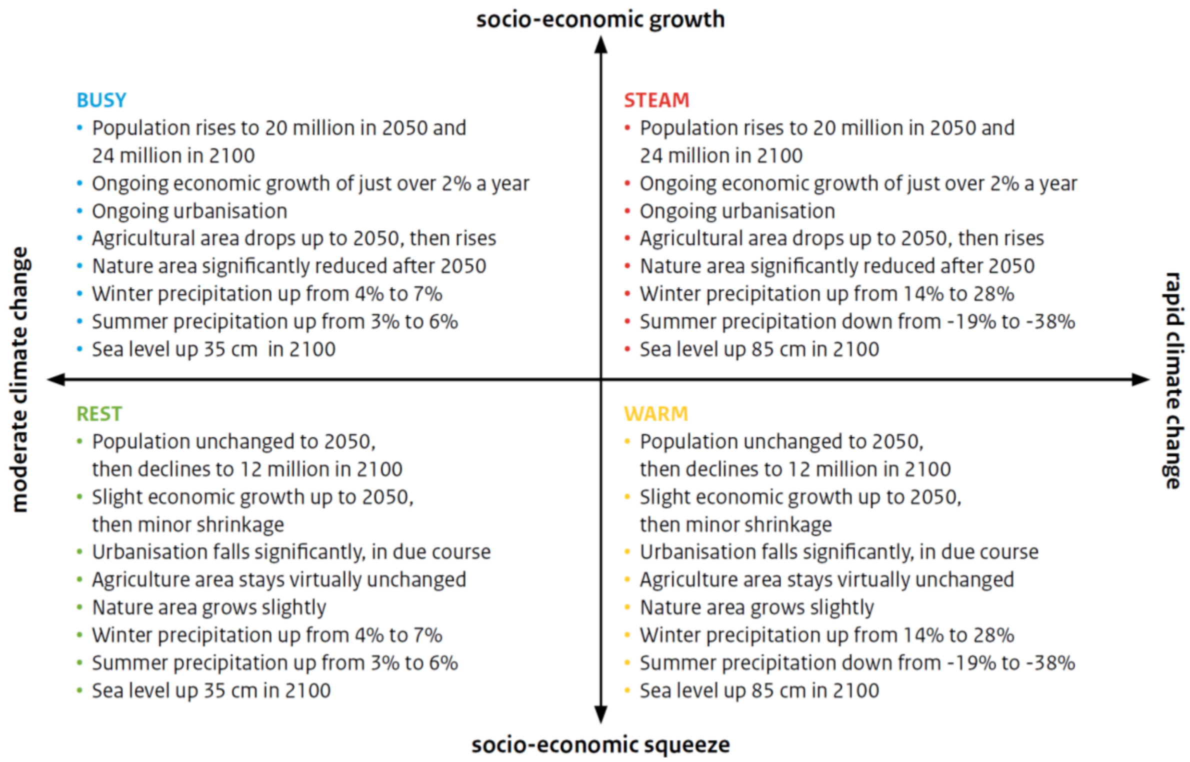
This chapter provides a discussion on the qualitative part of the shipping scenarios for the Delta programme (the quantification of the scenarios follows in Chapter 14). It provides the storyline for the four official shipping scenarios, that were developed in the framework of the broader Delta Scenario study – as well as two additional scenarios, that I added to the four official scenarios because I consider them more appropriate for the exploration of the outer corners of plausible future developments. Section 13.2 discusses the key drivers along which I developed the shipping scenarios; Section 13.3 provides a brief outline of the storyline for each of the scenarios; Section 13.4 continues with a full description of the very long term shipping scenarios; Section 13.5 addresses a few further considerations with respect to the development of the scenarios; and Section 13.6 finally contains a concluding summary that provides an answer to MSQ 5.

13.2 Defining the Key Drivers for the Shipping Scenarios

To gain insight in the outer corners of plausible future developments the four official Delta Scenarios were developed around four quadrants that are created by the intersection of the axes of two key drivers, being: (1) socio-economic developments; and (2) effects of climate change. Though I agree that these four quadrants provide a reasonable starting point for the exploration of plausible future developments, I think a third driver should have been added. This driver relates to the speed of the global transition towards a more sustainable society, that will also have its implications at the European and national policy level. This section discusses the three key drivers that were taken into account for the development of the very long term shipping scenarios, of which the first two drivers are similar to those applied in the broader Delta Scenario study, and the third driver was added thereto.

13.2.1 The two key drivers that were applied in the broader Delta Scenario study

The two key drivers that were applied in the broader Delta Scenario study are linked to other scenarios that were already available for the Netherlands. The level of economic growth is linked to the Global Economy (GE) and Regional Communities (RC) scenarios of the WLO-scenario study (see Chapter 3), for which the time horizon was extended. The effects of climate change are linked to the moderate (G) and extreme (W+) KNMI’06 scenarios that were available for a period up to the year 2100 (see Chapter 9). Figure 13-1 shows how the four official Delta Scenarios are framed around the axes of these two key drivers.



Source: Delta Committee (2012, p.35).

Figure 13-1: The two Key Drivers that were applied in the four Delta Scenarios

13.2.2 The three key drivers that were applied for the Shipping Scenarios

Prior to the development of the shipping scenarios I first assessed how well the primary drivers of the transport system (for sea and inland waterway transport) are covered by the two key drivers that were applied in the broader Delta Scenario study. I concluded, on the basis of the insights obtained in Chapter 7 to 10, that the most important drivers for the throughput volumes in the Dutch seaports as well as the transport volumes on the Dutch inland waterways should be related to:

1. The overall development of the aggregated demand for freight transport in Western Europe (see Chapter 7);
2. The development of the availability and quality of the West European IWT network (see Chapter 8 and 9); and
3. The development of the relative competitiveness and market share of IWT in the total transport system (see Chapter 10).

Chapter 7 made clear that there exists a very strong causal relation between the level of economic output and the level of transport. The development of the overall transport volumes can therefore be expected to be sufficiently covered by the first socio-economic key driver that is applied in the broader Delta Scenario study.

Chapter 8 and 9 indicated that the availability and quality of the West European IWT network can be regarded as a function of: (1) the extent to which climate change has an adverse effect on the navigability of the inland waterways; and (2) the extent to which the societal aim to become sustainable fosters new investments in an upgrade of the IWT infrastructure. The first aspect can be related to the climate change key driver of the broader Delta Scenario study, but for the second aspect the two key drivers of the broader Delta Scenarios study provide no explicit guidance. This dimension can therefore not be sufficiently explored.

Chapter 10 showed that the relative competitiveness and market share of IWT depends on a broad range of factors that I consider too detailed to be forecasted at a very long time horizon. This does not only hold for the primary cost factors, but also for the many local, national, and European policies that may be imposed to enhance a shift from unimodal road transport towards more sustainable modes of transport. Given the large impact that such measures can have on the IWT system, I consider it sensible to link the competitiveness of IWT to the extent in which our West-European society aims to become sustainable.

I therefore conclude that the outer corners of plausible future developments should be explored along the lines of the following three key drivers:

1. Socio-economic developments (low or high economic output scenarios);
2. Effects of climate change (moderate or rapid climate change);
3. Transition towards a sustainable society (slow or swift transition).

The first two key drivers are similar to those applied in the broader Delta Scenario study. I added the third key driver, that reflects the transition towards a more sustainable society. Each of these three key divers will have a different effect on shipping. The main implications of these key drivers for the development of the shipping scenarios are indicated below:

Key driver 1: Socio-economic developments

The first key driver is related to the size and composition of the (working) population as well as the development of labour productivity and overall economic output. Given the direct relation between *'economic output'* and the *'total demand for freight transport'* I regard socio-economic developments as the main driver for the development of the total port throughput and inland transport volumes (see Chapter 7).

Key driver 2: Climate change

The second key driver has a direct effect on: (1) the safety against flooding; (2) the availability of sufficient fresh water; and (3) the navigability of the inland waterways. In case of extreme climate change one can no longer expect all year round navigation to be sustained on free flowing rivers towards the end of the 21st century, in particular not on the upper rhine. According to the discussion of the W+ scenario for the year 2100 the barge utilisation will drop to just about 30% on the main stretch up to Ruhrort at the average water levels in the period from July to October – and sailing further upstream the Rhine will no longer be feasible with the standard West-European barges that are presently applied (see Chapter 9).

Key driver 3: Transition towards a more sustainable society

The third key driver has major effects on the way humanity shapes its future world (see Chapter 4). Most appealing is probably the sustainable energy transition, that will affect the costs of fuel and the composition of the freight flows that are shipped via the ports and inland waterways. One can further expect a reduction in the environmental footprint, a reduction in the use of materials, an increased recycling of materials, and a shift towards locally produced (e.g. bio-based) materials (see also Van den Akker et al., 2013). These developments are likely to result in the use of smaller more localised production facilities that require less freight transport. The global transition towards a more sustainable world is further expected to foster intermodal transport at the European and national levels (see Chapter 8 and 10). This increases the volumes that are shipped by means of IWT and short sea shipping – and thereby strengthens the relative position of the Dutch and Belgium seaports.

13.3 Outline of the Very Long Term Shipping Scenarios

From the available documentation on the broader Delta Scenarios (Bruggeman et al., 2013) I conclude that the transition towards a more sustainable society has been taken into account implicitly. Figure 13-2 shows the positioning of the four official Delta Scenarios amongst the axes of the three key drivers that I applied for the development of the shipping scenarios.

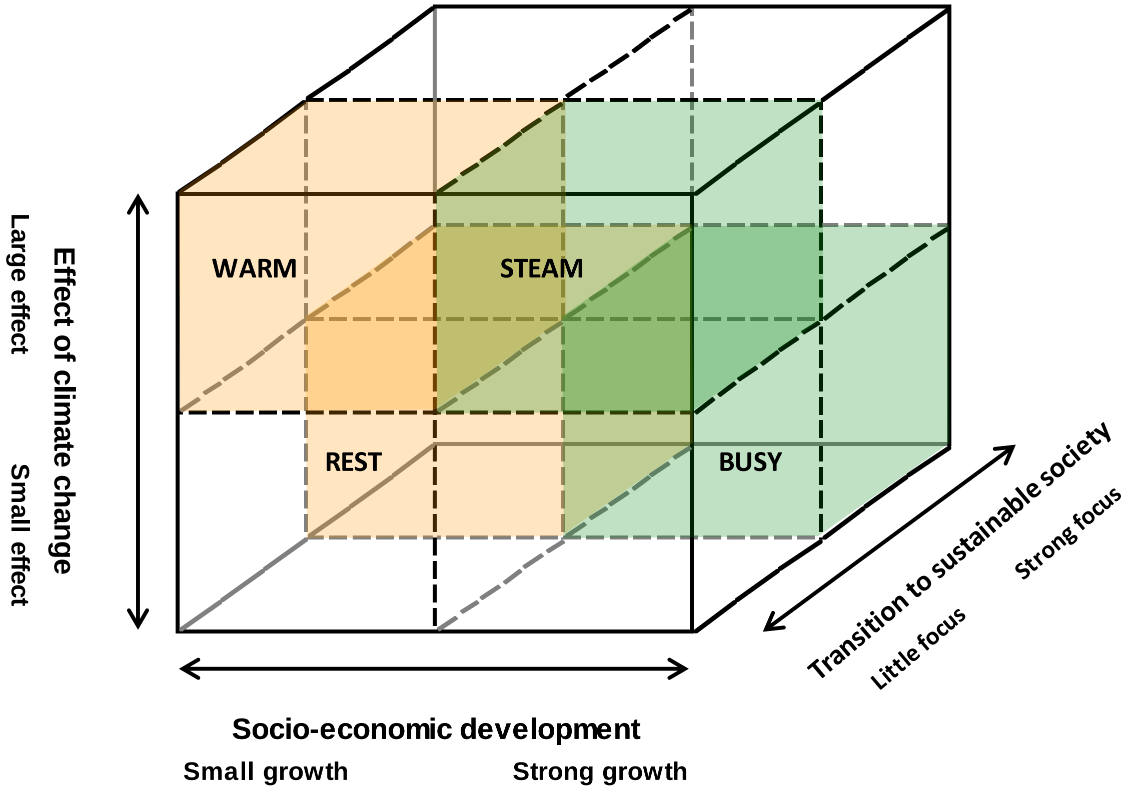


Figure 13-2: Positioning of the four official Delta Scenarios

The broader Delta Scenario study assumes a one way causal relation between the extent to which the global society becomes sustainable and the degree of climate change. In each of the scenarios it was implicitly assumed that rapid climate change can still be avoided if a swift transition towards a highly sustainable society is made. In line with this assumption I drafted the following outline for the storyline of the four official shipping scenarios, in which the *'italic'* phrases refer to the shipping section of these scenarios:

1. **BUSY:** Strong economic growth; successful transition towards a sustainable society; and moderate effects of climate change. The transition towards a sustainable society worked out very well. Sustainable technologies have become a strong pillar of the economy. The many efforts to reduce the level of greenhouse gasses in the atmosphere worked out well and only moderate changes to the climate have occurred. *As a result the river Rhine is still able to serve as a major transport corridor for the ever growing transport volumes to the German hinterland. The growing container volumes have resulted in a dense inland terminal network (for barge and rail transport) by the year 2020. This network enhances the full scale development of intermodal continental container barge transport. The successful development of continental IWT raises a strong political focus on: the development of waterborne business areas; the upgrade of the smaller waterways; and the construction of missing links (such as the Twente –*

Mittelland Canal). By the year 2050 many companies have shifted their operations to the waterfront. This considerably reduces the pre- and end-haulage costs for intermodal barge transport and sparks the development of intermodal pallet distribution networks in the second half of the century.

2. **STEAM:** Strong economic growth; failed transition towards a sustainable society; and large effects of climate change. In response to the very high level of economic growth, in combination with an absent societal focus on sustainability, large effects of climate change are inevitable. *The lack of interest for sustainability also affects the transport system. Where necessary investments are made to mitigate the effects of climate change on flooding of the Rhine, but hardly any efforts are made to improve the conditions for inland navigation. In response the river Rhine becomes unnavigable for several months of the year (mainly from July to October). There is no political will to upgrade the smaller waterways and only a small number of new waterborne business areas is developed. The large growth of the overall transport volumes does however foster a moderate modal shift of some continental cargoes towards intermodal IWT, in particular on the routes where IWT offers significant cost reductions.*

3. **REST:** Low economic growth; successful transition towards a sustainable society; and moderate effects of climate change. As a result of low global economic growth and a successful transition towards a sustainable global society the effects of climate change are still quite moderate. *The moderate effects of climate change imply that the free flowing rivers remain all year round navigable. The focus on sustainable development enhances some upgrades of the larger national and international inland waterways. There occurs a moderate shift of logistics activities towards new waterborne business areas, that also fosters the use of IWT. The improved conditions for IWT enables the development of some intermodal continental container transport flows, as well as some intermodal pallet distribution networks in the second half of the 21st century.*

4. **WARM:** Low economic growth; failed transition towards a sustainable society; and large effects of climate change. As a consequence of the poor economic climate there are no means available to shape a more sustainable society. The world continues to emit too much greenhouse gasses and becomes subject to rapid climate change. *Little efforts are put into an upgrade of the IWT network. Some efforts are made to reduce the risks of flooding in urban areas along the free flowing rivers, but no efforts are made to keep these rivers navigable. As a result the river Rhine becomes unnavigable for several months of the year (mainly from July to October). Due to the miserable condition of the IWT system intermodal continental container transport has no chance to develop. Inland container barge transport therefore loses market share.*

Despite the fact that the link between a successful transition towards a sustainable society and the avoidance of rapid climate change is in itself plausible, I question if it is the most logical choice. I argue that the inertia of the processes of climate change are much slower than those related to the transition towards a more sustainable society. In that respect I would not be surprised if mankind only has a fair chance to avoid rapid climate change in case of low economic output and a very strong focus on sustainable development. In case of high economic output I would be more inclined to apply the inverse causal relation, namely that the inevitable rapid change of the climate causes a strong focus on sustainability. In that case the high levels of economic growth will enable large investments in sustainable technologies to avoid the effects of climate change to become even worse. On the other hand it may still turn out that the effects of climate change remain quite moderate despite a large ongoing emission of greenhouse gasses[152]. I have therefore proposed an alternative set of climate change scenarios that is indicated in Figure 13-3.

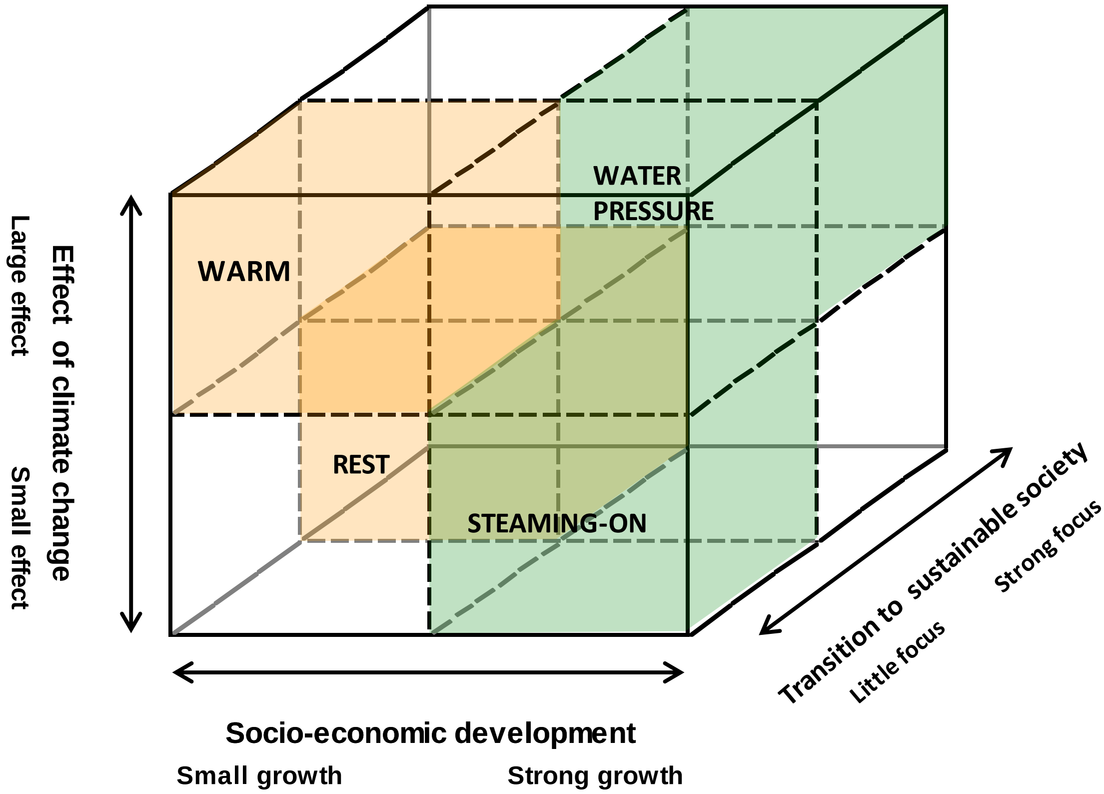


Figure 13-3: Positioning of the alternative set of Delta Scenarios

I argue that this alternative approach, in which scenarios are no longer placed in adjacent fields, is better able to explore the outer corners of possible future developments. In addition I also consider the storyline more credible, because it acknowledges the fact that the inertia of climate change is much larger than the inertia of the transition towards a more sustainable society. I would have preferred to use the 'STEAMING-ON' and 'WATER-PRESSURE' scenarios instead of the present 'STEAM' and 'BUSY' scenarios, but this was not possible, because the shipping scenarios were developed as a contribution to the four official Delta Scenarios. For this reason I have added the 'STEAMING-ON' and 'WATER-PRESSURE' scenarios as a sensitivity analysis to the four official Delta Scenarios.

The name 'STEAMING-ON' relates to ongoing unsustainable economic growth (keep the 'old economy' running) in combination with a rising global temperature (steam is hot). The name 'WATER-PRESSURE' relates to sea level rise in combination with a high pressure on the environment stemming from economic growth. With respect to the latter scenario it is worth mentioning that the related 'BUSY' scenario could have also been referred to as the 'PRESSURE' scenario as both words are a valid translation of the Dutch word 'DRUK'. The outline of the 'STEAMING-ON' and 'WATER-PRESSURE' scenarios is drafted as follows:

[152] Though according to the latest IPCC (2013) report this option is becoming less likely now.

5. **STEAMING-ON:** Strong economic growth; failed transition towards a sustainable society; and moderate effects of climate change. Despite high economic growth and an absent focus on sustainability no major effects of climate change occur. *The river Rhine remains navigable and serves well for the transport of large bulk shipments and intercontinental deepsea containers towards the German hinterland. There is not much societal interest to reduce the carbon footprint by developing intermodal barge transport services. Little investments are made in an expansion and upgrade of the smaller inland waterways. Logistics companies primarily rely on road transport, but still some intermodal continental container transport flows are developed due to the strong growth of the overall transport volumes, in particular on the routes where economies of scale from IWT offer significant cost reductions.*

6. **WATER-PRESSURE:** Strong economic growth; successful transition towards a sustainable society; and large effects of climate change. The substantial change of our global climate system results in a strong societal and political drive to invest in sustainable technologies and infrastructures. *This fosters a strong shift towards the development of intermodal continental barge transport. Heavy investments are made to upgrade the (smaller) waterways and construct the missing links (such as the Twente – Mittelland Canal). The Rhine and Gelderse IJssel are fully canalised to mitigate the negative effects of climate change on inland shipping. This improves the navigability compared to the situation at the beginning of the 21th century. The strong focus on sustainable IWT also enhances many companies to relocate their logistic activities. By the year 2050 many companies have shifted their operations to the waterfront. This reduces the pre- and end-haulage costs and sparks the development of intermodal pallet distribution networks throughout the second half of the century.*

13.4 Description of the Very Long Term Shipping Scenarios

The previous section drafted an outline of the four official Delta Scenarios as well as the two additional scenarios, that were added in order to widen the view on the possible very long term development of the IWT system. This section continues with a further elaboration on these scenarios, that is mainly based on the insights that were obtained in the previous chapters of this thesis. The elaboration includes a discussion on the perceived development of the fuel and energy system; the perceived throughput volumes shipped via the seaports; and the perceived development of the IWT volumes. The discussion on the fuel and energy system was included because this system has a major impact on shipping. Other issues such as land use and fresh water supply have not been discussed in detail because they are not that important to shipping. Apart from some minor corrections the text is similar to that reported by Van Dorsser (2012, in Dutch); which is based on the preliminary insights of Chapter 2 to 12, for which most of the research was already completed by the time I wrote the report. The level of detail in the scenarios is limited to the type and size of the transport flows. No efforts were made to define the specific characteristics of the applied barges, because such insights are hard to obtain and have not been addressed in this thesis. This section first provides a list of the main properties of the six different shipping scenarios and then continues with a detailed discussion on each individual scenario.

13.4.1 Main properties of the very long term shipping scenarios

Table 13-1 indicates the main properties of the four official Delta Scenarios as well as the two additional scenarios that were added as a sensitivity analysis. The table includes items that were taken from the background documents of the broader Delta Scenarios as well as items that I added for the shipping section. My contribution is written in *'italics'*.

Table 13-1a: Summary of the Transport Scenarios

SUBJECT	BUSY	STEAM
Population and economic growth	• Strong global and national economic growth. • Number of inhabitants increases to 20 million in the year 2050 and 24 million in the year 2100.	• Strong global and national economic growth. • Number of Dutch inhabitants increases to 20 million in the year 2050 and 24 million in the year 2100.
Effect of climate change	• Moderate global climate change. • Moderate climate change in the Netherlands. • Winter precipitation increases by 4 to 7 percent. • Summer precipitation increases by 3 tot 6 percent. • Sea level rise of 35 cm in the year 2100. • Little changes in river discharge.	• Substantial global climate change. • Substantial climate change in the Netherlands. • Winter precipitation increases by 14 to 28 percent. • Summer precipitation decreases by 19 to 38 percent. • Sea level rise of 85 cm in the year 2100. • Major changes in river discharge.
Transition towards a sustainable society and transport system	• *Strong global drive for the transition towards a sustainable society and transport system.* • Swift global energy transition. • *Swift greening of the transport system.* • *IWT succeeds to considerably reduce its emission levels compared to road and rail transport.*	• *Economy based on unrestrained exploitation of raw materials and fossil fuels.* • Late moderate global energy transition. • *Little interest in greening of the transport system. Some interest in intermodal transport to reduce transport cost.* • *Little interest for greening of the IWT system.*
Energy and fuel	• *Large scale transition towards a sustainable European energy infrastructure.* • *Strong focus on energy- and fuel reduction.* • *Up to the year 2050 freight transport (road, rail, short-sea and IWT) increasingly adopts second generation bio-fuels and LNG. From the year 2050 onwards a full shift towards more sustainable third generation bio-fuels (e.g. algae-fuels), hydrogen and solar-fuels takes place.*	• *Greening of the European energy infrastructure does not take place.* • *Limited focus on energy- and fuel reduction.* • *Up to the year 2050 little changes in the applied fuel for goods transport take place, from 2050 onwards oil becomes relatively scarce and the transport system therefore shifts to LNG (in particular shale gas).*
Spatial developments	• Strong ongoing but compact urbanisation. • Initial decrease of agricultural land, increase after 2050. • Nature areas significant reduced after 2050. • *Large scale redevelopment of waterborne business areas construction of new quays for IWT.*	• Strong ongoing area intensive urbanisation. • Initial decrease of agricultural land, increase after 2050. • Nature areas significant reduced after 2050. • *Limited reduction of waterborne business areas. On the one hand conversion of existing sites into real estate, on the other hand preservation of quays to serve the increased IWT volumes, refurbishment of existing quays.*
Water system	• Large issues with safety against flooding. • Large issues with fresh water supply.	• Very large issues with safety against flooding. • Very large issues with fresh water supply.
Transport demand	• *Ongoing growth of total transport demand throughout the entire period up to the year 2100.*	• *Ongoing growth of total transport demand throughout the entire period up to the year 2100.*
Development of European transport infrastructures	• *Strong focus on strengthening of European transport infrastructure with emphasis on the more sustainable networks (rail, short-sea-shipping, and IWT).* • *Large scale upgrade of the European IWT network to support the efficient transport of continental 45' high-cube pallet-wide containers.* • *Large scale extension of the European IWT network.*	• *Some focus on strengthening the European rail, short-sea, and IWT infrastructure to manage the increased transport volumes in a cost effective way.* • *Some investments are made to improve the ability of the IWT system to compete for continental freight flows (i.e. continental 45' high-cube pallet-wide containers).* • *Moderate expansion of the European IWT network.*
Seaports	• *Port of Rotterdam remains properly accessible, closure of the 'Nieuwe Waterweg' once every 5 years in the year 2100.* • *Despite an increase in the regional throughput volumes the port of Rotterdam maintains its market share by optimising the use of its IWT hinterland connection.* • *The Dutch seaports maintain their market share in the Le-Havre - Hamburg region throughout the 21st century.* • *Strong growth of the market share of short-sea-shipping in continental freight transport (now shipped by road).*	• *Access to the port of Rotterdam is hindered 3 times per year due to closure of the 'Nieuwe Waterweg' in the year 2100.* • *The strong growth of the throughput volumes reduces the relative importance of the 'hub-function' of the port. Rotterdam therefore loses market share in the region.* • *The Dutch seaports lose some market share in the period up to 2050 and considerable market share in the period thereafter.* • *Slight growth of the market share of short-sea-shipping in continental freight transport (now shipped by road).*
Inland waterway transport	• *Inland waterways remain properly accessible for inland barges. Effects of climate change are quite limited.* • *Relative share of bulk shipments is reduced due to sustainable energy and departure of heavy industries.* • *IWT keeps a very significant share in the hinterland transport of intercontinental deepsea containers.* • *Strong development of intermodal barge transport in the continental freight flows (containers and pallets).*	• *From 2050 onwards IWT encounters large negative effects of climate change.* • *Relative share of bulk shipments is maintained due to use of fossil energy and preservation of heavy industries.* • *IWT has a significant share in the transport of deepsea containers but loses a large fraction due to the effects of climate change on inland navigation after 2050.* • *Moderate development of intermodal barge transport in the continental freight flows (containers only).*

* Note: normal writing obtained from background documents of broader Delta Scenario study, *'italic'* writing highlights my contribution.

Table 13-1b: Summary of the Transport Scenarios

SUBJECT	REST	WARM
Population and economic growth	• Low global and national economic growth. • Size of the Dutch population remains the same up to the year 2050 and reduces to 12 million in the year 2100.	• Low global and national economic growth. • Size of the Dutch population remains the same up to the year 2050 and reduces to 12 million in the year 2100.
Effect of climate change	• Moderate global climate change. • Moderate climate change in the Netherlands. • Winter precipitation increases by 4 to 7 percent. • Summer precipitation increases by 3 tot 6 percent. • Sea level rise of 35 cm in the year 2100. • Little changes in river discharge.	• Substantial global climate change. • Substantial climate change in the Netherlands. • Winter precipitation increases by 14 to 28 percent. • Summer precipitation decreases by 19 to 38 percent. • Sea level rise of 85 cm in the year 2100. • Major changes in river discharge.
Transition towards a sustainable society and transport system	• *Strong global drive for the transition towards a sustainable society and transport system.* • Slow but steady global energy transition. • *Slow but steady greening of the transport system.* • *IWT succeeds to considerably reduce its emission levels compared to road and rail transport.*	• *Economy based on unrestrained exploitation of raw materials and fossil fuels.* • Absent global energy transition. • *No interest in greening of the transport system.* • *No interest for greening of the IWT system.*
Energy and fuel	• *Moderate transition towards a sustainable European energy infrastructure.* • *Focus on energy- and fuel reduction.* • *Up to the year 2050 freight transport (road, rail, short-sea and IWT) increasingly adopts second generation bio-fuels and LNG. From the year 2050 onwards a careful shift towards more sustainable third generation bio-fuels (e.g. algae-fuels), hydrogen and solar-fuels takes place.*	• *Greening of the European energy infrastructure does not take place.* • *Virtually no focus on energy- and fuel reduction.* • *Until the year 2100 there remain sufficient fossil fuels available, there is no incentive to develop new more sustainable fuels.*
Spatial developments	• Some compact urbanisation, gradually reducing. • Size of agricultural areas remain more or less the same. • Nature areas are slightly increased. • *Moderate redevelopment of waterborne business areas, construction of some new quays for IWT.*	• Some urbanisation, fairly reduced over time. • Size of agricultural areas remain more or less the same. • Nature areas are slightly increased. • *Loss of waterborne business areas due to ongoing real-estate developments at the waterfront.*
Water system	• Some issues with safety against flooding. • Some issues with fresh water supply.	• Large issues with safety against flooding. • Large issues with fresh water supply.
Transport demand	• *Limited growth of overall transport demand up to the year 2050, followed by a decline.*	• *Limited growth of overall transport demand up to the year 2050, followed by a decline.*
Development of European transport infrastructures	• *Some focus on strengthening of European transport infrastructure with emphasis on the more sustainable networks (rail, short-sea-shipping, and IWT).* • *Some investments are made to improve the ability of the IWT system to compete for continental freight flows (i.e. continental 45' high-cube pallet-wide containers).* • *Moderate expansion of the European IWT network.*	• *Absent focus on strengthening of European transport infrastructure. No further investments in the European transport network.* • *No further upgrades of the European IWT network. No attempts to make the IWT network suitable for transport of continental 45' high-cube pallet-wide containers.* • *No further expansion of the European IWT network.*
Seaports	• *Port of Rotterdam remains properly accessible, closure of the 'Nieuwe Waterweg' once every 5 years in the year 2100.* • *The relatively low throughput volumes strengthen the relative importance of the 'hub-function' of the port of Rotterdam. The availability of sustainable hinterland connections further enhances the market share.* • *The Dutch seaports gain market share in the Le-Havre - Hamburg region, in particular towards the year 2100.* • *Strong growth of the market share of short-sea-shipping in continental freight transport (now shipped by road).*	• *Access to the port of Rotterdam is hindered 3 times per year due to closure of the 'Nieuwe Waterweg' in the year 2100.* • *The relatively low throughput volumes strengthen the relative importance of the 'hub-function' of the port of Rotterdam. This enhances the market share of the port of Rotterdam.* • *The Dutch seaports maintain their market share in the region up to 2050, but lose market share thereafter.* • *Until 2050 short-sea-shipping maintains market share in continental freight transport, thereafter it is reduced.*
Inland waterway transport	• *Inland waterways remain properly accessible for inland barges. Effects of climate change are quite limited.* • *Relative share of bulk shipments is reduced due to sustainable energy and departure of heavy industries.* • *IWT keeps a reasonable share in the hinterland transport of intercontinental deepsea containers.* • *Moderate development of intermodal barge transport in the continental freight flows (containers only).*	• *From 2050 onwards IWT encounters large negative effects of climate change.* • *Relative share of bulk shipments is maintained due to use of fossil energy and preservation of heavy industries.* • *IWT holds only a very small share in the hinterland transport of intercontinental deepsea containers.* • *Absent development of intermodal barge transport of continental freight flows.*

* Note: normal writing obtained from background documents of broader Delta Scenario study, *'italic'* writing highlights my contribution.

Table 13-1c: Summary of the Transport Scenarios

SUBJECT	STEAMING-ON	WATER-PRESSURE
Population and economic growth	• Strong global and national economic growth. • Number of Dutch inhabitants increases to 20 million in the year 2050 and 24 million in the year 2100.	• Strong global and national economic growth. • Number of Dutch inhabitants increases to 20 million in the year 2050 and 24 million in the year 2100.
Effect of climate change	• Moderate global climate change. • Moderate climate change in the Netherlands. • Winter precipitation increases by 4 to 7 percent. • Summer precipitation increases by 3 tot 6 percent. • Sea level rise of 35 cm in the year 2100. • Little changes in river discharge.	• Substantial global climate change. • Substantial climate change in the Netherlands. • Winter precipitation increases by 14 to 28 percent. • Summer precipitation decreases by 19 to 38 percent. • Sea level rise of 85 cm in the year 2100. • Major changes in river discharge.
Transition towards a sustainable society and transport system	*• Economy based on unrestrained exploitation of raw materials and fossil fuels.* • Late moderate global energy transition. *• Little interest in greening of the transport system. Some interest in intermodal transport to reduce transport cost.* *• Little interest for greening of the IWT system.*	*• Strong global drive for the transition towards a sustainable society and transport system.* • Swift global energy transition. *• Swift greening of the transport system.* *• IWT succeeds to considerably reduce its emission levels compared to road and rail transport.*
Energy and fuel	*• Greening of the European energy infrastructure does not take place.* *• Limited focus on energy- and fuel reduction.* *• Up to the year 2050 little changes in the applied fuel for goods transport take place, from 2050 onwards oil becomes relatively scarce and the transport system therefore shifts to LNG (in particular shale gas).*	*• Large scale transition towards a sustainable European energy infrastructure.* *• Strong focus on energy- and fuel reduction.* *• Up to the year 2050 freight transport (road, rail, short-sea and IWT) increasingly adopts second generation bio-fuels and LNG. From the year 2050 onwards a full shift towards more sustainable third generation bio-fuels (e.g. algae-fuels), hydrogen and solar-fuels takes place.*
Spatial developments	• Strong ongoing area intensive urbanisation. • Initial decrease of agricultural land, increase after 2050. • Nature areas significant reduced after 2050. *• Limited reduction of waterborne business areas. On the one hand conversion of existing sites into real estate, on the other hand preservation of quays to serve the increased IWT volumes, refurbishment of existing quays.*	• Strong ongoing but compact urbanisation. • Initial decrease of agricultural land, increase after 2050. • Nature areas significant reduced after 2050. *• Large scale redevelopment of waterborne business areas construction of new quays for IWT.* *• Construction of dams in the Rijn, Waal and Gelderse IJssel completely changes the river landscape.*
Water system	• Large issues with safety against flooding. • Large issues with fresh water supply.	• Very large issues with safety against flooding. • Very large issues with fresh water supply.
Transport demand	*• Ongoing growth of total transport demand throughout the entire period up to the year 2100.*	*• Ongoing growth of total transport demand throughout the entire period up to the year 2100.*
Development of European transport infrastructures	*• Some focus on strengthening the European rail, short-sea, and IWT infrastructure to manage the increased transport volumes in a cost effective way.* *• Some investments are made to improve the ability of the IWT system to compete for continental freight flows (i.e. continental 45' high-cube pallet-wide containers).* *• Moderate expansion of the European IWT network.*	*• Strong focus on strengthening of European transport infrastructure with emphasis on the more sustainable networks (rail, short-sea-shipping, and IWT).* *• Large scale upgrade of the European IWT network to support the efficient transport of continental 45' high-cube pallet-wide containers.* *• Large scale extension of the European IWT network.*
Seaports	*• Port of Rotterdam remains properly accessible, closure of the 'Nieuwe Waterweg' once every 5 years in the year 2100.* *• The strong growth of the throughput volumes reduces the relative importance of the 'hub-function' of the port. Rotterdam therefore loses market share in the region.* *• The Dutch seaports lose some market share in the Le-Havre - Hamburg region throughout the 21st century.* *• Slight growth of the market share of short-sea-shipping in continental freight transport (now shipped by road).*	*• Access to the port of Rotterdam is hindered 3 times per year due to closure of the 'Nieuwe Waterweg' in the year 2100.* *• Despite an increase in the regional throughput volumes the port of Rotterdam maintains its market share by optimising the use of its IWT hinterland connection.* *• The Dutch seaports initially maintain their market share, and gain some market share after canalisation of the Rhine towards the end of the century.* *• Strong growth of the market share of short-sea-shipping in continental freight transport (now shipped by road).*
Inland waterway transport	*• Inland waterways remain properly accessible for inland barges. Effects of climate change are quite limited.* *• Relative share of bulk shipments is maintained due to use of fossil energy and preservation of heavy industries.* *• IWT keeps a significant share in the hinterland transport of intercontinental deepsea containers.* *• Moderate development of intermodal barge transport in the continental freight flows (containers only).*	*• Large negative effects of climate change are completely mitigated by the canalisation of free flowing rivers.* *• Relative share of bulk shipments is reduced due to sustainable energy and departure of heavy industries.* *• IWT keeps a very significant share in the hinterland transport of intercontinental deepsea containers.* *• Strong development of intermodal barge transport in the continental freight flows (containers and pallets).*

* Note: normal writing obtained from background documents of broader Delta Scenario study, *'italic'* writing highlights my contribution.

13.4.2 BUSY

The 'BUSY' scenario combines strong economic growth with a successful transition towards a sustainable society and a moderate effect of climate change.

Energy and fuel:

The successful transition of the energy sector results in: a strong reduction of the energy demand, a shift towards sustainable energy sources, such as wind-, solar-, tidal-, membrane-, and geothermal energy, and the construction of a smart high capacity energy grid with sufficient storage capacity (e.g. by using underground energy storage cylinders).

The electric car causes a revolution in passenger transport, but the battery packs remain too small for freight transport. Freight transport initially embraces biofuels and conventional liquid natural gas (LNG). From about the year 2050 onwards a shift towards fully renewable fuels such as hydrogen, algae-fuels, and/or solar fuels takes place.

Fuel remains relatively scarce up to the year 2050. During this period the fuel prices become quite high. The high fuel prices foster an increased inflow of investments into new sustainable energy production facilities, but the full transition towards a sustainable global energy supply system still takes a very long period of time and is likely to last about 100 years[153]. Eventually, by the year 2100 fuel and energy are no longer scarce. The availability of cheap renewable energy has then become a strong pillar of a new sustainable industry.

Seaports:

The high levels of economic growth are reflected by a considerable growth of the throughput volumes in the seaports. However, the strong focus on sustainability also implies that the growth of the throughput volumes will lag behind the growth of the economy. This is reflected by a strong decoupling of economic growth and transport.

The petrochemical industry initially adopts LNG as a replacement for oil (up to about the year 2050) and shifts towards the sustainable production of second and third generation bio-fuels, -plastics and -chemicals from about the year 2050 onwards. The supply of raw materials for the LNG based and later bio-based industry arrives in smaller parcels than we were used to in the past (the crude oil for the petrochemical industry was delivered in large oil tankers). This results in a considerable increase of the number of vessel calls. The shift from oil to gas enables the port of Rotterdam to develop a major gas hub and bunkering facility for LNG fuel. This also turns out to be very beneficial for inland- and short sea shipping, in particular throughout the period up to the year 2050 in which the use of LNG is booming.

Heavy industries are expected to move towards the countries in which the raw materials are mined. This results in a gradual decline of the relative import of bulk products. The shift of production facilities towards the countries in which the raw materials are mined increases the share of half-fabricates, that are mainly shipped in containers. In addition there is also a strong growth in the transport of recycled materials, that are also increasingly shipped in containers. Both trends lead to a further increase in the overall degree of containerisation.

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[153] See also Marchetti and Nakićenović (1978, p.16) who analysed transitions in the energy system and observed an *"extreme regularity and slowness of the substitution. It takes about 100 years to go from 1% to 50% of the market"*. I expect it to take at least two Kondratieff waves to change the system (see also Chapter 4 and 8).

The strong growth of deepsea container transport makes it more attractive to offer direct liner services. This reduces the competitive advantage of the largest container hubs in the Le-Havre – Hamburg range, such as the ports of Rotterdam and Antwerp. On the other hand, the availability of efficient inland container barge lines towards the hinterland enhances the competitiveness of the ARA ports (Antwerp, Rotterdam, Amsterdam). This enables the Dutch and Belgium seaports to maintain their market share in the Le-Havre – Hamburg range on the very long term towards the year 2100.

The European Union manages to meet its long term objectives to shift 30% of the long distance road haulage trips over 300 km to more sustainable modes of transport by the year 2030, and 50% by the year 2050. This results in a strong growth of continental short sea shipping, that mainly takes place in continental 45 foot (pallet-wide, high cube) containers. Large scale adjustments to the IWT network make it possible to transport a considerable share of the continental 45 foot short sea containers by barge to their hinterland destination or vice-versa. This further enhances the competitive position of the ARA ports in short sea shipping.

In absence of extreme effects of climate change the port of Rotterdam remains well accessible for shipping. The barrier in the 'Nieuwe Waterweg' closes once every 5 years towards the end of the century. The effects of such a closure are quite limited, because it generally concerns a closure for just one day, and because a large part of the port area (Maasvlakte I and II) is located outside of the barrier. In addition the smaller coastal and inland barges can still use the locks at Rozenburg (if sufficient capacity is available).

Inland Shipping:
The freight volumes on the inland waterways flourish due to: the strong growth of the overall transport volumes; the increased economies of scale and density for intermodal barge transport; the societal interest in green transport solutions; the successful modal shift policy of the European Union; and the absence of major effects of climate change. IWT is not only continuing to fulfil a leading role in the shipment of bulk commodities, but also takes a strong share in the hinterland transport of deepsea containers. In addition the IWT sector manages to gain a reasonable share in the transport of continental cargoes.

The share of inland shipping in the hinterland transport of deepsea containers shows a strong initial increase. This increase is partly caused by the opening of the Second Maasvlakte in the year 2014 for which a minimum share of rail and IWT was agreed upon with the terminal operators in their concession agreements, but also by the ongoing development of new inland terminals in the hinterland. By the year 2020 there exists a dense network of inland terminals that provides close access to virtually all major industrial sites located within a range of about 20 km from the inland waterways. In addition large investments in the development of existing and new waterborne business areas takes place. These areas provide many companies with an incentive to locate their logistics activities close to the waterfront.

The European Union invests in a major upgrade of the IWT system throughout the period from the year 2020 to the year 2050. These investments turn out to be a very adequate way to meet the ambitious emission targets for the transport sector. The works amongst other include the removal of the bottlenecks in the Danube and the construction of: the Canal Seine – Nord Europe; the Twente – Mittelland Canal; a new Rhine – Rhône connection; and a new Canal from Zeebrugge to Gent. In addition the bridges on the Mittelland Canal and the further connection to Berlin, Hamburg, and Bremen are raised by about 3.5 meters to allow for transport of three layers of high cube containers between the Ruhr area and Berlin.

Many efforts are put into an upgrade of the existing inland waterways to gradually improve the transport performance for the transport of continental 45 foot containers. The main focus is initially directed to the Class IV and Class V waterways. These waterways are upgraded to allow for respectively three and four layers of high cube containers. In addition the allowable width of the Class V waterways is slightly increased to make four wide loading of standard pallet wide containers (of 2.50 meter wide) possible. Towards the second half of the century a renewed interest arises in the use of the smaller Class III waterways.

The replacement of ship locks that are at the end of their lifetime takes place in such a way that the new locks on the Class V waterways are able to support the efficient loading of four special pallet wide containers (of up to 2.6 meter wide) next to each other in an upgraded Class V+ Rhine barge (see Chapter 10). The prescribed width for the construction of new locks is therefore increased from 12 meter to at least 12.5 meters.

The large investments in the European IWT network are mainly financed by taxes on the external costs of transport, that are generally higher for road transport than for IWT. The revenues of these taxes are used to invest in the most cost effective sustainable expansions and upgrades of the intermodal transport networks (including road, rail, and IWT). The higher road charges and improved IWT infrastructure network provides an extra stimulus for IWT, in particular once the inland barge fleet has considerably reduced its own emission levels.

The large scale development of waterborne business areas, major investments in upgrades of the European IWT infrastructure, and internalisation of the external transport costs provide a great incentive to shift continental freight flows from the road to the inland waterways. This results in a strong growth of continental container transport in the period from 2020 to 2050. IWT thereby contributes to the realisation of the 50% modal shift goal for the year 2050.

The shift of logistics companies towards the waterfront results in a strong reduction of the pre- and end-haulage costs. By the year 2050 this has resulted in the successful development of a small pallet distribution network. When the volumes on this network start to grow the network becomes a magnet, that attracts the smaller less that truck load (LTL) shipments for which the transport revenues are higher than for full truck load (FTL) shipments (see also Chapter 8). By the end of the 21st century there exists a dense pallet distribution network that not only covers the largest waterways, but also serves the smaller Class II and Class III waterways for which the bridge heights have been raised to meet the requirements.

13.4.3 STEAM

The ‘STEAM’ scenario combines strong economic growth with a very limited transition towards a sustainable society and a strong effect of climate change.

<u>Energy and fuel:</u>

In absence of global climate agreements the sustainable energy transition ends up as a complete failure. Though high levels of economic growth lead to a shortage of fossil fuels, the higher fuel prices make the mining of hard exploitable coal, oil, and gas reserves yet very lucrative. Initially the use of coal increases considerably due to the large relatively easy exploitable reserves. Oil also remains an important fuel for at least a few decades. From about the year 2050 onwards, the mining of unconventional European shale gas becomes booming in order to substitute the use of crude oil, for which the global production is then falling.

Oil initially remains the major source of energy for the transport sector, but in a later stage, from about the year 2050 onwards, the use of unconventional shale gas also gains a considerable market share in Europe. In addition there is also an increased production of coal to liquid fuels. This implies that large amounts of fossil fuels and oil products are continuously shipped over the world throughout the 21st century.

The discovery of new energy sources guarantees sufficient energy to remain available, albeit at a higher price level than in the past. The energy costs are raised considerable due to ongoing economic growth and globalisation throughout the first half of the century, but new mining techniques stabilise the cost levels in the second half of the century.

Seaports:
The high levels of economic growth are reflected by a considerable growth of the throughput volumes in the seaports. Little decoupling of economic growth and transport takes place due to ongoing global production and an absent focus on greening of transport activities.

The petrochemical industry remains a strong pillar for the ports of Rotterdam and Antwerp. The increased fuel prices and ongoing widening of the Suez Canal result in an increased size of large oil tankers. From the year 2050 onwards the oil reserves become smaller and the world increasingly shifts to gas (including large amounts of unconventional European shale gas). The port of Rotterdam develops into a major gas hub and bunkering facility for LNG fuel. This turns out to be very beneficial for inland- and short sea shipping, in particular in the second half of the 21st century, in which the use of LNG is booming.

Heavy industries remain located in Europe which implies that the supply of bulk commodities keeps playing a very important role in the port of Rotterdam. In addition more and more coal is imported from China to fulfil the ever increasing energy demand. The easiest recoverable and most profitable materials are still being recycled, but the overall effect of recycling on the size of the global transport volumes is still rather limited.

The strong growth of deepsea container transport makes it attractive for shipping lines to offer direct liner services. This reduces the competitive advantage of the largest container hubs in the Le-Havre – Hamburg range, such as the ports of Rotterdam and Antwerp. From about 2050 onwards the Dutch and Belgium seaports are confronted with major effects of climate change, that negatively affect the reliability of their IWT hinterland connection and thereby reduces their competitive advantage in the Le-Havre – Hamburg range.

Despite the limited focus on sustainable transport the short sea shipping sector still manages to increase its market share in the transport of continental cargoes (which are shifted away from unimodal road transport). This success is mainly caused by the vast economies of scale and density that come with the increased size of the overall transport volumes.

The extreme effects of climate change also result in a more frequent closure of the Maeslant barrier in the 'Nieuwe Waterweg'. By the year 2100 the Maeslant barrier closes about three times per year. The effects of these closures are nevertheless still manageable, as it generally concerns a closure for just one day, and because a large part of the port area (Maasvlakte I and II) is located outside of the barrier. In addition the smaller coastal and inland barges can still use the locks at Rozenburg (if sufficient capacity is available).

Inland shipping:

The strong growth of the overall transport volumes enhances economies of scale for IWT of bulk products and deepsea containers. IWT therefore maintains a strong position in the transport of these commodities throughout the first half of the 21st century. However, by the second half of the 21st century the adverse effects of climate change become so large, that IWT is bound to lose a substantial part of its market share.

The share of IWT in the hinterland transport of deepsea containers initially shows a considerable growth, that is not only caused by the opening of the Second Maasvlakte in the year 2014, for which a minimum share of rail and IWT was agreed upon with the terminal operators in their concession agreements; but also by the development of a few new inland container terminals in the hinterland. By the year 2020 there exists a reasonably dense network of inland terminals that provides close access to most of the major industrial sites located within a range of about 30 km from the inland waterways. Real-estate developments have a negative effect on the availability of quays for IWT, in particular on the smaller waterways. However, quite some waterfront areas are still preserved for IWT and sufficient efforts are put into the refurbishment of these existing transhipment facilities.

Some investments in an improvement of the European IWT infrastructure are still being made to cope with the strong growth in the overall transport volumes. The most important expansion of the IWT network is the new Canal Seine – Nord Europe, that was initially planned to be completed by the year 2016, but finally opens in the year 2030. In addition also a new connection between Zeebrugge and Gent is excavated. These new network expansions are mainly developed for the transport of bulk commodities and deepsea containers. They are not designed for efficient intermodal continental container transport.

The European Union puts its ambitious goals to obtain a modal shift aside. Major efforts to upgrade the inland waterways stay out, but waterway managers still try to improve the conditions for continental container transport within the constraints of their limited budgets. On some major routes they manage to increase the bridge heights and allow for a slightly wider beam of the Class IV barges. This amongst others result in the development of some intermodal continental container flows. The market shows no interest in the development of advanced continental pallet distribution networks. These networks are not developed.

The Rhine still remains all year round navigable in the year 2050, but inland barges have to cope with severe draft restrictions during the dry season. In the second half of the 21st century the variations in river discharge become so large that they start to create severe hinder to inland shipping. The average barge utilisation then drops to just about 30% on the main stretch up to Ruhrort in the period from July to October – and sailing further upstream the Rhine is no longer feasible with the standard West-European barges. To maintain sailing special shallow draft barges are required, but there is no business case for these barges. For transport towards the middle and upper Rhine an alternative solution is found in the use of barges from the Danube basin, which are developed for a much lower standard draft. However, the capacity of the Danube fleet is fairly small compared to the Rhine fleet and offers only a partial solution at much higher transport costs.

The severe effects of climate change result in a considerable increase in the average annual transport costs per tonne. In addition inland shipping also becomes less reliable which implies that larger storage facilities will be required. Climate change therefore has a strong negative effect on the total transport volumes, that are shipped by means of IWT.

13.4.4 REST

The 'REST' scenario combines low economic growth with a successful transition towards a sustainable society and a moderate effect of climate change.

Energy and fuel:

Despite the low levels of economic growth there is still a strong focus on greening of the energy system. Energy demand is reduced and still some major investments in sustainable energy sources (such a as wind-, solar-, tidal-, membrane-, and geothermal energy) as well as in the improvement of the energy network are made. LNG fuelled power plants are intensively used in combination with sustainable energy to guarantee the reliability of the energy system as these plants are relatively clean and easy to switch on and off.

The electric car causes a revolution in passenger transport, but the battery packs remain too small for freight transport. Freight transport initially embraces biofuels and conventional liquid natural gas (LNG). From about the year 2050 onwards a careful shift towards fully renewable fuels such as hydrogen, algae-fuels, and/or solar fuels starts to take place, but LNG remains to play an important role in freight transport up to the end of the century.

Due to the low levels of economic growth there remains sufficient crude oil and other fossil fuel available. The European Union nevertheless makes a deliberate choice to green its energy system and to reduce its dependency on fuel imports from other regions in the world. In addition it is also determined to achieve its climate targets to reduce carbon emission by 80-95% in the year 2050 compared to the year 1990 (European Commission, 2011). From about the year 2050 onwards energy starts to become relatively cheap. The availability of cheap renewable energy has then become a strong pillar of the new sustainable industry.

Seaports:

The low levels of economic growth are reflected by a moderate initial increase of the overall port throughput volumes. In addition the strong focus on sustainable developments results in a strong decoupling of economic growth and transport that even further reduces the overall port throughput volumes. From about the year 2050 onwards the ports are confronted with a decline in the total port throughput volumes.

The petrochemical industry initially adopts LNG as a replacement for oil (up to about the year 2050) and shifts towards the sustainable production of second and third generation bio-fuels, -plastics and -chemicals from about the year 2050 onwards. The supply of raw materials for the LNG based and later bio-based industry arrives in smaller parcels than we were used to in the past (the crude oil for the petrochemical industry was delivered in large oil tankers). This results in a relative increase of the number of vessel calls, but there is sufficient port capacity available to meet the demand. The shift from oil to gas enables the port of Rotterdam to develop a major gas hub and bunkering facility for LNG fuel. This also turns out to be very beneficial for inland- and short sea shipping, in particular throughout the period up to the year 2050 in which the use of LNG is booming.

Heavy industries are expected to move towards the countries in which the raw materials are mined. This results in a gradual decline of the relative import of bulk products. The shift of production facilities towards the countries in which the raw materials are mined increases the share of half-fabricates, that are mainly shipped in containers. In addition there is also a strong growth in the transport of recycled materials, that are also increasingly shipped in containers. Both trends lead to a further increase in the overall degree of containerisation.

The moderate growth of deepsea container transport makes it less attractive to offer direct liner services. This enhances the competitive position of the larger ports within the Le-Havre – Hamburg range (i.e. the ports of Rotterdam and Antwerp). The competitive position of the Dutch and Belgium ports is further enhanced by the availability of a strong sustainable IWT hinterland connection towards the German hinterland.

The European Union is determined to meet its long term objectives to shift 30% of the long distance road haulage trips over 300 km to more sustainable modes of transport by the year 2030, and 50% by the year 2050. Short sea shipping sees an opportunity to serve a part of these flows. This enhances the transport of continental 45 foot containers. The allowable width on the Class V waterways is slightly increased to enhance cost effective barge transport of continental 45 foot containers from the sea terminal to the hinterland (or vice-versa). This strengthens the competitiveness of intermodal short sea shipping.

In absence of extreme effects of climate change the port of Rotterdam remains well accessible for shipping. The barrier in the 'Nieuwe Waterweg' closes once every 5 years towards the end of the century. The effects of such a closure are however quite limited, because it generally concerns a closure for just one day, and because a large part of the port area (Maasvlakte I and II) is located outside of the barrier. In addition the smaller coastal and inland barges can still use the locks at Rozenburg (if sufficient capacity is available).

<u>Inland shipping:</u>
The inland waterways are able to play an important role in the transport system because of: the societal interest in green transport solutions; the successful modal shift policy of the European Union; and the absence of major effects of climate change. IWT is not only continuing to fulfil a leading role in the shipment of bulk commodities, but also takes a strong share in the hinterland transport of deepsea containers. In addition the IWT sector manages to gain a moderate share in the transport of continental cargoes.

The share of inland shipping in the hinterland transport of deepsea containers shows a high initial growth that gradually reduces towards the end of the century. The high initial growth is partly caused by the opening of the Second Maasvlakte in the year 2014 for which a minimum share of rail and IWT was agreed upon with the terminal operators in their concession agreements, but also by the ongoing development of new inland terminals in the hinterland. By the year 2020 there exists a reasonably dense network of inland terminals that provide close access to many industrial sites located within a range of about 25 km from the inland waterways. In addition efforts are put into the development of waterborne business areas that enable companies to locate their logistics activities close to the waterfront.

The European Union still invests in a few important upgrades of the IWT network throughout the period from the year 2020 to the year 2050. The works include the construction of the Canal Seine – Nord Europe that becomes operational by the year 2025 and the construction of a new Canal from Zeebrugge to Gent. In addition the bridges on the Mittelland Canal and the further connection to Berlin, Hamburg, and Bremen are raised by about 1 meter to allow for transport of two layers of high cube containers between the Ruhr area and Berlin.

Where possible the limited available means are also used to improve the quality of the existing waterway connections for the transport of continental 45 foot containers. The main focus is initially directed to the Class IV and Class V waterways. These waterways are upgraded to allow for respectively three and four layers of high cube containers. In addition the allowable width of the Class V waterways is slightly increased to make four wide loading of standard pallet wide containers (of 2.50 meter wide) possible. Towards the second half of the century a renewed interest arises in the use of the smaller Class III waterways.

The replacement of ship locks that are at the end of their lifetime takes place in such a way that the new locks on the Class V waterways are able to support the efficient loading of four special pallet wide containers (of up to 2.6 meter wide) next to each other in an upgraded Class V+ Rhine barge (see Chapter 10). The prescribed width for the construction of new locks is therefore increased from 12 meter to at least 12.5 meters.

The large investments in the European IWT network are mainly financed by taxes on the external costs of transport, that are generally higher for road transport than for IWT. The revenues of these taxes are used to invest in the most cost effective sustainable expansions and upgrades of the intermodal transport networks (including road, rail, and IWT). The higher road charges and improved IWT infrastructure network provides an extra stimulus for IWT, in particular once the inland barge fleet has considerably reduced its own emission levels.

The development of waterborne business areas, investments in upgrades of the European IWT infrastructure, and internalisation of external transport costs provide a reasonable incentive to shift continental cargoes from unimodal road transport towards intermodal IWT. This results in a reasonable growth of continental container transport in the period from 2020 to 2050. IWT thereby contributes to the realisation of the 50% modal shift goal for the year 2050.

The shift of logistics companies to the waterfront results in a reduction of the pre- and end-haulage costs for intermodal transport. This eventually enables the development of some intermodal pallet distribution flows by the year 2050. Towards the end of the century there exists a small but cost effective pallet distribution network that not only covers the large waterways, but also serves the smaller Class II and Class III waterways, for which some bridge heights have been raised to meet the requirements.

13.4.5 WARM

The ‘WARM’ scenario combines low economic growth with a very limited transition towards a sustainable society and a strong effect of climate change.

Energy and fuel:

In absence of global climate agreements the sustainable energy transition ends up as a complete failure, but crude oil and other fossil fuels remain sufficiently available for yet a very long period of time due to the low global economic output levels.

Oil initially remains the major source of energy for the transport sector, but in a later stage (from about the year 2050 onwards) unconventional shale gas also gains a considerable market share in Europe. In addition there is also an increased production of coal to liquid fuels. This implies that considerable amounts of fossil fuels will continuously be shipped over the world throughout the 21st century.

The discovery of new energy sources guarantees sufficient energy to remain available, albeit at a higher price level than in the past. The low levels of economic growth result in a lack of investments in new mining technologies. For this reason prices steadily continue to rise throughout the century up to the year 2100.

Seaports:
The low levels of economic growth are also reflected by a moderate increase of the overall port throughput volumes. Very little decoupling of economic growth and transport takes place due to ongoing global production and an absent focus on greening of transport activities.

The petrochemical industry remains a strong pillar for the ports of Rotterdam and Antwerp. In absence of strong economic growth the size of the oil tankers has remained more or less the same. In the period from the year 2050 onwards the oil price increases considerable which also causes a shift towards the use of unconventional shale gas on the European continent.

Heavy industries remain located in Europe which implies that the supply of bulk commodities keeps playing a very important role in the port of Rotterdam. The easiest recoverable and most profitable materials are still being recycled, but the majority of the waste products still ends up in an incinerator. The overall effects of recycling on the size of the global transport volumes is therefore rather limited.

The moderate growth of deepsea container transport makes it less attractive to offer direct liner services. This enhances the competitive position of the larger ports within the Le-Havre – Hamburg range (i.e. the ports of Rotterdam and Antwerp). These effects are however completely offset by the adverse effects of climate change in the second half of the century. Climate change causes long periods of extreme draught on the river Rhine and thereby reduces the water depth and consequently the quality of this important waterway connection. The Dutch ports are still able to maintain their market share in the period up to the year 2050, but they lose market share in the period thereafter.

In response to the low levels of economic growth and absent focus on sustainable transport short sea shipping sees no chance to increase its market share in the continental freight flows. On the very long term short sea shipping even start to lose market share due to the shrinking overall freight volumes, that result in reduced economies of scale and density.

The extreme effects of climate change also result in a more frequent closure of the Maeslant barrier in the 'Nieuwe Waterweg'. By the year 2100 the Maeslant barrier closes about three times per year. The effects of these closures are nevertheless still manageable, as it generally concerns a closure for just one day, and because a large part of the port area (Maasvlakte I and II) is located outside of the barrier. In addition the smaller coastal and inland barges can still use the locks at Rozenburg (if sufficient capacity is available).

Inland shipping:
The share of IWT in the hinterland transport of deepsea containers shows a small initial growth that is mainly caused by the opening of the Second Maasvlakte in the year 2014, for which a minimum share of rail and IWT was agreed upon with the terminal operators in their concession agreements. However, due to the limited growth of the overall throughput volumes and the fierce competition with other ports, the Rotterdam Port Authority is forced to drop its strict 'modal split' requirements by the year 2020. At that time the IWT sector is no longer able to increase its market share in the container segment. In addition it also turns out that the inland terminal landscape has become too dense to be maintained by the limited size of the container flows. As a result the number of terminals shows a decline.

The ambitious modal shift policies of the European Union are completely put aside. Hardly any improvements are made to the IWT network. The development of the new Canal Seine –

Nord Europe is completely abandoned by the year 2020. Investments in an upgrade of the IWT system stay out and additional dues to internalise the external costs of transport are not put in place. Sustainable transport has absolutely no priority.

By the year 2020 the transport volumes on the smaller waterways are reduced considerable because most of the smaller barges have become obsolete (hardly any Class II and Class III barges have been constructed since the 1960) – and because barge operators are still reluctant to invest in these smaller barges, for which the economies of scale are rather limited and a business case is hard to achieve. IWT is nevertheless able to maintain its market share in the transport of bulk materials and deepsea containers on the main IWT routes up to the year 2050. It does however fail to enter the market of for continental freight transport that remains almost entirely served by unimodal road transport.

The Rhine still remains all year round navigable in the year 2050, but inland barges have to cope with severe draft restrictions during the dry season. In the second half of the 21st century the variations in river discharge become so large that they start to create severe hinder to inland shipping. The average barge utilisation then drops to just about 30% on the main stretch up to Ruhrort in the period from July to October – and sailing further upstream the Rhine is no longer feasible with the standard West-European barges. To maintain sailing special shallow draft barges are required, but there is no business case for these barges. For transport towards the middle and upper Rhine an alternative solution is found in the use of barges from the Danube basin, which are developed for a much lower standard draft. However, the capacity of the Danube fleet is fairly small compared to the Rhine fleet and offers only a partial solution at a much higher transport costs.

The severe effects of climate change result in a considerable increase in the average annual transport costs per tonne. In addition inland shipping also becomes less reliable which implies that larger storage facilities will be required. Climate change therefore has a strong negative effect on the total transport volumes that are shipped by barge. IWT continues to lose a substantial part of its market share in the second half of the century.

13.4.6 STEAMING-ON

The ‘STEAMING-ON’ scenario combines strong economic growth with a very limited transition towards a sustainable society and a moderate effect of climate change. As large parts of the text in this scenario are similar to the text in the STEAM scenario I highlighted the sections that differ from the STEAM scenario with an *‘italic font’*.

<u>Energy and fuel:</u>
In absence of global climate agreements the sustainable energy transition ends up as a complete failure. Though high levels of economic growth lead to a shortage of fossil fuels, the higher fuel prices make the mining of hard exploitable coal, oil, and gas reserves yet very lucrative. Initially the use of coal increases considerably due to the large relatively easy exploitable reserves. Oil also remains an important fuel for at least a few decades. From about the year 2050 onwards, the mining of unconventional European shale gas becomes booming in order to substitute the use of crude oil, for which the global production is then falling.

Oil initially remains the major source of energy for the transport sector, but in a later stage, from about the year 2050 onwards, the use of unconventional shale gas also gains a considerable market share in Europe. In addition there is also an increased production of coal to liquid fuels. This implies that large amounts of fossil fuels and oil products are continuously shipped over the world throughout the 21st century.

The discovery of new energy sources guarantees sufficient energy to remain available, albeit at a higher price level than in the past. The energy costs are raised considerable due to ongoing economic growth and globalisation throughout the first half of the century, but new mining techniques stabilise the cost levels in the second half of the century.

<u>Seaports:</u>
The high levels of economic growth are reflected by a considerable growth of the throughput volumes in the seaports. Little decoupling of economic growth and transport takes place due to ongoing global production and an absent focus on greening of transport activities.

The petrochemical industry remains a strong pillar for the ports of Rotterdam and Antwerp. The increased fuel prices and ongoing widening of the Suez Canal result in an increased size of large oil tankers. From the year 2050 onwards the oil reserves become smaller and the world increasingly shifts to gas (including large amounts of unconventional European shale gas). The port of Rotterdam develops into a major gas hub and bunkering facility for LNG fuel. This turns out to be very beneficial for inland- and short sea shipping, in particular in the second half of the 21st century, in which the use of LNG is booming.

Heavy industries remain located in Europe which implies that the supply of bulk commodities keeps playing a very important role in the port of Rotterdam. In addition more and more coal is imported from China to fulfil the ever increasing energy demand. The easiest recoverable and most profitable materials are still being recycled, but the overall effect of recycling on the size of the global transport volumes is still rather limited.

The strong growth of deepsea container transport makes it attractive for shipping lines to offer direct liner services. This reduces the competitive advantage of the largest container hubs in the Le-Havre – Hamburg range, such as the ports of Rotterdam and Antwerp. From about 2050 onwards the Dutch and Belgium seaports are confronted with major effects of climate change, that negatively affect the reliability of their IWT hinterland connection and thereby reduces their competitive advantage in the Le-Havre – Hamburg range.

Despite the limited focus on sustainable transport the short sea shipping sector still manages to increase its market share in the transport of continental cargoes (which are shifted away from unimodal road transport). This success is mainly caused by the vast economies of scale and density that come with the increased size of the overall transport volumes.

In absence of extreme effects of climate change the port of Rotterdam remains well accessible for shipping. The barrier in the 'Nieuwe Waterweg' closes once every 5 years towards the end of the century. The effects of such a closure are generally quite limited, because it generally concerns a closure for just one day, and because a large part of the port area (Maasvlakte I and II) is located outside of the barrier. In addition the smaller coastal and inland barges can still use the locks at Rozenburg (if sufficient capacity is available).

<u>Inland shipping:</u>
The strong growth of the overall transport volumes enhances economies of scale for IWT of bulk products and deepsea containers. IWT therefore maintains a strong position in the transport of these commodities throughout the first half of the 21st century. However, by the

second half of the 21st century the adverse effects of climate change become so large, that IWT is bound to lose a substantial part of its market share.

The share of IWT in the hinterland transport of deepsea containers initially shows a considerable growth, that is not only caused by the opening of the Second Maasvlakte in the year 2014, for which a minimum share of rail and IWT was agreed upon with the terminal operators in their concession agreements; but also by the development of a few new inland container terminals in the hinterland. By the year 2020 there exists a reasonably dense network of inland terminals that provides close access to most of the major industrial sites located within a range of about 30 km from the inland waterways. Real-estate developments have a negative effect on the availability of quays for IWT, in particular on the smaller waterways. However, quite some waterfront areas are still preserved for IWT and sufficient efforts are put into the refurbishment of these existing transhipment facilities.

Some investments in an improvement of the European IWT infrastructure are still being made to cope with the strong growth in the overall transport volumes. The most important expansion of the IWT network is the new Canal Seine – Nord Europe, that was initially planned to be completed by the year 2016, but finally opens in the year 2030. In addition also a new connection between Zeebrugge and Gent is excavated. These new network expansions are mainly developed for the transport of bulk commodities and deepsea containers. They are not designed for efficient intermodal continental container transport.

The European Union puts its ambitious goals to obtain a modal shift aside. Major efforts to upgrade the inland waterways stay out, but waterway managers still try to improve the conditions for continental container transport within the constraints of their limited budgets. On some major routes they manage to increase the bridge heights and allow for a slightly wider beam of the Class IV barges. This amongst others result in the development of some intermodal continental container flows. The market shows no interest in the development of advanced continental pallet distribution networks. These networks are not developed.

The strong growth of the overall freight volumes results in additional economies of scale and density for IWT (i.e. larger barges and inland terminals). In absence of major effects of climate change this enhances the competitiveness and increases the market share of IWT.

13.4.7 WATER-PRESSURE

The 'WATER-PRESSURE' scenario combines strong economic growth with a successful transition towards a sustainable society and a strong effect of climate change. The negative effects of climate change for IWT are however completely mitigated by the construction of new hydraulic infrastructures (i.e. the further canalisation of the Rhine and Gelderse IJssel). As large parts of the text in this scenario are similar to the text in the BUSY scenario I highlighted the sections that differ from the BUSY scenario with an *'italic font'*.

<u>Energy and fuel:</u>
The successful transition of the energy sector results in: a strong reduction of the energy demand, a shift towards sustainable energy sources, such as wind-, solar-, tidal-, membrane-, and geothermal energy, and the construction of a smart high capacity energy grid with sufficient storage capacity (e.g. by using underground energy storage cylinders).

The electric car causes a revolution in passenger transport, but the battery packs remain too small for freight transport. Freight transport initially embraces biofuels and conventional liquid natural gas (LNG). From about the year 2050 onwards a shift towards fully renewable fuels such as hydrogen, algae-fuels, and/or solar fuels takes place.

Fuel remains relatively scarce up to the year 2050. During this period the fuel prices become quite high. The high fuel prices foster an increased inflow of investments into new sustainable energy production facilities, but the full transition towards a sustainable global energy supply system still takes a very long period of time and is likely to last about 100 years. Eventually, by the year 2100 fuel and energy are no longer scarce. The availability of cheap renewable energy has then become a strong pillar of a new sustainable industry.

Seaports:
The high levels of economic growth are reflected by a considerable growth of the throughput volumes in the seaports. However, the strong focus on sustainability also implies that the growth of the throughput volumes will lag behind the growth of the economy. This is reflected by a strong decoupling of economic growth and transport.

The petrochemical industry initially adopts LNG as a replacement for oil (up to about the year 2050) and shifts towards the sustainable production of second and third generation bio-fuels, -plastics and -chemicals from about the year 2050 onwards. The supply of raw materials for the LNG based and later bio-based industry arrives in smaller parcels than we were used to in the past (the crude oil for the petrochemical industry was delivered in large oil tankers). This results in a considerable increase of the number of vessel calls. The shift from oil to gas enables the port of Rotterdam to develop a major gas hub and bunkering facility for LNG fuel. This also turns out to be very beneficial for inland- and short sea shipping, in particular throughout the period up to the year 2050 in which the use of LNG is booming.

Heavy industries are expected to move towards the countries in which the raw materials are mined. This results in a gradual decline of the relative import of bulk products. The shift of production facilities towards the countries in which the raw materials are mined increases the share of half-fabricates, that are mainly shipped in containers. In addition there is also a strong growth in the transport of recycled materials, that are also increasingly shipped in containers. Both trends lead to a further increase in the overall degree of containerisation.

The strong growth of deepsea container transport makes it more attractive to offer direct liner services. This reduces the competitive advantage of the largest container hubs in the Le-Havre – Hamburg range, such as the ports of Rotterdam and Antwerp. On the other hand, the availability of efficient inland container barge lines towards the hinterland enhances the competitiveness of the ARA ports (Antwerp, Rotterdam, Amsterdam). This enables the Dutch and Belgium seaports to maintain their market share in the Le-Havre – Hamburg range on the very long term towards the year 2100.

The European Union manages to meet its long term objectives to shift 30% of the long distance road haulage trips over 300 km to more sustainable modes of transport by the year 2030, and 50% by the year 2050. This results in a strong growth of continental short sea shipping, that mainly takes place in continental 45 foot (pallet-wide, high cube) containers. Large scale adjustments to the IWT network make it possible to transport a considerable share of the continental 45 foot short sea containers by barge to their hinterland destination or vice-versa. This further enhances the competitive position of the ARA ports in short sea shipping.

The extreme effects of climate change also result in a more frequent closure of the Maeslant barrier in the 'Nieuwe Waterweg'. By the year 2100 the Maeslant barrier closes about three times per year. The effects of these closures are nevertheless still manageable, as it generally concerns a closure for just one day, and because a large part of the port area (Maasvlakte I and II) is located outside of the barrier. In addition the smaller coastal and inland barges can still use the locks at Rozenburg (if sufficient capacity is available).

<u>Inland Shipping:</u>
The effects of climate change become more and more visible throughout the 21st century. To guarantee sufficient safety against flooding, sufficient fresh water, and proper all year round navigation for inland shipping the Rhine is completely canalised. In addition the Waal and Gelderse IJssel are also canalised up to Gorinchem and Kampen. Sufficient lock capacity is provided to safeguard the smooth passage of inland barges (with only very limited delays at the ship locks). As a result of the weirs in these rivers the average annual loading draft of the barges increases (see Chapter 9). In addition the IWT system becomes more reliable, and the effect of strong current flows is reduced. The full canalisation of the rivers has therefore not only mitigated the effects of climate change, but also improved the performance of the IWT system compared to the situation without climate change[154].

The freight volumes on the inland waterways flourish due to: the strong growth of the overall transport volumes; the increased economies of scale and density for intermodal barge transport; the societal interest in green transport solutions; the successful modal shift policy of the European Union; and the absence of major effects of climate change. IWT is not only continuing to fulfil a leading role in the shipment of bulk commodities, but also takes a strong share in the hinterland transport of deepsea containers. In addition the IWT sector manages to gain a reasonable share in the transport of continental cargoes.

The share of inland shipping in the hinterland transport of deepsea containers shows a strong initial increase. This increase is partly caused by the opening of the Second Maasvlakte in the year 2014 for which a minimum share of rail and IWT was agreed upon with the terminal operators in their concession agreements, but also by the ongoing development of new inland terminals in the hinterland. By the year 2020 there exists a dense network of inland terminals that provides close access to virtually all major industrial sites located within a range of about 20 km from the inland waterways. In addition large investments in the development of existing and new waterborne business areas takes place. These areas provide many companies with an incentive to locate their logistics activities close to the waterfront.

The European Union invests in a major upgrade of the IWT system throughout the period from the year 2020 to the year 2050. These investments turn out to be a very adequate way to meet the ambitious emission targets for the transport sector. The works amongst other include the removal of the bottlenecks in the Danube and the construction of: the Canal Seine – Nord Europe; the Twente – Mittelland Canal; a new Rhine – Rhône connection; and a new Canal from Zeebrugge to Gent. In addition the bridges on the Mittelland Canal and the further

[154] The effects of the full canalisation of the river Rhine have not been investigated in Chapter 9. I therefore recommend further research on the options to canalise the Rhine and the possible effects of the full canalisation of the Rhine on the safety against flooding and the performance of the IWT system.

connection to Berlin, Hamburg, and Bremen are raised by about 3.5 meters to allow for transport of three layers of high cube containers between the Ruhr area and Berlin.

Many efforts are put into an upgrade of the existing inland waterways to gradually improve the transport performance for the transport of continental 45 foot containers. The main focus is initially directed to the Class IV and Class V waterways. These waterways are upgraded to allow for respectively three and four layers of high cube containers. In addition the allowable width of the Class V waterways is slightly increased to make four wide loading of standard pallet wide containers (of 2.50 meter wide) possible. Towards the second half of the century a renewed interest arises in the use of the smaller Class III waterways.

The replacement of ship locks that are at the end of their lifetime takes place in such a way that the new locks on the Class V waterways are able to support the efficient loading of four special pallet wide containers (of up to 2.6 meter wide) next to each other in an upgraded Class V+ Rhine barge (see Chapter 10). The prescribed width for the construction of new locks is therefore increased from 12 meter to at least 12.5 meters.

The large investments in the European IWT network are mainly financed by taxes on the external costs of transport, that are generally higher for road transport than for IWT. The revenues of these taxes are used to invest in the most cost effective sustainable expansions and upgrades of the intermodal transport networks (including road, rail, and IWT). The higher road charges and improved IWT infrastructure network provides an extra stimulus for IWT, in particular once the inland barge fleet has considerably reduced its own emission levels.

The large scale development of waterborne business areas, major investments in upgrades of the European IWT infrastructure, and internalisation of the external transport costs provide a great incentive to shift continental freight flows from the road to the inland waterways. This results in a strong growth of continental container transport in the period from 2020 to 2050. IWT thereby contributes to the realisation of the 50% modal shift goal for the year 2050.

The shift of logistics companies towards the waterfront results in a strong reduction of the pre- and end-haulage costs. By the year 2050 this has resulted in the successful development of a small pallet distribution network. When the volumes on this network start to grow the network becomes a magnet, that attracts the smaller less that truck load (LTL) shipments for which the transport revenues are higher than for full truck load (FTL) shipments (see also Chapter 8). By the end of the 21st century there exists a dense pallet distribution network that not only covers the largest waterways, but also serves the smaller Class II and Class III waterways for which the bridge heights have been raised to meet the requirements.

13.5 Further Considerations

Having discussed the storylines of the individual scenarios I would now like to share a few further considerations concerning the development of the very long term shipping scenarios. First of all I would like to point out that the joint assessment of the anticipated development of the energy system, seaports, and IWT system in each of the scenarios turned out to be very effective. The main reasons for this approach to be effective are: (1) the fact that there is a lot of interaction between the seaports and the IWT system; and (2) the fact that both systems are highly affected by the development of the energy system. In addition, I would like to emphasise that very long term IWT scenarios cannot be seen apart from European and national policies to upgrade the IWT system, stimulate the use of intermodal transport solutions, and reduce the effects of climate change. A good example is the canalisation of the Rhine in the ‘WATER-PRESSURE’ scenario. This scenario could not have been developed without taking general policies into account.

I would argue that it is important to include general policies in the development of very long term scenarios. Taking general policies into account does not imply that they need to be adopted in the plans for the study area under consideration by the policy maker (e.g. a certain stretch of the river on which the hydraulic structures need to be replaced). They only describe the possible development in the rest of the world. It is up to the policy maker to decide what actions need to be taken within the study area under consideration.

13.6 Concluding Summary

This chapter addresses the fifth methodological sub question (MSQ 5): *“What would be a plausible set of qualitative storyline scenarios for the very long term development of freight transport on the inland waterways?”*. It shows how a plausible set of storyline scenarios can be developed to explore the outer corners of anticipated future developments. The scenarios were not only developed as a part of this thesis. They also contributed to the official Delta Scenarios of the Dutch Delta Programme up to the year 2100, for which they provide the shipping section (see Van Dorsser, 2012; and Bruggeman et al., 2013).

13.6.1 Development of the Delta Scenarios

The outer corners of plausible future developments can be identified by developing a set of deductive storyline scenarios along the axes of the most significant key drivers. The Delta Scenarios are developed along the axes of two important key drivers. The first axis concerns socio-economic developments (i.e. population and GDP). The second axis concerns the speed in which climate change takes place. In line with these two axes the following four official Delta Scenarios were developed: **BUSY** (strong economic growth, moderate effects of climate change); **STEAM** (strong economic growth, large effects of climate change); **REST** (low economic growth, moderate effects of climate change); and **WARM** (low economic growth, large effects of climate change). However, in my opinion a third axis should have been added that concerns the transition towards a more sustainable society.

The four official Delta Scenarios make the implicit assumption that a strong focus on sustainability will result in a reduced effect of climate change, but this does not necessarily have to be the case. I would argue that the inertia of climate change is much larger than the inertia of the transition towards a sustainable society. For that reason I question to what extent future policies can still affect the rate of climate change. In case of high economic growth I consider it more sensible to adopt the inverse causal relation, that the inevitable rapid change of the climate causes a strong social drive to become sustainable. On the other hand it may still turn out that the negative effects of climate change remain quite moderate despite an ongoing emission of greenhouse gasses, though according to the latest IPCC (2013) report this option is becoming less likely now. I think that in case of strong economic growth the inverse causal relation (in which climate change fosters a strong societal drive to become sustainable) is better able to explore the outer corners of plausible future developments than the relation that has been applied in the BUSY and STEAM scenarios. For this reason I added two additional scenarios that were presented as a sensitivity analysis to the official Delta Scenarios. These are referred to as the **STEAMING-ON** and **WATER-PRESSURE** scenarios. The position of the applied scenarios with respect to the main drivers has been indicated in Figure 13-2 and 13-3.

For each scenario a storyline was developed that departs from the broader description of the Delta Scenarios and elaborates on the plausible development of the energy system, seaports, and IWT system. A joint discussion of these three subjects is logical because these topics are heavily interrelated and need to be addressed in conjunction to each other.

13.6.2 Basic Outline of the Shipping Scenarios

The **BUSY** scenario combines a high level of economic output with a strong societal drive to become sustainable and the non-occurrence of major effects of climate change. The strong focus on sustainable development enhances the use of environmentally friendly intermodal transport solutions for transport of continental cargoes (e.g. in continental pallet wide high cube 45 foot containers). For the seaports this implies a strong growth of the continental short sea shipping volumes. On the inland waterways it implies that IWT will not only maintain a strong position in the transport of bulk commodities and conventional deepsea containers, but also gains a strong market share in the transport of continental full load cargoes (i.e. full truck and container loads). The strong focus on intermodal transport enhances companies to shift their logistics operations to the waterfront. This considerably reduces the intermodal pre- and end-haulage costs and thereby enables the development of advanced IWT pallet distribution networks in the second half of the century.

The **STEAM** scenario combines a high level of economic output with a virtual absent focus on sustainability and large effects of climate change on sea level rise and river discharge. A strong growth of the overall transport volumes takes place throughout the century. However, from about the year 2050 onwards the Dutch ports start to lose market share to other ports in the Le-Havre – Hamburg range due to the poor navigability of the river Rhine (as well as the Waal and Gelderse IJssel) in the months July to October. The absolute port throughput volumes nevertheless keep growing. Inland shipping loses an even larger market share in response to the effects of climate change, but due to the strong growth of the overall transport volumes the absolute IWT volumes will still continue to grow. Despite an as good as absent focus on sustainability the strong growth of the transport volumes enables the market to develop some cost effective intermodal continental container barge lines. The potential development of intermodal pallet distribution networks does not take place.

The **REST** scenario combines a low level of economic output with a strong focus on sustainability and the non-occurrence of major effects of climate change. The overall transport volumes still continue to grow throughout the first half of the century but decline in the second half of the century due to reduced economic output and ongoing decoupling of economic output and transport. The strong societal drive to develop sustainable transport solutions enables the IWT sector to increase its market share. Apart from bulk cargoes and conventional deepsea containers the IWT sector also captures a fair share of the continental full cargo loads. The focus on intermodal transport enhances companies to shift their logistics operations to the waterfront. This eventually reduces the intermodal pre- and end-haulage costs considerably and thereby enables the development of some advanced IWT pallet distribution networks in the second half of the century.

The **WARM** scenario combines a low level of economic output with a virtual absent focus on sustainability and large effects of climate change on sea level rise and river discharge. The port throughput volumes initially show a moderate growth, but this growth turns into a decrease in the second half of the century. This decrease in transport volumes is mainly caused by reduced economic output and worsened IWT connections to the hinterland. Inland shipping loses an even larger market share in response to the effects of climate change. Very little options exist to develop cost effective intermodal continental container barge transport. The potential development of intermodal pallet distribution networks does not take place.

The **STEAMING-ON** scenario is related to the STEAM scenario but differs to the extent that major effects of climate change do not occur despite the ongoing emission of greenhouse gasses and an absent focus on sustainability. The main difference with the STEAM scenario is therefore that the overall growth of the Dutch port throughput- and IWT transport volumes is not tempered by the negative effects of climate change on the accessibility of the seaports and the navigability of the main IWT connections towards the hinterland.

The **WATER-PRESSURE** scenario is related to the BUSY scenario, but differs to the extent that despite a strong societal focus on sustainability the effects of climate change cannot be avoided. The world has reacted too late to avoid major effects of climate change from taking place. Large efforts are put into the reduction of carbon emissions in order to avoid the impact of global warming to become even worse. Substantial investments are made to maintain and improve the performance of the more environmentally friendly modes of transport such as IWT. These investments amongst others include: a substantial increase in the dimensions of the inland waterways; the development of a number of missing links; and the canalisation of the river Rhine (to guarantee safety against flooding and mitigate low water levels in the dry season). In response to these measures the quality of the IWT system is improved compared to the BUSY scenario and IWT volumes are therefore slightly higher.

13.6.3 Further Considerations

The IWT scenarios cannot be seen apart from the national and European policies to upgrade the IWT system, stimulate the use of intermodal transport solutions, and adapt to climate change. A good example is the canalisation of the Rhine in the WATER-PRESSURE scenario. This scenario could not have been developed without taking policies into account. In my opinion general policies should be included in the development of very long term scenarios. Taking general policies into account does not imply that they need to be adopted in the plans for the area under consideration by the policy maker. They only describe the development in the rest of the world.

13.6.4 Answer to Methodological Sub Question 5

In answer to MSQ 5, I prepared a set of six deductive storyline scenarios that explore the outer corners of plausible future developments. The scenarios were not only prepared in the framework of this thesis, but also contributed to the official Delta Scenarios of the Dutch Delta Programme up to the year 2100, for which they provide the shipping section. In line with the broader Delta Scenario study the scenarios were developed along the axes of the following two key drivers: (1) socio-economic developments (i.e. population and GDP); and (2) effects of climate change. However, in my opinion there exists a third key driver that also needs to be taken into account explicitly. This third key driver is related to the global transition towards a more sustainable society. By adding this third key driver one obtains eight scenario octants instead of four scenario quadrants. I selected six of these eight octants for the development of the very long term shipping scenarios. These include the four octants that were used in the broader Delta Scenario study as well as two octants that were added thereto because I consider them better able to explore the outer corners of plausible future developments. A summary of the storyline for the four official shipping scenarios (**BUSY**, **STEAM**, **REST**, and **WARM**) as well as the two additional scenarios that I added thereto (**WATER-PRESSURE** and **STEAMING-ON**) is provided in the section above. The quantification of the scenarios follows in Chapter 14.

Literature:

Bruggeman, W., E. Dammers, G.J. van den Born, B. Rijken, B. van Bemmel, A. Bouwman en K. Nabielek, J. Beersma, B. van den Hurk, N. Polman, Vincent Linderhof, C. Folmer, F. Huizinga, S. Hommes, and A. te Linde (2013) *Deltascenario's voor 2050 en 2100, Nadere uitwerking 2012-2013*, Deltares, KNMI, PBL, CPB, and LEI.

Delta Committee (2008) *Working together with water, A living land builds for its future*, www.deltacommissie.com.

Delta Committee (2012) *Delta Programme 2013, Working on the Delta, The road towards the Delta Decisions*, Ministry of Infrastructure and the Environment, Ministry of Economic Affairs, Agriculture and Innovation.

European Commission (2011) *A Roadmap for moving to a competitive low carbon economy in 2050*, COM(2011) 112 final.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Van den Akker, J., M. Betsema, T. Oegema, G. Wurpel (2013) *Updating the future – The next steps in becoming the sustainable global port, using scenarios from limits to Growth*, A report for the Port of Rotterdam Authority by the Club of Rome Climate Programme, IMSA, Amsterdam, The Netherlands.

Van Dorsser, J.C.M. (2012) *Scheepvaartscenario's voor Deltaprogramma, 100 jaar later...*, Rijkswaterstaat, https://deltaprogramma.pleio.nl/file/download/15938322.

14 Quantification of the Shipping Scenarios

“Transport structures are built to last, they are almost immortal. Once their original use declines in importance because of changing societal preferences and requirements for the transport system, new uses may evolve.”
- A. Grübler (The Rise and Fall of Infrastructures, 1990, p.194)

14.1 Introduction

The fact that still considerable research efforts will be required to develop a workable transport model for the very long term development of the IWT flows at the network level (see Chapter 12), does not necessarily imply that it is impossible to quantify the aggregated shipping scenarios, that were defined in the previous chapter. This chapter addresses the sixth methodological sub question (MSQ 6): *“What would be a sensible quantification of the plausible storyline scenarios for the very long term development of freight transport on the inland waterways?”*. It shows how the Shipping Scenarios for the Delta Programme were quantified on the basis of the insights that were obtained in this thesis. Apart from some minor corrections the discussion is fully in line with my earlier report (Van Dorsser, 2012), that provided the background for the shipping section of the Dutch Delta Scenarios.

The scenarios were quantified in close cooperation with Turpijn, an expert of Rijkswaterstaat who provided the historical transport data as well as the detailed estimates of the WLO projections (see Appendix E); and further served as a sparring partner with whom the obtained scenario quantifications were discussed. In addition a specific review session was held after the completion of my draft report (Van Dorsser, 2012) in which experts of Rijkswaterstaat, Deltares, the Ministry of Infrastructure and Environment, and the Port of Rotterdam Authority commented on the results (see also Chapter 13 and Appendix E).

For the quantification of the Delta Scenarios I had to deal with the fact that my very long term transport forecasts (see Chapter 7) are developed in line with the post-neo-classical paradigm on economic growth (see Chapter 4); while the official macroeconomic section of the Delta Scenario report (Bruggeman et al., 2013) endorses the mainstream neo-classical exponential growth assumptions of the CPB (Netherlands Bureau for Economic Policy Analysis). Because the aim of my report was to make the insights of this thesis available to the Delta Programme, I decided to base the scenario quantifications on the GDP projections of Chapter 7 rather than on the official GDP projections that were applied in the broader Delta Scenario study.

To this end I linked the high and low scenario quantifications to the high and low percentiles of the probabilistic forecasts that were developed in Chapter 7. This approach created some discussion as the spread in the obtained scenario quantifications is smaller than the spread in the scenario quantifications for other aspects such as land use and fresh water demand. The obtained scenario quantifications were nevertheless accepted because the involved experts of Rijkswaterstaat considered them realistic and because shipping concerns an isolated topic that is not affecting the overall fresh water demand.

Section 14.2, 14.3, and 14.4 show how I quantified the port throughput-, inland transport-, and IWT volumes for the shipping section of the broader Delta Scenario report; Section 14.5 continues with a reflection on the use of my post-neo-classical economic growth projections, instead of the CPB projections that were defined in the macroeconomic section of the broader Delta Scenario report of Bruggeman et al. (2013); and Section 14.6 finally contains a concluding summary that provides an answer to MSQ 6. The Excel sheet with the calculation of the scenario quantifications is made available on the internet and referred to in Appendix F.

14.2 Quantification of Port Throughput Volumes

This section addresses the scenario quantifications for the very long term development of the throughput volumes in the Dutch seaports. It departs from a very long term probabilistic forecast of the overall port throughput volumes in the Le-Havre – Hamburg range (LHR) and continues with a discussion on the development of the overall market share of the Dutch seaports. In the next step a distinction is made between bulk cargoes and containers. The containerised fraction is estimated by considering the total volume of containerisable cargoes (i.e. cargoes that can be sensibly shipped in containers) and the degree of containerisation for these cargoes. For containers a distinction was made between conventional deepsea- and continental 45 foot containers. The bulk volumes were obtained by deducting the container throughput volumes from the total throughput volumes.

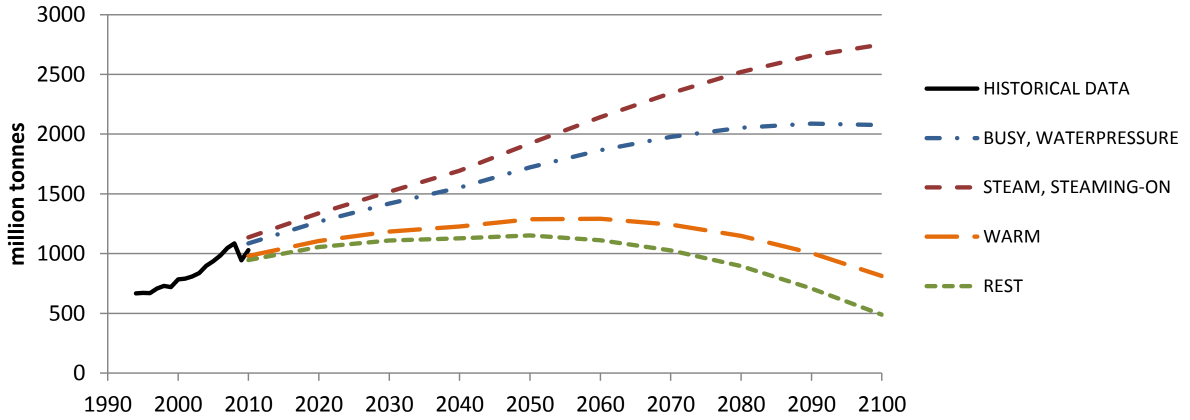
14.2.1 Total port throughput in the Le-Have – Hamburg range

The scenario quantifications for the very long term development of the port throughput are based on the probabilistic very long term forecast of Van Dorsser et al. (2012), that has been discussed in Chapter 7 (see Figure 7-19). This forecast provides insight in the expected very long term development of the total port throughput volumes in the Le-Havre – Hamburg range up to the year 2100. The probabilistic nature of this forecast implies that it does not only provide insight in the mean value of the expected trend, but also in the corresponding uncertainty levels. This makes the forecast very well suited to explore the outer corners of plausible future developments (as intended by the Delta Scenario study). The scenarios were therefore quantified by means of a direct link to the various percentiles of the probabilistic very long term port throughput forecast. The following links have been applied:

- STEAM, STEAMING-ON: 85% percentile;
- BUSY, WATER-PRESSURE: 70% percentile;
- WARM: 30% percentile;
- REST: 20% percentile.

The rationale behind selecting the 85%, 70%, 30%, and 20% percentiles is that I consider them well positioned for the exploration of the outer corners of plausible future developments. By applying these percentiles I took into account: (1) the fact that there exists a direct relation between economic output and transport; and (2) the fact that the more sustainable scenarios are likely to show a higher degree of decoupling between economic growth and transport. A 20% instead of a 15% percentile was selected in the REST scenario to account for the fact that the lower percentiles may be underestimated due to some outstanding issues with the forecast methodology (see discussion on negative alpha coefficient in Chapter 7).

The obtained scenarios for the total port throughput in the LHR are indicated in Figure 14-1.



Note: The figure indicates the total throughput of the eight largest ports within the LHR.
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-1: Total Port Throughput in the Le-Havre – Hamburg Range

Please note that the reported port throughput volumes relate to the following seaports: Le-Havre, Antwerp, Dunkirk, Gent, Rotterdam, Amsterdam, Bremen, and Hamburg. The total throughput of these seaports accounts for about 90% of the total throughput in the LHR (see Chapter 7). This implies that the total port throughput volumes for the entire LHR are some 10% higher than the volumes indicated in Figure 14-1. For the quantification of the shipping scenarios this is not considered an issue as long as it is recognised when making assumptions on the development of the market share of the Dutch seaports within the LHR.

It should further be noted that I had to limit the length of the historical data ranges that are presented in this chapter to the period from about the year 1995 to the year 2010, because the obtained CBS data (that were kindly provided by Rijkswaterstaat) did not go further back in time[155]. I am nevertheless of the opinion that it is good practice to base very long term scenario quantifications on a much longer historical data range. I would therefore recommend to use much longer data series in follow-up studies (e.g. containing data from the year 1950 onwards in order to cover at least the length of one full Kondratieff wave).

14.2.2 Market Share of the Dutch Seaports

The next step is to quantify the market share of the Dutch seaports within the LHR, which I defined as the combined port throughput volume of the Dutch seaports divided by the total port throughput volume of the eight seaports that were included in the very long term

[155] I could have presented longer historical data series in Figure 14-1 (i.e. those presented in Figure 7-19), but for most other aspects discussed in this chapter the historical data was only available from CBS statistics that cover the period 1994/1995 to 2010. I have therefore only presented the CBS data series in Figure 14-1.

throughput forecast of Figure 7-19[156]. The quantification of this market share requires insight in the main scenario drivers up to the year 2020, 2050, and 2100. The considerations with respect to the development of these drivers are addressed below.

Scenario drivers for the period up to the year 2020
The market share of the Dutch Seaports is initially expected to increase due to the opening of the 2nd Maasvlakte, but this is not the only factor that affects the market share. The market share of the Dutch ports tends to be higher in case of low economic output, because the 'hub status' of the port of Rotterdam will be more important in a smaller stagnating market than in a large booming market. In addition it can be expected that a strong focus on sustainability enhances the use of IWT. The increased use of IWT creates economies of scale (larger barges) and density (higher terminal utilisation) on the main IWT hinterland connections. This enhances the position of the Dutch and Belgium Seaports which implies that a relatively high market share should be applied in the REST, BUSY, and WATER-PRESSURE scenario.

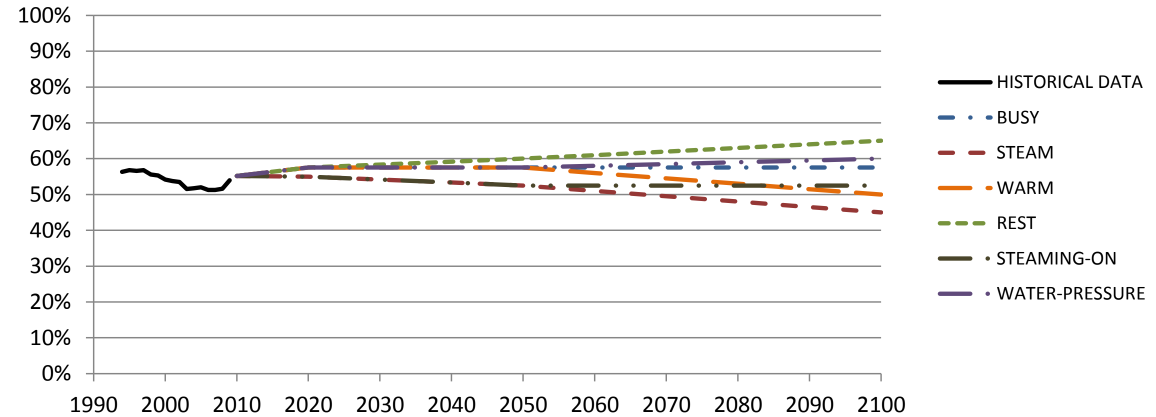
Scenario drivers for the periods up to the year 2050 and the year 2100
The most important drivers for the development of the market share are: (1) the growth of the overall transport volumes (i.e. higher throughput volumes result in a lower market share); (2) the transition towards a more sustainable world (i.e. an increased focus on sustainability enhances the market share); and (3) the possible negative effects of climate change on the navigability of the IWT hinterland connections, that may become quite severe in the second half of the century and mainly affect the competitiveness of the Dutch and Belgium seaports.

Based on these consideration the following scenarios assumptions were made:

- REST: The low levels of economic growth and strong focus on sustainability result in a strong growth of the market share for the Dutch seaports in both the period up to the year 2050 as well as in the period thereafter up to the year 2100.
- WARM: The low levels of economic growth do not result in an increased market share because an absent interest in sustainable IWT counters the effect. The market share still remains constant up to the year 2050 but decreases in the period thereafter due to negative effects of climate change on the navigability of the inland waterways.
- BUSY: The intensive use and high quality of the IWT hinterland connections enables the Dutch seaports to maintain their market share despite the high growth of the overall port throughput volumes.
- WATER-PRESSURE: Same as BUSY, but due to canalisation of the Rhine, Waal and Gelderse IJssel the quality of the hinterland connection is even further improved which slightly enhances the market share.
- STEAMING-ON: From the year 2020 onwards the Dutch seaports lose some market share compared to other ports in the LHR because the high overall port throughput volumes enhance the development of direct shipping lines to the smaller ports.
- STEAM: Same as STEAMING-ON, but with a further decrease of the market share from the year 2050 onwards, due to the effects of climate change on the navigability of the inland waterways.

[156] Note that by applying this definition the reported market share of the Dutch seaports in the LHR is about 10% overestimated, because the total volume in the LHR, by which the volumes of the Dutch seaports are divided, is about 10% lower than it would be if all the ports in the LHR would have been taken into account.

Figure 14-2 indicates the applied assumptions on the development of the market share of the Dutch seaports within the LHR.



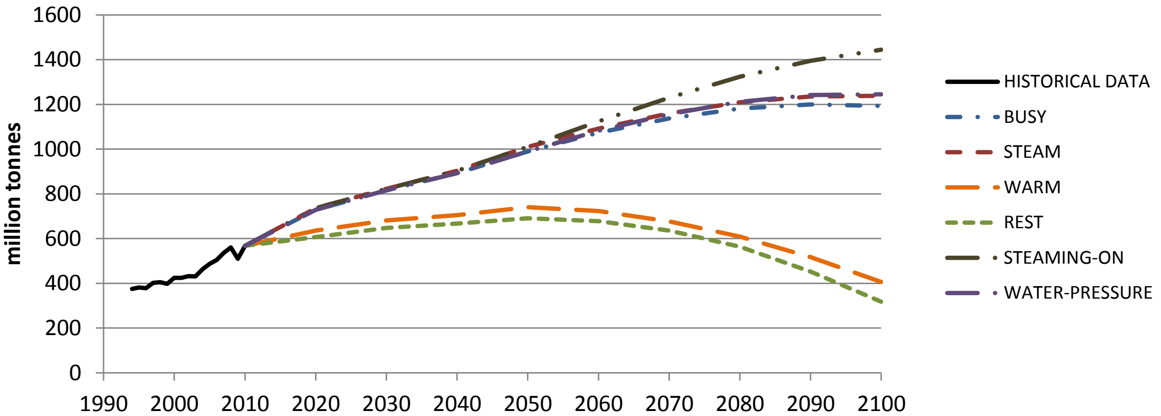
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-2: Market Share of the Dutch Seaports within LHR

I would like to emphasize that a decreasing market share does not necessarily imply a drop in the total throughput volumes. In particular for container transport the total throughput volumes can still show a strong growth, while the market share decreases.

14.2.3 Total port throughput volumes of the Dutch seaports

Insight in the development of the Dutch port throughput volumes is obtained by multiplying the market shares of Figure 14-2 with the port throughput volumes presented in Figure 14-1. The results of this exercise are indicated in Figure 14-3.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-3: Total Port Throughput of the Dutch Seaports

Figure 14-3 points out that the relative differences in the Dutch port throughput scenarios are considerably smaller than the relative differences in the scenarios for the LHR (see Figure 14-1). This can be explained by the fact that the reduction in port throughput volumes for the more sustainable scenarios (stemming from a higher decoupling between economic growth and transport) is countered by the improved quality of the IWT hinterland connections (that enhances the market share of the Dutch and Belgium seaports). It can further be observed that the highest port throughput volumes are expected in the additional STEAMING-ON and

WATER-PRESSURE scenarios. One can therefore conclude that these scenarios are most suitable to address the outer corners of plausible future developments.

When comparing the bandwidth of my scenario quantifications with the bandwidth of the WLO scenarios for the year 2040 (see Chapter 3), it can be observed that I obtained a much smaller bandwidth. Where the WLO scenarios for the year 2040 indicate a total throughput between 400 and 1,000 million tonnes my volumes range between 670 and 900 tonnes. A logical explanation for this difference is the fact that the estimates of the WLO scenarios are based on a summation of disaggregated projections while my estimates are based on an aggregated projection. The smaller bandwidth confirms that it is sensible to base very long term scenario quantifications on the outcome of high level projections.

14.2.4 Relative share of containerisable cargoes

The quantification of the total container throughput volumes requires insight in: (1) the development of the relative share of containerisable cargoes as a fraction of the overall transport volumes; and (2) the development of the overall degree of containerisation for containerisable cargoes. Rijkswaterstaat kindly provided the following datasets that provided insight in the historical development of the relative share of containerisable cargoes:

1. A detailed sample of the total- and containerised port throughput volumes (in tonnes) by NSTR2 commodity group for the month April 2007;
2. Detailed statistics on the port throughput volumes (in tonnes) by NSTR2 commodity group for the Dutch seaports in the period from 1994 to 2009.

I used the detailed sample to investigate how the NSTR2 groups (for which the historical port throughput data is available in the second file) can be subdivided into three commodity classes that were defined as follows: (1) non containerisable (less than 0.1% transported in containers); (2) partly containerisable (0.1% to 10% transported in containers); and (3) fully containerisable (over 10% transport in containers). This resulted in the following rule:

- Non containerisable: NSTR 00,21,31,32,33,34,41,71;
- Partly containerisable: NSTR 11,17,18,23,45,52,61,63,65,72,81,82,83;
- Fully containerisable: All other NSTR2 commodity classes.

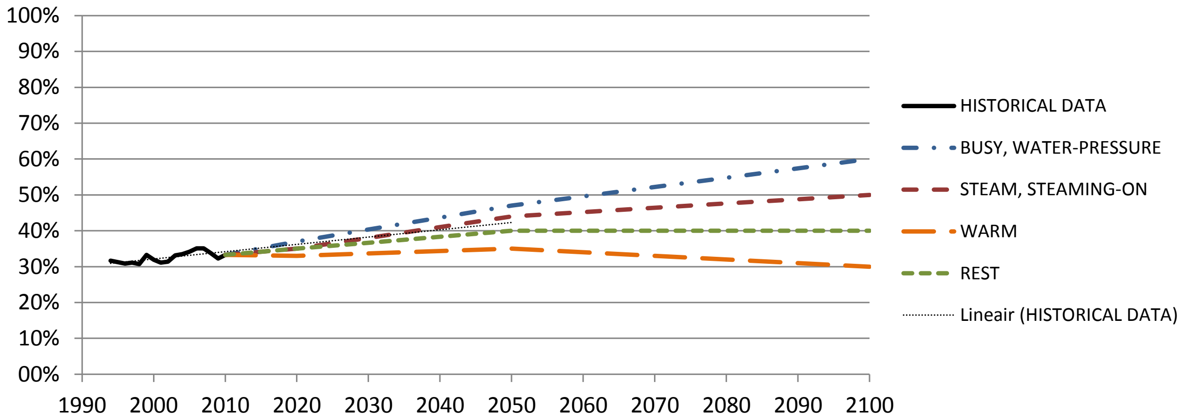
I further assumed that the containerisable cargoes can be estimates as 100% of the fully containerisable cargoes plus 25% of the partly containerisable cargoes (based on my personal judgement), and applied this rule to the detailed port statistics for the years 1994 to 2009 in order to obtain insight in the historical development of the share of containerisable cargoes.

The scenario assumptions for the development of the relative share of containerisable cargoes were further based on the following considerations:

- BUSY, WATER-PRESSURE: Decreased demand for bulk commodities stemming from sustainable energy demand, recycling, a shift of heavy industries to countries in which raw materials are mined, and high international trade volumes that are reflected by a relatively high share of containerisable cargoes;
- STEAM, STEAMING-ON: The very strong growth of the economy results in a strong growth of half-fabricates and final products. This also causes an increased share of containerisable cargoes in the total port throughput.
- REST: Initially an increase in the share of containerisable cargoes is expected due to a loss of demand for fossil fuels. The share of containerisable cargoes is later stabilised at a fixed level due to an increased share of locally produced goods.

- WARM: Low economic growth and high dependency on fossil fuels result in a very slow initial growth of the relative share of containerisable goods. From about the year 2050 onwards the shrinking economy even causes the demand for consumer goods to drop faster than the demand for base products (e.g. foodstuff and fuels) which causes a decrease in the fraction of containerisable goods on the very long term.

Figure 14-4 shows the effect of the applied assumptions on the share of containerisable goods in the various scenarios.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

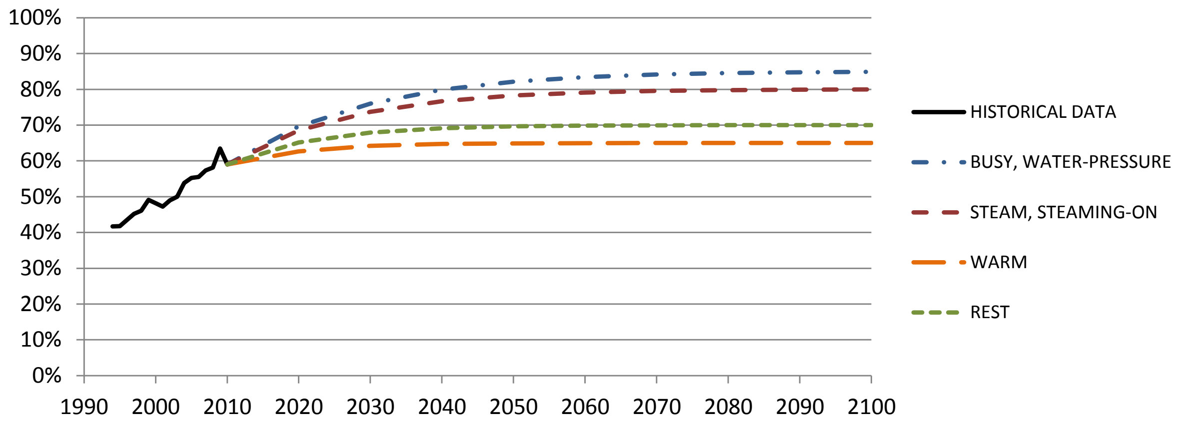
Figure 14-4: Relative Share of Containerisable Cargoes

The assumptions on the development of the share of containerisable cargoes are defined in line with the historical trend and take into account the fact that the growth in the share of containerisable cargoes concerns a transition process that cannot continue forever (maximum attainable is 100%). The share of containerisable cargoes was therefore assumed to stabilise or even decrease in the lower economic output scenarios. If these assumptions are compared with the estimates of the WLO scenarios (i.e. 43% to 47% in 2020; 50% to 62% in 2030; and 51% to 62% in 2040) it can be observed that I expect a much lower market share. Considering the fact that this concerns a transition process I do not understand why such a high growth in the share of containerisable cargoes is assumed in the WLO scenarios.

14.2.5 The degree of containerisation

The next step is to define the degree of containerisation for the containerisable cargoes. Insight in the historical development of this trend was obtained by analysing the historical data, which indicated that the degree of containerisation has increased considerable over the period from 1994 to 2009 (see Figure 14-5).

The degree of containerisation can by definition not be higher than 100%. This implies that the growth of the degree of containerisation can be expected to follow a transition S-curve that will eventually level off at a certain value below 100%. As the final level of this S-curve cannot be known on forehand, I have applied different limits to the various Delta Scenarios. These limits are based on the considerations that: (1) larger transport volumes result in a higher eventual degree of containerisation; and that: (2) a strong global and European focus on sustainable development will result in a higher eventual degree of containerisation. The first assumption is based on the principle that high transport volumes result in high economies of scale, and relatively low costs for the transport of goods in containers. This will increasingly enhance lower valued goods to be shipped in containers. The second assumption is related to the fact that the recycling industry is increasingly shipping recyclable products in containers (e.g. metals, paper, plastics) – and the fact that sustainable intermodal short sea transport also enhances freight volumes to be shipped in containers. The effects of the applied scenario assumptions on the degree of containerisation are shown in Figure 14-5.

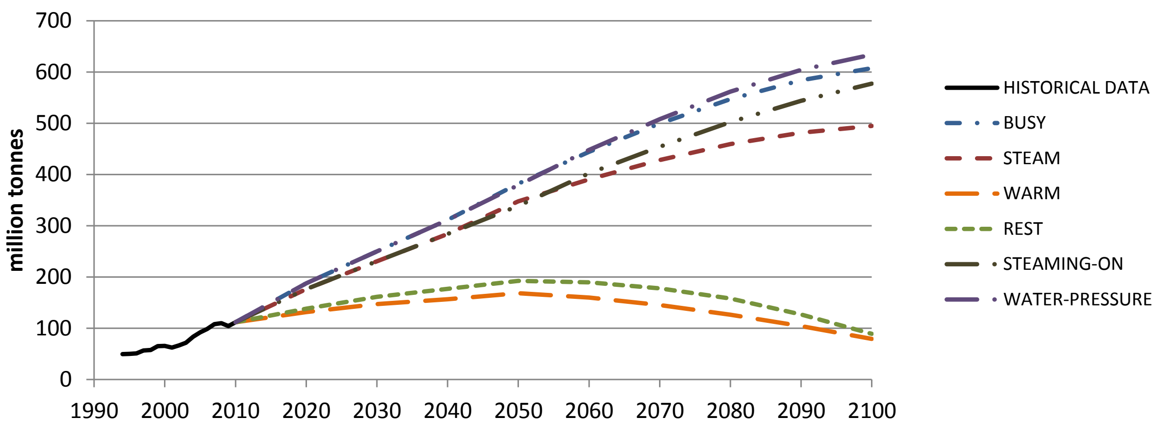


Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-5: Degree of Containerisation

14.2.6 Total container throughput volumes

Insight in the overall development of the total container throughput volumes can be obtained by multiplying the total throughput volumes (see Figure 14-3) by the relative fraction of containerisable cargoes (see Figure 14-4) and the assumed degree of containerisation (see Figure 14-5). The obtained scenario quantifications are presented in Figure 14-6.



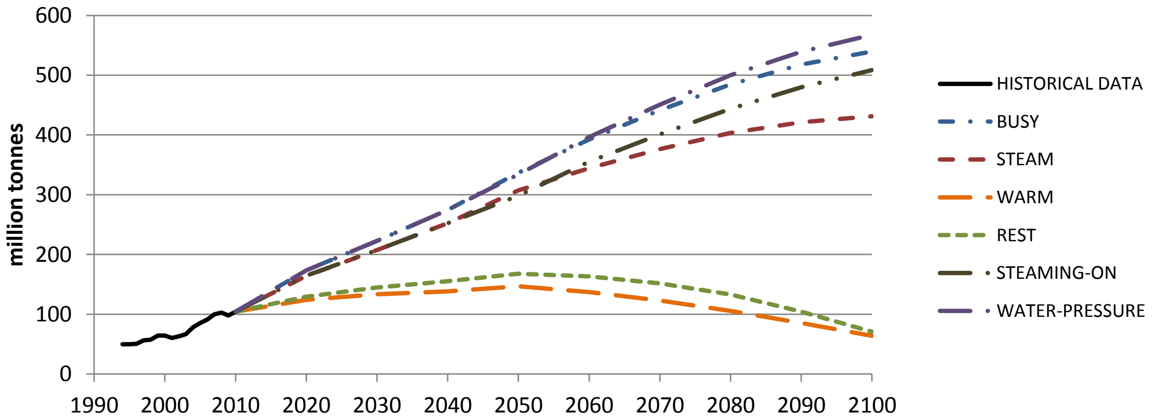
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-6: Total Container Throughput Volumes

It can be observed that the total container throughput in the Dutch seaports is likely to range between 170 and 380 million tonnes in the year 2050. For the year 2100 the bandwidth of the scenario quantifications is much wider and varies between 80 and 630 million tonnes. If these volumes are compared with the container throughput volumes in the WLO scenarios (see Figure 3.3) one can conclude that the bandwidth of my scenario quantifications is much smaller. Where the throughput volumes in the WLO scenarios range from about 100 to 400 million tonnes in the year 2040 my scenarios range from about 160 to 310 million tonnes.

14.2.7 Conventional container throughput volumes

The total container throughput volumes consist of conventional (deepsea) containers and continental 45 foot (short sea) containers. The share of continental 45 foot containers is discussed in Section 14.4.2. The conventional container throughput volumes are defined by deducting the share of continental 45 foot containers (see Figure 14-16) from the total container throughput volumes (see Figure 14-6). The overall size of the conventional container throughput volumes is indicated in Figure 14-7.

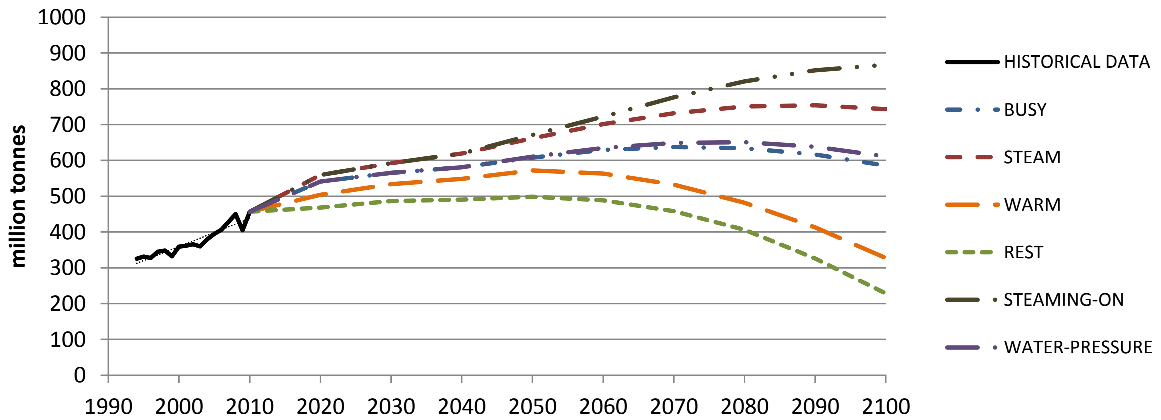


Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-7: Conventional Container Throughput Volumes

14.2.8 Total bulk and break-bulk throughput volumes

The total throughput of non-containerised bulk and break-bulk commodities can be defined by deducting the total container throughput volumes of Figure 14-6 from the overall throughput volumes in Figure 14-3. The results of this exercise are indicated in Figure 14-8.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-8: Bulk and Break-Bulk Throughput Volumes

The largest growth of bulk and break-bulk commodities occurs in the STEAMING-ON scenario that is characterised by a strong growth in the demand for fossil fuels in combination with the non-occurrence of negative effects of climate change on the navigability of the inland waterways. The STEAM scenario initially follows the same path, but the growth of the bulk volumes is significantly tempered from the year 2050 onwards due to severe issues with the navigability of the Rhine. As a result many industrial complexes in the Ruhr area (e.g. steel industries) will relocate their activities to other (German) sea ports and/or countries in which the raw materials are mined. This trend is reflected by an overall decrease in the throughput of bulk commodities shipped via the Dutch seaports towards the end of the century.

The bulk throughput also remains quite substantial in the BUSY and WATER-PRESSURE scenarios although the volumes will be lower than in the STEAMING-ON and STEAM scenarios due to the greening of the energy sector and the strong focus on recycling of materials. In addition a shift of conventional bulk commodities towards more sustainable new bulk products such as recycled materials, biofuels and biochemicals can be expected. The throughput volumes in the WATER-PRESSURE scenario are slightly larger than in the BUSY scenario. This difference is caused by the canalisation of the Rhine, Waal, and Gelderse IJssel that further improves the quality of the IWT network (compared to the BUSY scenario) and therefore slightly increases the market share of the Dutch and Belgium seaports within the Le-Havre – Hamburg region.

The WARM scenario is characterised by a relatively high demand for fossil fuels and raw materials. This demand results in a continuing increase of the bulk volumes throughout the first half of the 21st century. However, the economic decline and adverse effects of climate change on the navigability of the Rhine in the second half of the century cause a severe drop in the throughput volumes. Many industries in the Ruhr area are forced to close down and/or relocate their activities to the countries where the raw materials are mined. This causes a strong decrease in the bulk throughput volumes handled by the Dutch seaports.

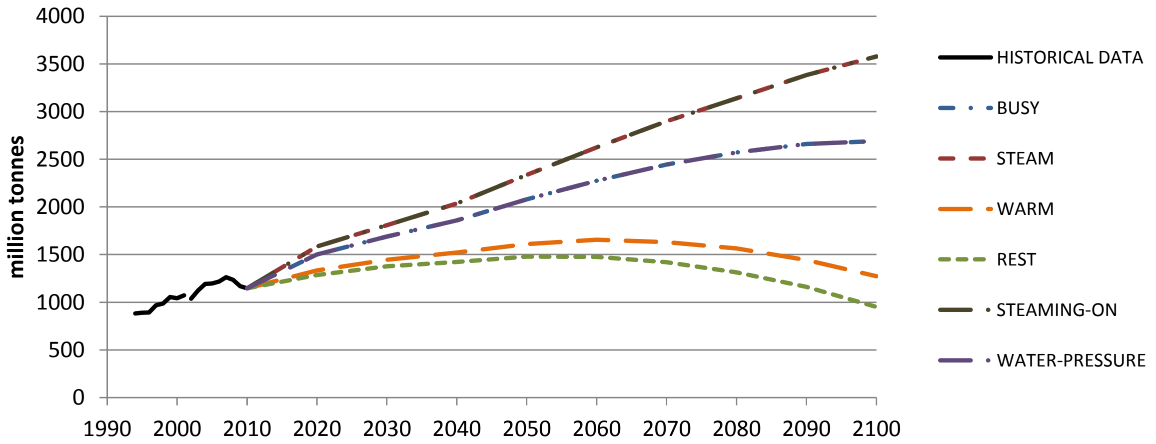
The REST scenario shows the highest decrease in bulk throughput volumes that is caused by a massive shift towards sustainable decentralised energy production (that no longer depends on the use of fossil fuels) and a very strong focus on recycling of materials (for which most of the products are transported in containers).

14.3 Quantification of Inland Transport Volumes

This section addresses the quantification of the inland transport volumes (i.e. the transport volumes shipped by inland modes such as road, rail, IWT, and pipelines). It starts with the quantification of the total inland transport volumes, and then continues with a more detailed discussion on the following three cargo segments: (1) non-containerised bulk and break-bulk cargoes; (2) conventional container cargoes; and (3) other continental general cargoes. These three cargo segments have been linked to the categories of my new commodity classification system that was introduced in Chapter 11. The non-containerised bulk and break-bulk cargo segment contains the non-containerised bulk volumes (NCB); The conventional container cargo segment contains the containerised bulk (CB) and deepsea container (DC) volumes; and the other continental general cargo segment contains the continental container and full truck loads (CL), the parcel loads (PL), and the small packages (CS). The transport volumes in the other continental general cargo segment are still predominantly concerned with unimodal road transport of full truck loads (FTL), parcel loads (LTL), and packages – but in some of the scenarios I have assumed intermodal transport of continental cargoes (e.g. in continental 45 foot containers) to gain importance. This section therefore concludes with an analysis of the full potential for intermodal transport of continental cargoes that, depending on the scenario, will or will not be realised. On the basis of this analysis an estimate will be made of the expected intermodal transport volumes by means of short sea shipping (at the end of this section) and by means of IWT (in the next section).

14.3.1 Total inland transport volumes

The total inland transport volumes were quantified by multiplying the base year 2000 data on national freight transport of the CBS (as provided by Rijkswaterstaat) by the percentiles of the very long term probabilistic forecast of the combined transport index, for which the year 2000 serves as base year (see Figure 7-25). For inland transport the same percentiles were selected as for port throughput (see Section 14.2.1). The obtained scenario quantifications for the total inland transport volumes are indicated in Figure 14-9.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-9: Total Inland Transport Volumes

Problematic for the quantification of the total inland transport volumes is the fact that the European Commission shifted in the year 2001 (after the opening of the internal borders) from road transport measurement based on total haulage by national territory to road transport measurements by haulage of companies registered within the individual member states (see also discussion in Appendix A). As a result the CBS data on road transport were also reported by haulage of companies registered within the member states (even for the year 2000 data that preceded the shift). To deal with this issue I applied a correction based on the 1998 and 2004 *'base year files for freight transport'* (see also Chapter 12), that includes an estimate of the total transport volumes on the national territory. This allowed me to define the inland transport volumes on the Dutch National territory for the base year 2000. On the basis of these adjusted statistics the total inland transport volumes were estimated at 1,041 million tonnes in the year 2000. This number consists of: 644.2 million tonnes of road transport (compared to 584.6 million tonnes transported by Dutch transport companies); 315.1 million tonnes of IWT; 28.1 million tonnes of rail transport; and 53.4 million tonnes of pipeline transport. Similar corrections were also made for the other years in the historical data range.

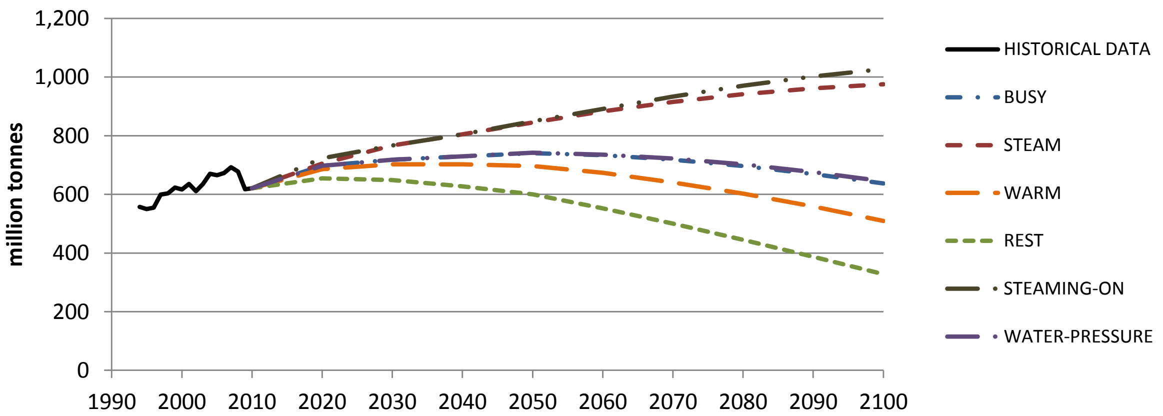
I could have used a more recent base year than the year 2000. However, if I would have applied the year 2010 instead (i.e. the last year in the dataset), the quantitative estimates would have only been about 1% lower than reported. This implies that the choice for the base year 2000 had only a small effect on the outcome of the scenario quantifications.

More important is my decision to base the quantification of the inland transport volumes on the forecast of the combined transport index (see Figure 7-25), instead of on the forecast of the inland transport volumes (see Figure 7-20). The reason for using the forecast of the combined transport index is that I consider this forecast more robust. It should however be noted that this choice resulted in respectively 26%, 21%, 8%, and 6% higher scenarios for the

REST, WARM, BUSY/WATER-PRESSURE and STEAM/STEAMING-ON scenarios. The differences are in particular large for the scenarios that are linked to the lower percentiles of the very long term forecast, because for these percentiles the issues with the applied forecast methodology (i.e. the issues with the constant negative alpha coefficient as discussed in Chapter 7) are most predominant. I think that higher values will been found that are more in line with the applied estimates of the combined transport index if these issues can be solved. This further justifies the use of the forecast for the combined transport index.

14.3.2 Inland bulk and break-bulk volumes

In order to quantify the size of the inland bulk and break-bulk flows I assumed that they can be modelled as a function of the size of the Dutch population and the corresponding throughput of the Dutch seaports. I applied a simple regression function that was defined on the basis of year 1995 to 2010 data. On the basis of this function the total inland transport of bulk and break-bulk commodities was estimated at 29.1 tonnes per capita and at 0.41 tonnes per tonne of bulk and break-bulk throughput in the Dutch seaports. In retrospect it may have been better to link the bulk volumes to the population of the broader hinterland instead of using the Dutch population as an estimator for the development of the population in the region, but scenarios for the broader hinterland population were not available. I further assumed a 10% reduction of the per capita consumption in the REST, BUSY, and WATER-PRESSURE scenarios for the year 2050 and a 30% reduction for the year 2100, to account for the effects of the transition towards a sustainable society. The obtained scenarios for inland bulk and break-bulk transport are indicated in Figure 14-10.



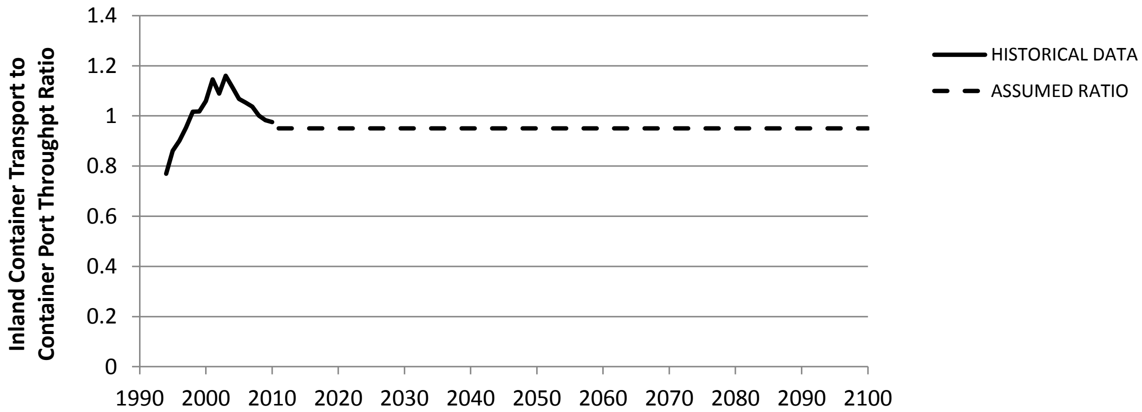
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-10: Inland Bulk and Break-Bulk Transport Volumes

The largest growth of the bulk and break-bulk volumes is expected in the STEAM and STEAMING-ON scenarios. These scenarios show a continuous growth of the bulk transport volumes throughout the 21st century. The BUSY and WATER-PRESSURE scenarios show a moderate growth of the bulk volumes in the first half of the century after which they slowly start to decrease. The WARM scenario indicates the volumes to remain more or less constant throughout the first half of the century, but show a significant drop in the period thereafter. This drop is caused by economic contraction and severe effects of climate change on the navigability of the Rhine, that reduces the competitiveness of the Dutch seaports. The largest drop in the transport volumes of the inland bulk commodities can be observed in the REST scenario where low economic output and a strong focus on sustainability cause a large decrease in the inland transport of bulk and break-bulk cargoes.

14.3.3 Conventional inland container volumes

The quantifications for the conventional inland container flows (mainly deepsea containers transported to the hinterland) are based on the ratio between the conventional inland container volumes and the conventional container throughput volumes in the Dutch seaports. The historical data does however not provide a clear trend. I have therefore applied a simple assumption that is indicated together with the historical data in Figure 14-11.

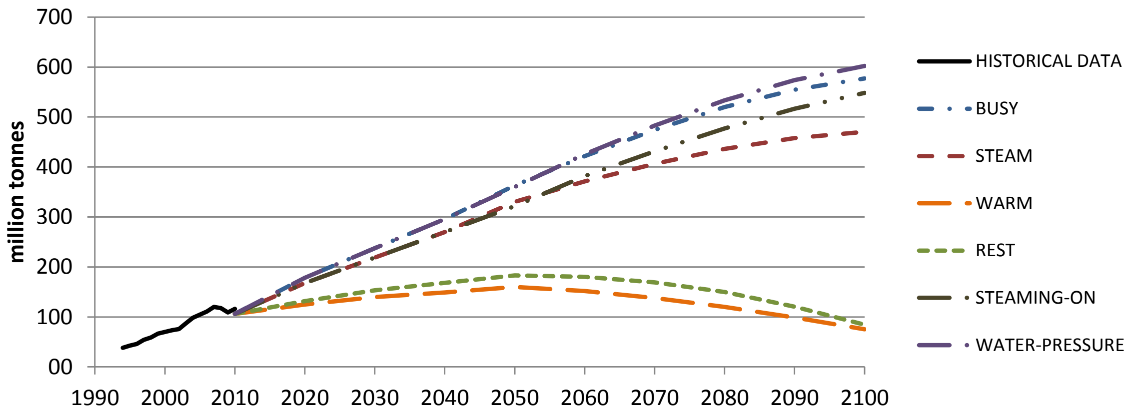


Note: The ration has been defined on the basis of the volumes in tonnes.
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-11: Inland Container Transport to Container Port Throughput Ratio

The historical values were initially below one which implies that the throughput volumes were higher than the inland container volumes. This can be explained by the fact that seaport hubs also handle transhipment containers. However the peak value is larger than one which implies that the inland transport volumes were larger than the port throughput volumes. At the time of developing the shipping scenarios I could not understand this peak value and still lacked a sensible explanation (see Van Dorsser, 2012). My latest thoughts on this subject are that the high values of this ratio are caused by interference with other ports outside the Netherlands, in particular with the port of Antwerp. The fact that large numbers of containers are shipped via Dutch territory to/from the port of Antwerp (e.g. by inland barge to/from the Netherlands or Germany), is likely to cause the *'inland container transport to container port throughput ratio'* to become larger than one. Additional research on this topic is necessary before more detailed statements on the development of this ratio can be made.

For the quantification of the shipping scenarios I argued that the last eight years showed a decreasing trend, that I assumed to move towards an equilibrium value of about 0.95. I thought that a value just below one would make sense as conventional containers are not that much used in non-port related intermodal inland transport flows (i.e. by road, rail, and IWT) and hub seaports such as the port of Rotterdam attract quite some transhipment cargoes. In addition I did not apply different assumptions to the various scenarios, because at that time I was still unable to understand why this ratio could take values that are larger than one. I have therefore estimated the inland container transport volumes by applying a 0.95 ratio to the container throughput volumes presented in Figure 14-6. My new insights in the possible explanation for the high values of this ratio do not provide a reason to revise the numbers, because I still consider the 0.95 ratio the best possible mean estimate. For this reason no adjustments to the initial scenarios were made to take these new insights into account. The obtained scenario quantifications are indicated in Figure 14-12.



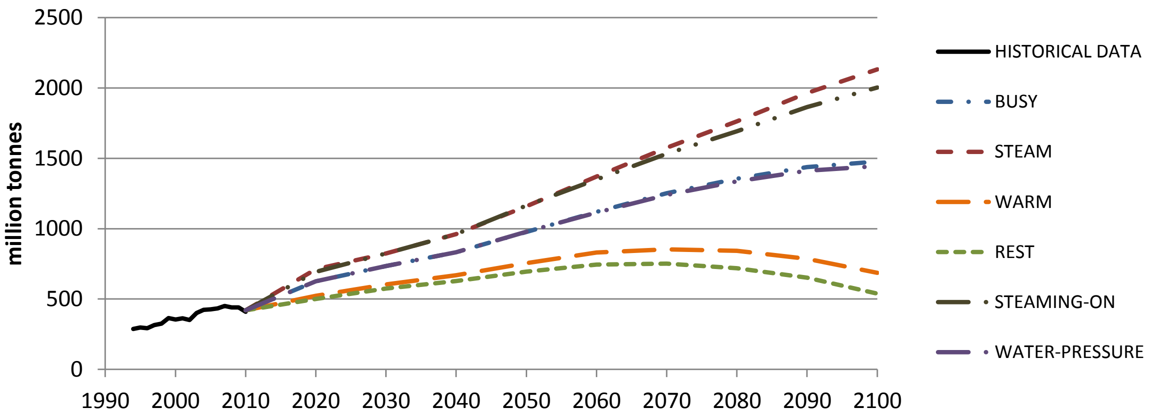
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-12: Conventional Inland Container Transport Volumes

It can be observed that the conventional container transport volumes in the BUSY, STEAM, STEAMING-ON and WATER-PRESSURE scenarios are more or less similar. The same holds for the conventional container transport volumes in the WARM and REST scenarios. The reason that these volumes are quite similar is that the effect of decoupling in the more sustainable scenarios is offset by an increased use of the waterways, which reduces the cost levels of IWT and enhances the competitiveness of the Dutch seaports.

14.3.4 Other continental general cargo volumes

An indication of the size of the other continental general cargo volumes can be obtained by deducting the bulk and break-bulk volumes (see Figure 14-10) as well as the conventional container volumes (see Figure 14-12) from the total inland transport volumes (see Figure 14-9). The results of this analysis are indicated in Figure 14-13.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-13: Other Continental General Cargo Volumes

The highest continental inland transport volumes occur in the STEAM and STEAMING-ON scenarios. The volumes in the BUSY and WATER-PRESSURE scenarios are significantly lower. The WARM and REST scenarios contain the lowest volumes. For these scenarios the shrinking economy in the second half of the century results in a drop of the continental inland transport volumes. The volumes in the REST scenario are lower than in the WARM scenario due to a strong focus on more sustainable local production.

14.3.5 Full potential for development of intermodal continental transport

The continental general cargo volumes appear as: (1) full truck or container loads; (2) less than truck or container loads; and (3) small packages (see Chapter 11 and 12). Most of these volumes are still transported by unimodal road transport, but except for the category small packages one can expect a shift towards intermodal continental transport in some of the scenarios. To define the full potential for the development of intermodal continental container and pallet transport, I took into account the ambitious aim of the European Commission, to shift 50% of all long haulage road freight over 300 km towards more sustainable intermodal transport by the year 2050 (see Chapter 2). This subsection investigates the full potential in case this aim is realised. In later sections I will assume that the EU ambitions are fully realised in the sustainable high volume BUSY and WATER-PRESSURE scenarios, still rather successful in the sustainable low volume REST scenario, and hardly realised in the unsustainable STEAM, STEAMING-ON, and WARM scenarios.

Insight in the potential volumes for these flows can be obtained from the converted data of the *'2004 base year files for freight transport'* for road transport over 300 kilometre as reported in Table 12-4. If these numbers are compared with the data on the total transport flows for all modes of transport combined (see Table 12.2) they provide insight in the relative size of the targeted 50% modal shift for continental road transport over 300 kilometre as a fraction of the total continental transport volumes. However, the development of advanced pallet distribution networks is likely to have only just begun by the year 2050 (see Chapter 8), and small packages will continue to be transported by road. Parcel loads (CP) and small packages (CS) can therefore not be expected to be shifted by the year 2050. This implies that a higher modal shift has to be targeted for the other commodities in order to realise the 50% overall target of the European Commission. The modal shift for the combined non-containerised bulk (NCB), containerised bulk (CB), deepsea containers (DC), and continental containers and full truck loads (CL) commodity classes therefore has to be increased to 57% to meet the target.

The potential continental cargo volume that can be shifted to intermodal transport by the year 2050 is based on the assumption that the relative distribution of the freight flows is the same as in the base year 2004. By applying the 57% target value to the 74.9 million tonnes of continental full load cargoes (CL) it becomes clear that some 42.6 million tonnes will have to be shifted towards intermodal transport (based on year 2004 volumes). The total continental general cargo volume (CL, CP, and CS) for all combined inland modes of transport consisted of 436.1 million tonnes in the year 2004 (see Table 12.2). This implies that some 10% of the total continental general cargo volume has to be shifted by the year 2050 to meet the target.

The scenario quantifications further require a number of additional assumptions concerning the rate at which the intermodal continental container and pallet transport networks can be expected to develop. In line with the discussion in Chapter 8, the individual transition S-curves for the development of intermodal continental short-sea-, rail-, and barge container transport, as well as the S-curve for the development of an advanced intermodal continental pallet distribution network, are expected to cover a period of about two Kondratieff waves. The phasing of these S-curves is further based on the considerations that:

- Continental short-sea and rail transport in 45 foot containers has become a success after the introduction of the carved corner fitting in the year 1998 (Platz, 2009);
- Recent developments show the first signs that continental container transport may now start to develop on the inland waterways (see Chapter 10);
- Intermodal continental pallet distribution networks can be assumed to be developed in the period from about the year 2045 onwards (see Chapter 8).

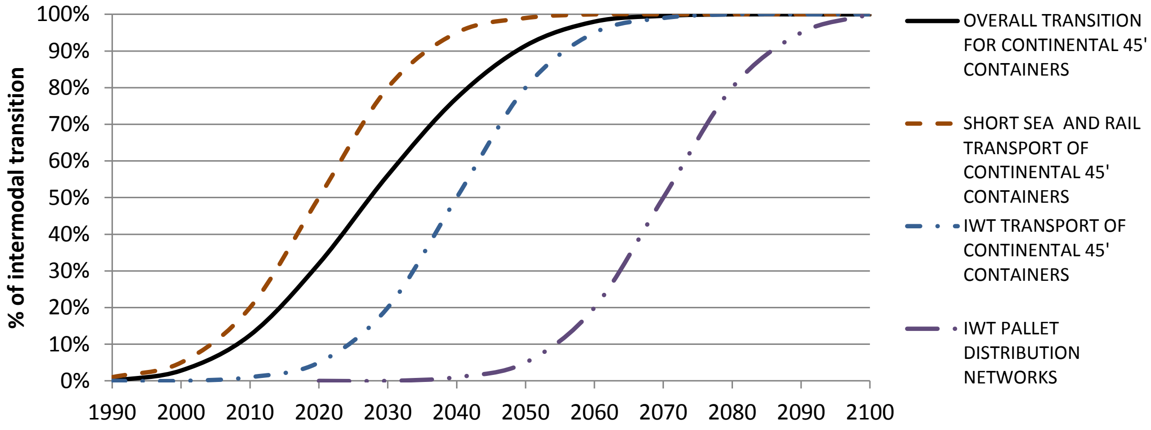


Figure 14-14: Development of Intermodal Continental Container and Pallet Transport

The assumed transition S-curves are indicated in Figure 14-14. The overall transition S-curve for continental container transport (e.g. in 45 foot containers) is based on a calculation that takes into account the relative share of short-sea-, rail-, and barge transport and further assumes: (1) that the modal split will eventually (when the intermodal transition has been completed for continental cargoes) be similar to the modal split for conventional deepsea containers; and (2) that the long term projections of the WLO study on the development of the modal split for conventional containers up to the year 2040 can be extrapolated towards the end of the century. Both assumptions are of course incorrect, but they at least provide some guidance in absence of a more sophisticated very long term transport model.

Assuming that the development of the intermodal continental container transport network is completed for 93% in the year 2050 (see Figure 14-14) the ultimate share of long haulage intermodal continental transport over 300 kilometre will account for about 11% of the total continental inland transport volumes (i.e. 10% / 93%). This 11% has therefore been applied to estimate the maximum attainable continental long haulage volumes that will be shifted in case the ambitious aims of the European Commission are fully realised. The implications of such a 50% shift of all continental cargoes over 300 kilometre are indicated in Figure 14-15.

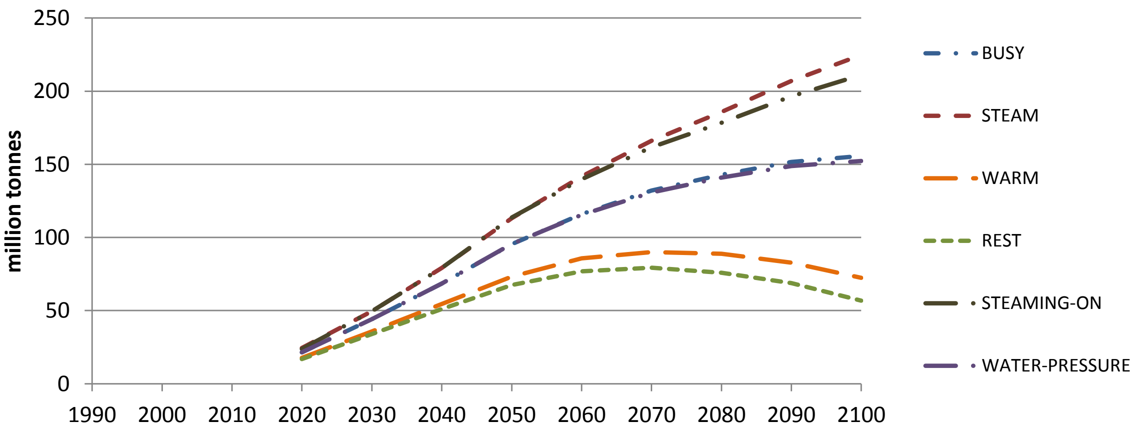
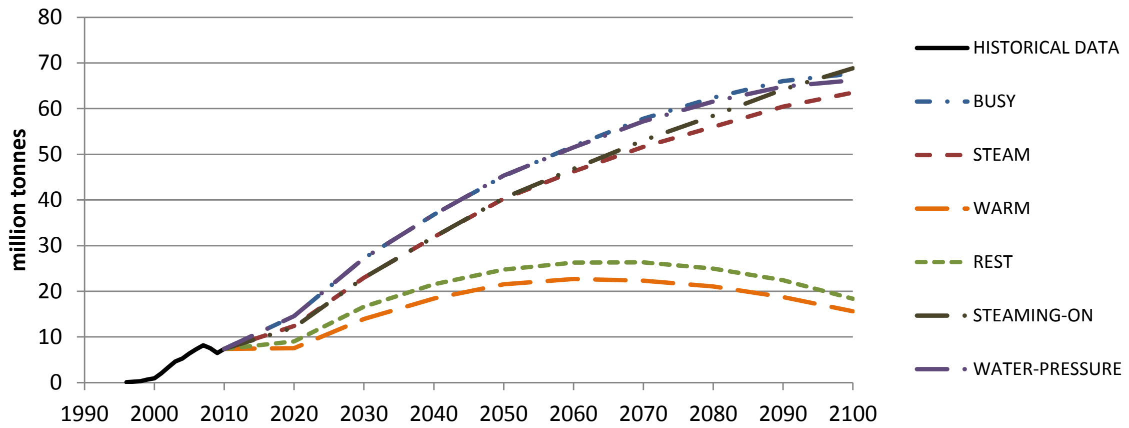


Figure 14-15: Potential Continental Volumes over 300 km shifted if EU Policy succeeds

The obtained numbers provide the basis on which the port throughput volumes for continental short sea shipping as well as the share of IWT in the intermodal transport of continental full cargo loads over 300 kilometre are defined in Section 13.3.6 and Section 14.4.3.

14.3.6 Continental intermodal short sea container transport

The full scale development of continental short sea container transport is estimated by simply assuming the share of short sea shipping in the transport of continental containers to match the share of short sea shipping in the transport of conventional containers – and by taking into account a factor that addresses the extent to which the modal shift ambitions of the European Commission are finally achieved. In addition the modal shift policies are assumed to be the most successful in the scenarios with a high transport volume and a strong focus on sustainability. The obtained scenario quantifications are indicated in Figure 14-16.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-16: Continental Short Sea Container Throughput in 45 foot Containers

14.4 Quantification of Inland Waterway Transport Volumes

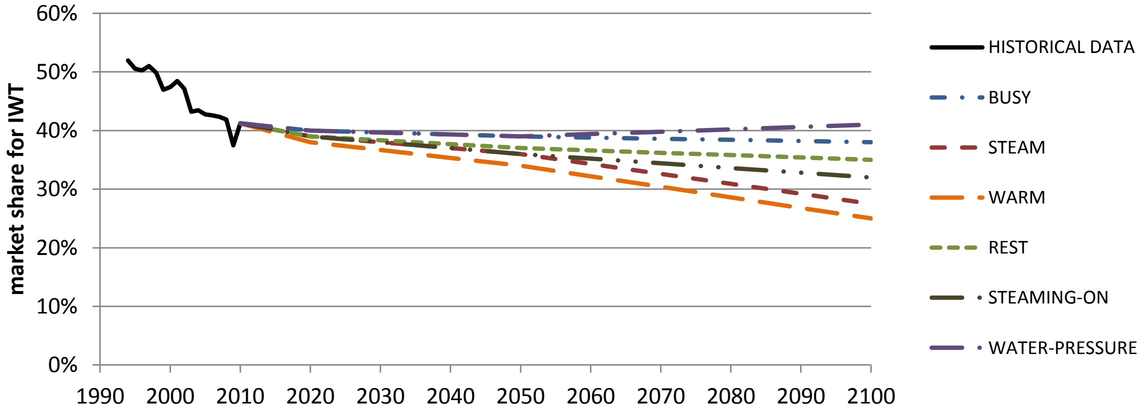
This section addresses the quantification of the IWT volumes for the three main cargo segments (bulk and break-bulk cargoes, conventional container cargoes, and other continental general cargoes) that were defined in the previous section. The first two segments reflect almost 100% of the present IWT volumes. By the year 2010 virtually no ‘other continental general cargoes’ were shipped by IWT (see Chapter 10), but intermodal continental container transport (e.g. shipped in continental 45 foot containers) could very well be developed in the first half of the 21st century – and if this happens continental pallet distribution networks may also be developed in the second half of the century (see Chapter 8). I therefore included these two continental cargo flows in the quantification of the very long term IWT scenarios.

14.4.1 IWT of bulk and break-bulk volumes

The following assumptions on the development of the relative market share of IWT in the bulk and break-bulk segment were made to define the inland bulk and break-bulk volumes, that are shipped via the inland waterways:

- The market share of IWT is assumed to be larger in the more sustainable REST, BUSY and WATER-PRESSURE scenarios than in the less sustainable WARM, STEAM, and STEAMING-ON scenarios;
- The market share of IWT is assumed to be higher in the scenarios with a higher transport volume, because high transport volumes offer more economies of scale and therefore improve the competitiveness of the IWT system;
- A decrease in the market share of IWT is assumed in the WARM and STEAM scenarios from about the year 2050 onwards, due to the adverse effects of climate change on the navigability of the inland waterways.

Figure 14-17 indicates the applied scenarios for the development of the market shares of IWT in the transport of bulk and break-bulk cargoes. It can be observed that the historical market share of IWT for bulk commodities is showing a gradual decline, which is amongst others caused by the fact that bulk shipments of ores and agricultural products are declining (Luman, 2013), and the fact the smaller barges nowadays tend to be phasing out and seem to be replaced by direct road transport (Van Hassel, 2011).

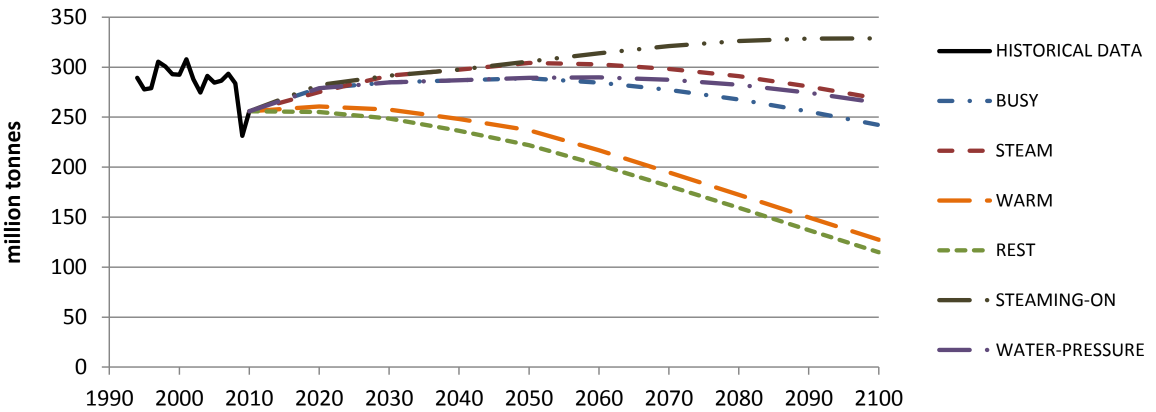


Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-17: Market Share of IWT in Bulk and Break-Bulk Transport

It should however be noted that I have not made an in depth study of the underlying dynamics, that are taking place in the development of the bulk and break-bulk market for IWT. Additional research on this subject still has to take place.

The size of the inland bulk and break-bulk volumes that are shipped by IWT is obtained by multiplying the total inland bulk and break-bulk volumes (see Figure 14-10) by the assumed market shares for IWT (see Figure 14-17). The results are indicated in Figure 14-18.



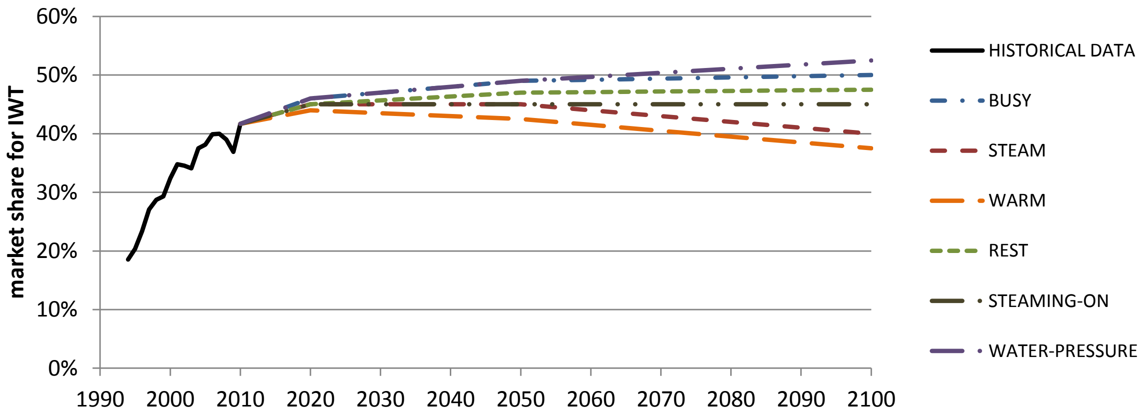
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-18: Bulk and Beak-Bulk Volumes Transported by IWT

It can be observed that very little growth of bulk and break-bulk transport is expected in the various scenarios. The volumes are assumed to initially recover from the substantial drop that followed the 2009 financial crisis, remain stable for a certain period thereafter, and then continue to decrease. The obtained bulk and break-bulk scenarios are reasonably in line with the projections of Quispel (2013) for the period up to the year 2020.

14.4.2 IWT of conventional container volumes

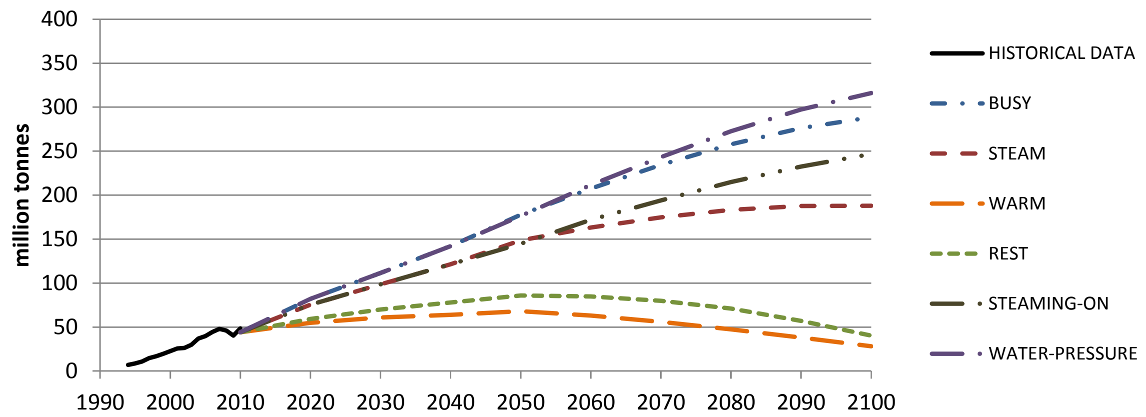
In a similar way a number of assumptions was made on the development of the modal share for IWT in the hinterland transport of conventional deepsea containers. These assumptions are based on similar considerations as for bulk and break-bulk cargoes. I assumed a higher share of IWT in high throughput scenarios, sustainable scenarios, and scenarios with very limited effects of climate change on the navigability of the waterways. The assumed market share for IWT of conventional containers is indicated in Figure 14-19.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-19: Market Share of IWT in Conventional Container Volumes

The overall size of the conventional inland container volumes that are shipped by IWT is obtained by multiplying the total conventional container volumes (in Figure 14-12) with the assumed market share of IWT (in Figure 14-19). The results are indicated in Figure 14-20.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-20: Conventional Container Volumes Transported by IWT

It can be observed that the conventional container volumes show a significant growth. Even the low economic growth scenarios indicate a reasonable growth of 30% in the WARM scenario and 60% in the REST scenario up to the year 2050 (compared to the year 2010 volumes). The high growth scenarios indicate a much higher growth of about 200% to 250%

up to the year 2050 and about 280% to 540% up to the year 2100 (also compared to the year 2010 volumes). The large growth of these volumes creates additional economies of scale in the hinterland transport of containers. This further reduces the costs of barge transport and terminal operations and thereby enhances the development of continental intermodal IWT flows, for which an estimate is made in the next section.

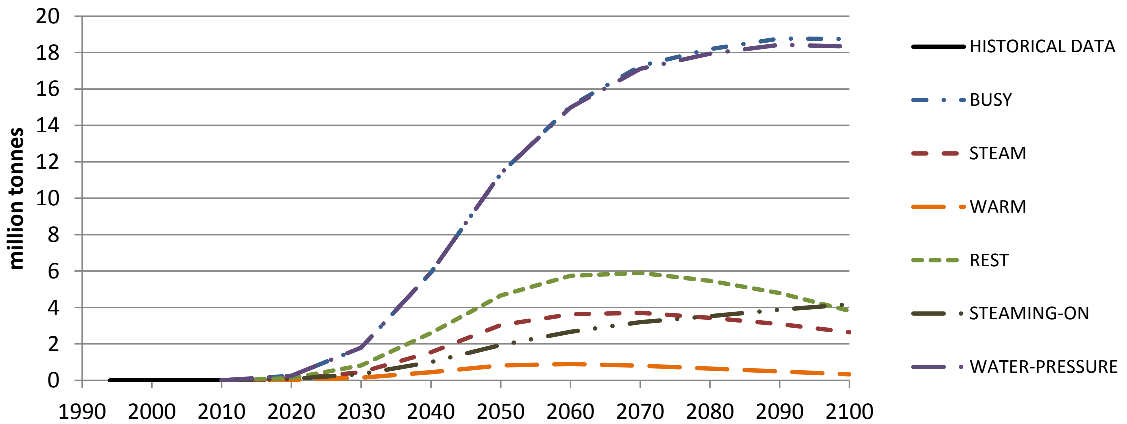
14.4.3 IWT of continental full load cargoes

The most convenient way to define the true potential for the very long term development of continental container flows is probably to apply a sophisticated very long term transport model as drafted in Chapter 11. However, Chapter 12 indicated that still a very substantial amount of research efforts is required to obtain a workable very long term transport model.

I have therefore looked at the issue from a different angle and departed from the aim of the European Commission (2011) *"to shift 50% shift of long haulage road transport (over 300 km) to more environmentally friendly intermodal transport solutions by the year 2050"*. This EU policy goal is assumed to reflect the upper limit in the most optimistic sustainable high growth scenarios. I have already discussed the full potential for continental intermodal inland transport with a haulage distance over 300 kilometre (see Figure 14-15) and the expected volumes for continental intermodal short sea container transport (see Figure 14-16). The next step is to quantify the intermodal continental container barge transport volumes. These volumes can be subdivided into: (1) the share of IWT in the hinterland transport of continental short-sea containers; (2) the share of IWT in the continental full load cargoes over 300 kilometre; and (3) the share of IWT in the continental full load cargoes below 300 kilometre.

<u>Share of IWT in the hinterland transport of continental short-sea containers</u>

IWT is expected to gain a share in the hinterland transport of continental short sea containers. I have defined the maximum potential for the development of these flows by simply assuming a similar modal share of IWT in the hinterland transport of short sea containers and continental containers. For each scenario I further made some assumptions on how successful IWT will eventually be in achieving its maximum potential for the hinterland transport of continental short sea containers. The obtained results are indicated in Figure 14-21.



Source: Historical trend based on notion that volumes were still negligible in 2010.

Figure 14-21: Hinterland Transport of Continental Short Sea Containers by IWT

I have assumed IWT to be able to capture a large market share in the more sustainable BUSY and WATER-PRESSURE scenarios and substantial market share in the REST scenario for which the development of continental container barge transport is more complicated, because economies of scale and density are harder to obtain in a low growth scenario than in a high growth scenario. I have not assumed IWT to capture much of its potential market share in the STEAM and STEAMING-ON scenarios as these scenarios put very little emphasis on the development of sustainable transport solutions. An even smaller market share is assumed in the WARM scenario for which the transport volumes are low and interest in the development of sustainable transport solutions is as good as absent.

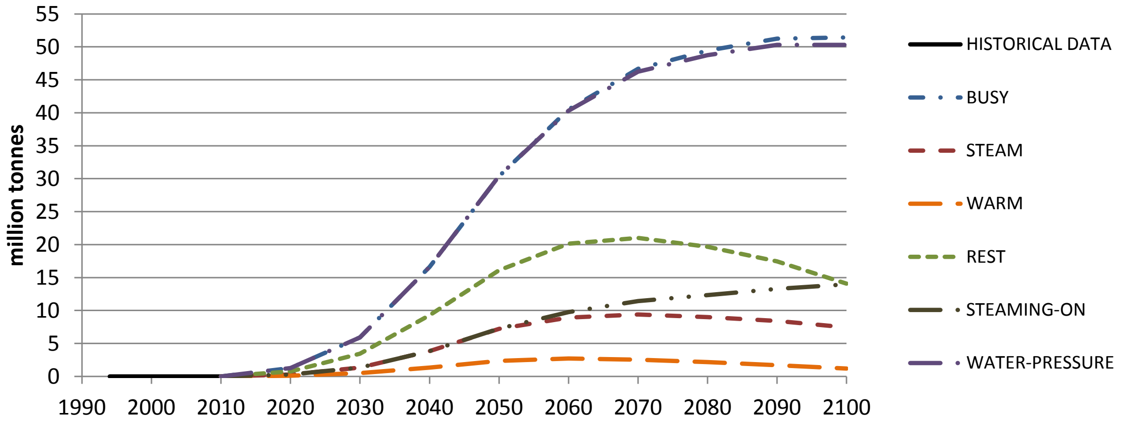
Table 14-1: IWT Market Share in Short Sea Hinterland Transport

Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
STEAM	0.0%	0.5%	2.0%	4.8%	7.5%	7.9%	7.1%	6.1%	5.1%	4.2%
BUSY	0.0%	1.7%	6.6%	16.1%	25.1%	29.1%	29.6%	29.1%	28.4%	27.7%
WARM	0.0%	0.3%	1.0%	2.4%	3.8%	3.9%	3.5%	3.1%	2.6%	2.1%
REST	0.0%	1.3%	4.9%	12.1%	18.8%	21.8%	22.2%	21.9%	21.3%	20.8%
STEAMING-ON	0.0%	0.5%	2.0%	4.8%	7.5%	8.7%	8.9%	8.7%	8.5%	8.3%
WATER-PRESSURE	0.0%	1.7%	6.6%	16.1%	25.1%	29.1%	29.6%	29.1%	28.4%	27.7%

Table 14-1 shows the expected market share of IWT in the hinterland transport of continental short sea containers. It can be observed that I expect the market share of IWT to grow considerable in the first half of the century and to stabilise thereafter. The eventual market share varies from 2.1% in the WARM scenario to 27.7% in the BUSY and WATER-PRESSURE scenarios for the year 2100. Further details on the calculation of Table 14-1 to 14-6 can be found in the corresponding Excel sheet that is referred to in Appendix F.

<u>Share of IWT in continental full load cargoes over 300 kilometre</u>

The market share of IWT in the transport of continental full load cargoes over 300 kilometre is estimated by multiplying the full potential for continental full load cargoes over 300 kilometre (see Figure 14-15) by the assumed market share for IWT and the assumed extent to which the ambitious aims of the European Commission are finally realised. The relative share of road, rail, and IWT in the intermodal transport of continental cargoes is simply assumed to be similar to that for the transport of conventional containers. The assumptions on the success of the European modal shift policies are based on my personal judgement (see corresponding Excel sheet for details). The obtained estimates are indicated in Figure 14-22.



Source: Historical trend based on notion that volumes were still negligible in 2010.

Figure 14-22: Intermodal Continental Container Loads over 300 km shipped by IWT

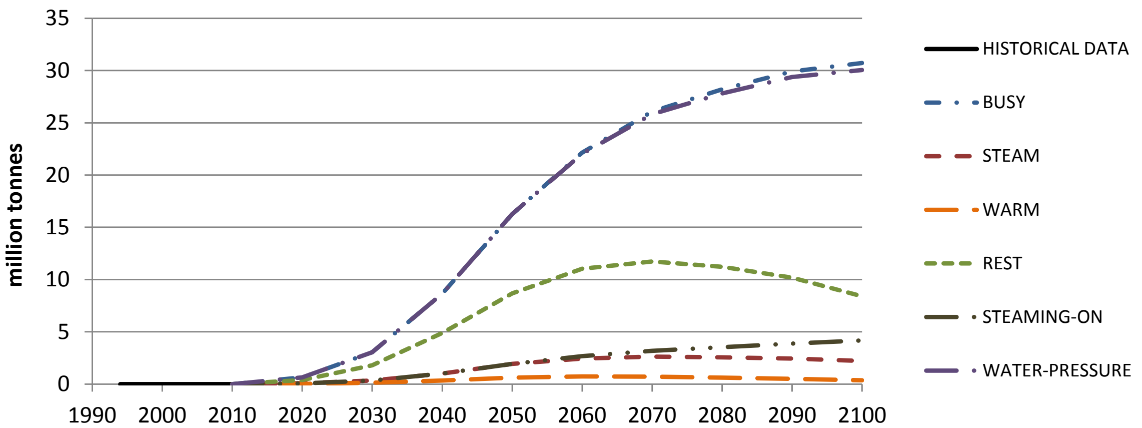
It can be observed that the intermodal continental full load container volumes are much higher in the sustainable BUSY, WATER-PRESSURE and REST scenarios than in the unsustainable STEAM, STEAMING-ON and WARM scenarios. The BUSY and WATER-PRESSURE scenarios show the highest continental long haulage IWT flows over 300 kilometre. The volumes are also quite substantial in the REST scenario, although a drop in volumes can be observed from the year 2070 onwards due to a strong reduction in the overall transport volumes, that stem from reduced economic output and ongoing decoupling of economic output and transport. The decline in the volumes of the STEAM scenario from the year 2070 onward is caused by the negative effects of climate change on the navigability of the inland waterways. The decline in the WARM scenario is caused by a decreased level of economic output in combination with adverse effects of climate change.

Table 14-2: IWT Market Share in Continental Full Load Shipments over 300 km

Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
STEAM	0.0%	0.2%	0.9%	2.3%	3.6%	3.8%	3.5%	3.0%	2.5%	2.0%
BUSY	0.0%	1.2%	4.7%	11.7%	18.2%	21.2%	21.6%	21.4%	20.9%	20.4%
WARM	0.0%	0.1%	0.5%	1.2%	1.8%	1.9%	1.7%	1.5%	1.3%	1.0%
REST	0.0%	0.9%	3.5%	8.7%	13.6%	15.9%	16.2%	16.0%	15.7%	15.3%
STEAMING-ON	0.0%	0.2%	0.9%	2.3%	3.6%	4.2%	4.3%	4.3%	4.2%	4.1%
WATER-PRESSURE	0.0%	1.2%	4.7%	11.7%	18.2%	21.2%	21.6%	21.4%	20.9%	20.4%

Table 14-2 shows the expected overall market share for IWT as a percentage of the overall transport of continental full load shipments over 300 kilometre. It can be observed that I expect the market share to grow considerable up to the year 2060 and to stabilise or decline in the period thereafter. The eventual market share for the year 2100 varies considerable from just 1.0% in the WARM scenario to 20.3% in the BUSY and WATER-PRESSURE scenarios.

<u>Share of IWT in continental full load cargoes below 300 kilometre</u>
In case IWT obtains a considerable share in the transport of long haulage cargo flows over 300 kilometre it can also be expected to attract some cargoes at shorter distances (see Chapter 10). It is therefore logic to include these flows in the quantitative scenarios. I assumed a maximum attainable market share of 5% in the most sustainable high volume scenarios and applied lower values in the scenarios with smaller transport volumes and/or an absent focus on sustainability. The obtained estimates are indicated in Figure 14-23.



Source: Historical trend based on notion that volumes were still negligible in 2010.

Figure 14-23: Intermodal Continental Container Loads below 300 km shipped by IWT

Figure 14-23 shows that I only expect these volumes to become substantial in the more sustainable scenarios. Table 14-3 indicates the assumed market share for IWT as a percentage of the overall continental full load shipments below 300 kilometre.

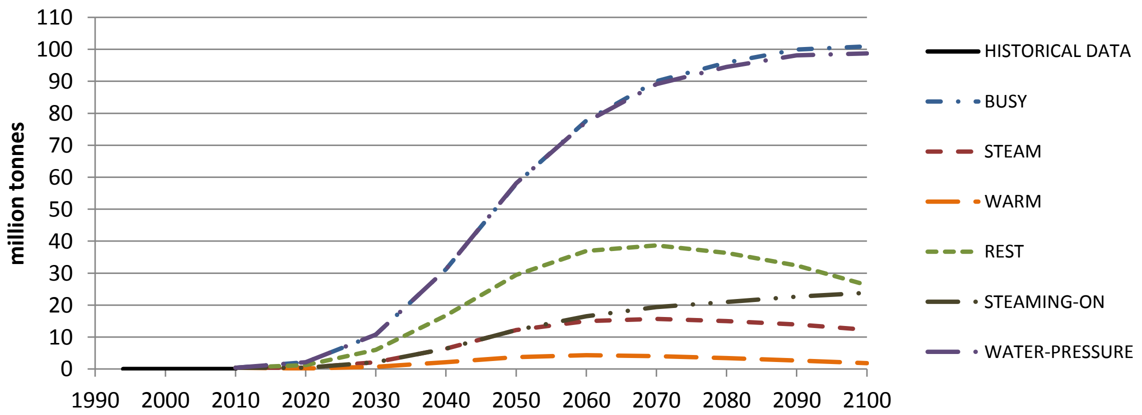
Table 14-3: IWT Market Share in Continental Full Load Shipments below 300 km

Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
STEAM	0.0%	0.0%	0.1%	0.3%	0.4%	0.4%	0.4%	0.4%	0.3%	0.3%
BUSY	0.0%	0.3%	1.0%	2.5%	4.0%	4.8%	5.0%	5.0%	5.0%	5.0%
WARM	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.2%	0.2%	0.2%	0.1%
REST	0.0%	0.2%	0.8%	1.9%	3.0%	3.6%	3.7%	3.8%	3.8%	3.8%
STEAMING-ON	0.0%	0.0%	0.1%	0.3%	0.4%	0.5%	0.5%	0.5%	0.5%	0.5%
WATER-PRESSURE	0.0%	0.3%	1.0%	2.5%	4.0%	4.8%	5.0%	5.0%	5.0%	5.0%

Table 14-3 shows that I assumed very low market shares in the unsustainable scenarios that lack interest in intermodal transport solutions.

Total intermodal continental container loads shipped by IWT

The total intermodal continental container loads that are shipped by means of IWT are obtained by adding up the transport volumes for the three abovementioned segments. The obtained scenario quantifications are indicated in Figure 14-24.



Source: Historical trend based on notion that volumes were still negligible in 2010.

Figure 14-24: Total Intermodal Continental Container Loads shipped by IWT

The figure clearly points out that the most substantial volumes are expected in the BUSY and WATER-PRESSURE scenarios, for which a clear transition towards intermodal continental container transport is expected. A similar transition is also expected in the REST scenario, for which, despite the lower growth of the overall transport volumes, a considerable amount of continental containers is shipped by IWT. The decline of the transport volumes in the REST scenario from the year 2070 onwards is caused by a strong decrease in the overall transport volumes, that stem from an overall reduction in economic output and a strong ongoing decoupling of economic output and transport. A relatively small shift towards intermodal continental container barge transport can be observed in the STEAM and STEAMING-ON scenarios. The decline of the transport volumes in the STEAM scenario towards the end of the century is caused by the adverse effects of climate change on the navigability of the inland waterways. The share of IWT in the transport of continental cargoes remains very small in the WARM scenario due to the low overall level of economic output, the absent interest in sustainable transport solutions, and the adverse effects of climate change on the navigability of the waterways. The achieved overall market share for IWT in the continental full load shipments is indicated in Table 14-4.

Table 14-4: Overall Market Share of IWT in Continental Full Load Shipments

Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
STEAM	0.0%	0.1%	0.4%	1.1%	1.8%	1.9%	1.7%	1.5%	1.2%	1.0%
BUSY	0.0%	0.6%	2.5%	6.4%	10.1%	11.9%	12.2%	12.1%	11.9%	11.7%
WARM	0.0%	0.0%	0.2%	0.5%	0.9%	0.9%	0.8%	0.7%	0.6%	0.5%
REST	0.0%	0.4%	1.8%	4.6%	7.2%	8.5%	8.7%	8.6%	8.5%	8.3%
STEAMING-ON	0.0%	0.1%	0.4%	1.1%	1.8%	2.1%	2.1%	2.1%	2.1%	2.0%
WATER-PRESSURE	0.0%	0.6%	2.5%	6.4%	10.1%	11.9%	12.2%	12.1%	11.9%	11.7%

Table 14-4 shows that the potential market share of IWT in the transport of continental cargoes (i.e. by means of continental 45 foot containers) is expected to vary between 0.5% and 11.6% of all the continental full load cargoes that are shipped on the Dutch territory in the year 2100. The lowest continental cargo volumes are expected in the scenarios with an absent focus on sustainability, while the higher volumes occur in the more sustainable scenarios.

To put the development of continental container transport in perspective the continental container volumes can be compared to the conventional deepsea container volumes. The continental container volumes that are shipped by IWT in the BUSY scenario for the year 2100 are about 100 million tonnes, while the conventional container volumes are about 290 million tonnes. This implies that the development of continental container transport could increase the total container barge transport volumes by up to about 35%. The effect on the overall number of barge movements will be even larger, because continental containers are harder to bundle and therefore expected to be shipped in smaller barges.

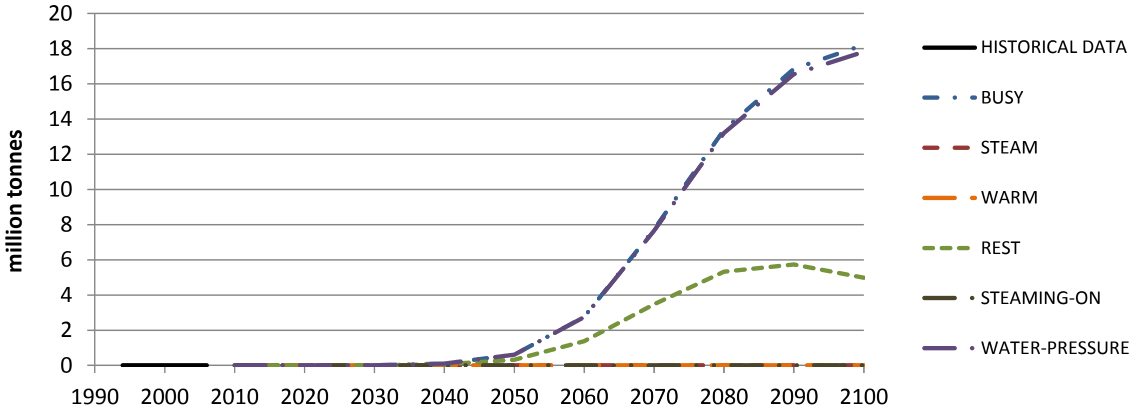
14.4.4 IWT of continental parcel loads

In case intermodal IWT is able to gain a considerable share in the transport of continental full load cargoes one can also expect logistical companies to shift their transport operations towards the waterfront. This will considerably reduce the pre- and end haulage costs for intermodal transport and thereby enhance the development of intermodal continental pallet distribution networks (see Chapter 8). Groothedde (2005) investigated the full potential for the development of large scale pallet distribution networks in the Netherlands. He concluded, on the basis of a large dataset of Dutch pallet flows, that the potential market share for IWT is about 10% to 15%. It is however unclear if such a high market share can be obtained in practice. I have therefore decided to use a much more conservative estimate and assumed a maximum attainable market share of 5% for the IWT of continental parcel loads (e.g. pallets) at distanced below 300 kilometre in the most sustainable high volume scenarios. The assumed market shares are indicated in Table 14-5.

Table 14-5: IWT Market Share in Continental Parcel Load Shipments below 300 km

Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
STEAM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BUSY	0.0%	0.0%	0.0%	0.1%	0.3%	1.0%	2.5%	4.0%	4.8%	5.0%
WARM	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
REST	0.0%	0.0%	0.0%	0.0%	0.2%	0.8%	1.9%	3.0%	3.6%	3.8%
STEAMING-ON	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
WATER-PRESSURE	0.0%	0.0%	0.0%	0.1%	0.3%	1.0%	2.5%	4.0%	4.8%	5.0%

I do not expect IWT to capture a market share in the segment of the parcel loads over 300 kilometre, because the overall transport time for these flows is likely to become too large to meet the requirements of an advanced pallet distribution network. Figure 14-25 indicates the intermodal continental parcel load volumes that are assumed to be shipped by IWT.



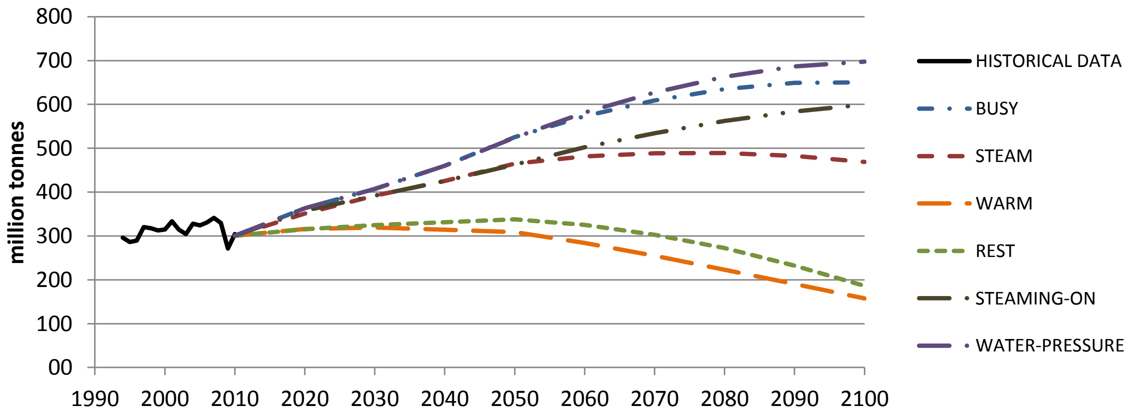
Source: Historical trend based on notion that volumes were still negligible in 2010.

Figure 14-25: Total Intermodal Continental Parcel Loads shipped by IWT

Figure 14-25 indicates that the largest potential for the development of continental pallet distribution networks occurs in the BUSY and WATER-PRESSURE scenarios. Reasonable volumes are also expected in the REST scenario. Pallet distribution networks are not expected to develop in the unsustainable STEAM, STEAMING-ON, and WARM scenarios.

14.4.5 Total IWT Volumes

The previous subsections presented the scenario quantifications for the IWT of bulk and break-bulk cargoes, conventional containers, continental full load cargoes, and continental parcel loads. When these commodity segments are summarised it becomes possible to obtain an estimate of the overall IWT volumes, as well as an estimate of the overall share of IWT in the total inland transport volumes.



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-26: Development of the Total IWT Volumes

Figure 14-26 shows the development of the overall IWT volumes in the various scenarios. The IWT volumes are expected to more or less remain at their year 2010 level or increase by up to about 75% of their year 2010 level in the first half of this century – and start to decrease or continue to grow at a slower pace in the subsequent period up to the year 2100.

The growth of the IWT volumes (as presented in Figure 14-26) is lower than the growth of the total inland transport volumes (as presented in Figure 14-9). This implies that the overall market share of IWT is likely to decrease.

Table 14-6: Development of Market Share of IWT in Total Inland Transport Flows

Scenario	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
STEAM	26.2%	22.1%	21.7%	20.9%	19.9%	18.3%	16.9%	15.6%	14.3%	13.1%
BUSY	26.2%	24.2%	24.1%	24.8%	25.3%	25.2%	24.9%	24.7%	24.4%	24.2%
WARM	26.2%	23.7%	22.1%	20.7%	19.2%	17.2%	15.6%	14.3%	13.2%	12.4%
REST	26.2%	24.5%	23.6%	23.3%	22.9%	22.0%	21.3%	20.7%	20.0%	19.6%
STEAMING-ON	26.2%	22.6%	21.7%	20.9%	19.8%	19.1%	18.4%	17.9%	17.3%	16.8%
WATER-PRESSURE	26.2%	24.2%	24.1%	24.8%	25.2%	25.6%	25.6%	25.8%	25.8%	25.9%

Table 14-6 shows the development of the overall market share for IWT. All scenarios indicate a drop in the market share compared to the year 2010 value of 26.2%. The market share stabilises at about 25% in the most favourable BUSY and WATER-PRESSURE scenarios, and continues to decrease in the other scenarios. This outcome is surprising as it seems to contradict the earlier findings of Chapter 2.

The decrease in the overall market share of IWT can be explained by an ongoing decrease in the market share for bulk and break-bulk commodities. My earlier observation that the very long term decrease in the market share of IWT may have come to a hold from about the year 2000 onwards (see Chapter 2), resulted from the fact that the decrease in the market share for bulk and break-bulk commodities has been temporarily offset by an increase in the transport of containers. The growth of the container volumes is however expected to be insufficient to compensate the expected ongoing losses for the bulk and break-bulk segment, and for that reason the overall market share of IWT is likely to continue to decrease in the future.

It is nevertheless possible that the assumed decrease in the market share of IWT for bulk commodities (see Figure 14-17) will eventually turn out to be too pessimistic. The numbers presented in this chapter provide my best estimate on the basis of a continuation of the present trend, but the future for IWT on the smaller waterways is still very uncertain (see Chapter 2). If new concepts such as the Watertruck become successful, they may well have a positive effect on the market share for IWT in the bulk and break-bulk segment. Though I have not incorporated the effect of such new developments in the scenarios, I recommend to pay more attention to this subject in follow up studies.

14.5 Reflection on the applied Economic Growth Assumptions

As discussed in Chapter 4, I do not agree with the mainstream neo-classical view that labour productivity and economic output can remain growing at an exponential rate for yet another very long period of time. I have therefore based the probabilistic very long term transport forecasts, that served as primary input for the quantification of the scenarios in this chapter, on my post-neo-classical labour productivity and economic growth assumptions (see Chapter 7). This section address the implications of using my GDP projections instead of the official ones, that are defined in the macroeconomic section of the Delta Scenario report. It starts with a comparison of the applied growth assumptions and continues with a reflection on the effect, that the use of the official GDP scenarios would have had on the quantification of the scenarios. It makes clear why I consider it necessary to adopt the post-neo-classical economic growth paradigm in order to obtain sensible very long term transport projections up to the year 2100.

14.5.1 Comparison of the applied labour productivity and GDP assumptions

The economic growth and labour productivity assumptions, as defined in the macroeconomic section of the Delta Scenario report, are based on the memorandum of Huizinga and Folmer (2012). This memorandum assumes an ongoing exponential growth of labour productivity and economic output by 1.2% per annum in the REST and WARM scenario and by 2.1% per annum in the BUSY and STEAM scenarios, for the entire time period from the year 2011 up to the year 2100. The underlying assumptions are indicated in Table 14-7.

Table 14-7: Macroeconomic Assumptions applied in the official Delta Scenarios

Scenario Year	REST & WARM 2012-2050	REST & WARM 2050 - 2100	BUSY & STEAM 2012-2050	BUSY & STEAM 2050 - 2100
Population	-0.2%	-0.5%	0.5%	0.4%
Labour	-0.2%	-0.5%	0.5%	0.4%
Labour Productivity	1.2%	1.2%	2.1%	2.1%
GDP	1.0%	0.7%	2.6%	2.5%
GDP per Capita	1.2%	1.2%	2.1%	2.1%

Note: The presented numbers concern annual growth rates.

Source: Huizinga and Folmer (2012).

The above listed annual growth rates result in a growth of labour productivity by respectively a factor 1.6 to 2.3 from the year 2011 to the year 2050 and by a factor 2.9 to 6.4 from the year 2011 to the year 2100. These numbers can be compared with my assumptions on the growth of labour productivity that have been presented in Figure 7-15. I assumed a median growth by a factor 1.5 from the year 2011 to the year 2050, and by a factor 2.2 from the year 2011 to the year 2100. This implies that my median expectations on the growth of labour productivity lie below the lowest growth scenarios that were applied in the macroeconomic section of the Delta Scenario study. If I compare the average value of the high- and low labour productivity scenarios with my median estimate, I find values that are respectively a factor 1.3 and 2.1 higher than the numbers that I apply for the years 2050 and 2100.

Labour productivity is an important factor in the composition of the GDP, but it is not the only factor. I will therefore continue with a comparison of the applied GDP projections. The official growth rates listed in Table 14-7 imply that the overall GDP output is assumed to grow by a factor 1.5 to 2.7 from the year 2011 to the year 2050, and by a factor 2.1 to 9.4 from the year 2011 to the year 2100. The 80% confidence interval (between the 10% and 90% percentiles) of my very long term GDP projection (see Figure 7-16), shows a growth of the Dutch GDP by a factor 1.2 to 1.8 from the year 2011 to the year 2050, and by a factor 1.1 to 3.0 from the year 2011 to the year 2100. When comparing these numbers I find that the official GDP scenarios of the CPB are roughly about 25% to 50% higher than the numbers that I apply for the year 2050 and roughly about 100% to 200% (i.e. a factor 2 to 3) higher than the numbers that I apply for the year 2100.

I therefore conclude that the differences between the neo-classical and post-neo-classical views on labour productivity are already quite large for the year 2050 and become very large when looking farther ahead towards the year 2100.

14.5.2 Reflection and further discussion

Given the strong (almost one to one) relation between economic output and transport, it is obvious that such large differences between the mainstream and post-neo-classical views on economic growth will also result in completely different transport projections. If I would have based my probabilistic transport forecasts and scenario quantifications on similar exponential economic growth assumptions as applied in the Dutch WLO and Delta scenarios, as well as in all official scenario studies that I know of, I would have obtained transport projections for the year 2100 that are presumably a factor 2 to 3 higher than those presented in this thesis.

During the process of developing the qualitative and quantitative shipping scenarios for the Delta Programme I had some meetings and discussions with experts from the Government, Deltares, and the Port of Rotterdam. In these meetings I understood that experts from other disciplines are also struggling with the exponential economic growth scenarios, that tend to result in unrealistic very long term projections for amongst others land use and fresh water demand. The consulted experts nevertheless questioned how fruitful it would be to enter into a tough and lengthy discussion with the CPB, who provided the macroeconomic projections for the Dutch WLO and Delta Scenarios. One of the experts suggested to apply a higher than expected rate of decoupling and mentioned that this approach was also applied for the development of the WLO scenarios. In other words he suggested to use decoupling as an instrument to reduce the long term transport volumes to the levels that I would still consider sensible on the basis of my economic growth projections. I do not consider this approach acceptable from a scientific point of view, nor do I consider it sensible from a practical point of view, as the extreme differences that arise at a very long time horizon up to the year 2100 will result in very unrealistic assumptions regarding the level of decoupling.

After some discussion I decided to drop the direct link between the official macroeconomic scenarios and the transport scenarios for the shipping section of the Dutch Delta Scenarios. I have instead linked the high and low transport scenarios to the high and low percentiles of my very long term probabilistic transport forecasts, that were developed in line with the post-neo-classical paradigm on economic growth in Chapter 7.

In addition I followed the advice not to enter into a very tough and lengthy discussion on the subject of labour productivity and economic growth prior to the completion of this thesis. Such a discussion would have endangered the completion of this thesis too much. However, with the publication of this thesis I intend to intensify the academic and political debate on the appropriate paradigm of economic growth (and the related issue of future discounting), in the hope that the outcome of this debate will be in time for the next generation of Delta Scenarios, as well as for the evaluation of other important very long term policy issues, such as those related to pensions, energy demand, and climate change.

I have discussed the outcome of the obtained scenario quantifications with a few experts of the Dutch Government, Deltares, and the Rotterdam Port Authority[157]. These experts indicated that the presented transport scenarios seem to be realistic and more or less in line with their long term expectations. This confirms my view that a different paradigm on economic growth has to be adopted in order to obtain realistic long term transport projections.

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[157] The experts commented on the draft report of Van Dorsser (2012) in which the shipping scenarios were presented prior to the writing of this chapter. See also Appendix E for details on the consulted experts.

14.6 Concluding Summary

This chapter addresses the sixth methodological sub question (MSQ 6): *"What would be a sensible quantification of the plausible storyline scenarios for the very long term development of freight transport on the inland waterways?"*. It shows how an aggregated set of shipping scenarios for the Dutch Delta Programme was quantified on the basis of the insights that were obtained in this thesis. Apart from some minor corrections and a few new insights the text is fully in line with my earlier report (Van Dorsser, 2012), that provided the background for the shipping section in the official Delta Scenario report of Bruggeman et al. (2013).

14.6.1 The applied methodology for quantifying the Shipping Scenarios

The quantification of the four official and two additional Delta Scenarios (see Chapter 13) started with the output of the very long term probabilistic forecasts that were developed in Chapter 7. These forecasts provide explicit insight in the expected size- and the uncertainty levels of the transport volumes up to the year 2100. They are very well suited to explore the outer corners of plausible future developments (as intended by the Delta Scenarios). The six transport scenarios were linked to various percentiles of the probabilistic forecasts by taking into account the fact that there exists a direct relation between economic output and transport, as well as the fact that the more sustainable scenarios are likely to show a higher degree of decoupling between the levels of economic output and transport.

The quantification of the total Dutch port throughput volumes started with an estimate of the future development of the overall market share of the Dutch seaports within the Le-Havre – Hamburg range (for which a very long term probabilistic forecast is available from Chapter 7). The obtained estimates for the total Dutch port throughput volumes were then divided into containerised cargoes and non-containerised bulk and break-bulk cargoes. The containerised cargoes were obtained by defining the relative share of the containerisable cargoes as a fraction of the total port throughput volumes and assuming a certain development path for the degree of containerisation (that is defined as a fraction of the containerisable port throughput volumes). The containerized port throughput was further divided into conventional deepsea containers and continental short sea containers. The bulk and break-bulk cargoes were finally obtained by deducting the containerised port throughput from the total throughput.

The total inland transport volumes on Dutch national territory were quantified by multiplying the base year 2000 volumes by the combined transport index for the development of the overall transport demand (for which a probabilistic forecast is also available from Chapter 7). The total inland transport volumes were subdivided into bulk and break-bulk volumes, conventional container transport volumes (mainly deepsea containers transported to the hinterland), and other continental transport volumes. The bulk and break-bulk volumes were estimated as a function of the corresponding bulk and break-bulk throughput in the Dutch seaports and the size of the Dutch population; the conventional container volumes were related to the container throughput in the seaports; and the other continental general cargo volumes were finally obtained by deducting the bulk and break-bulk volumes as well as the conventional container volumes from the total inland transport volumes.

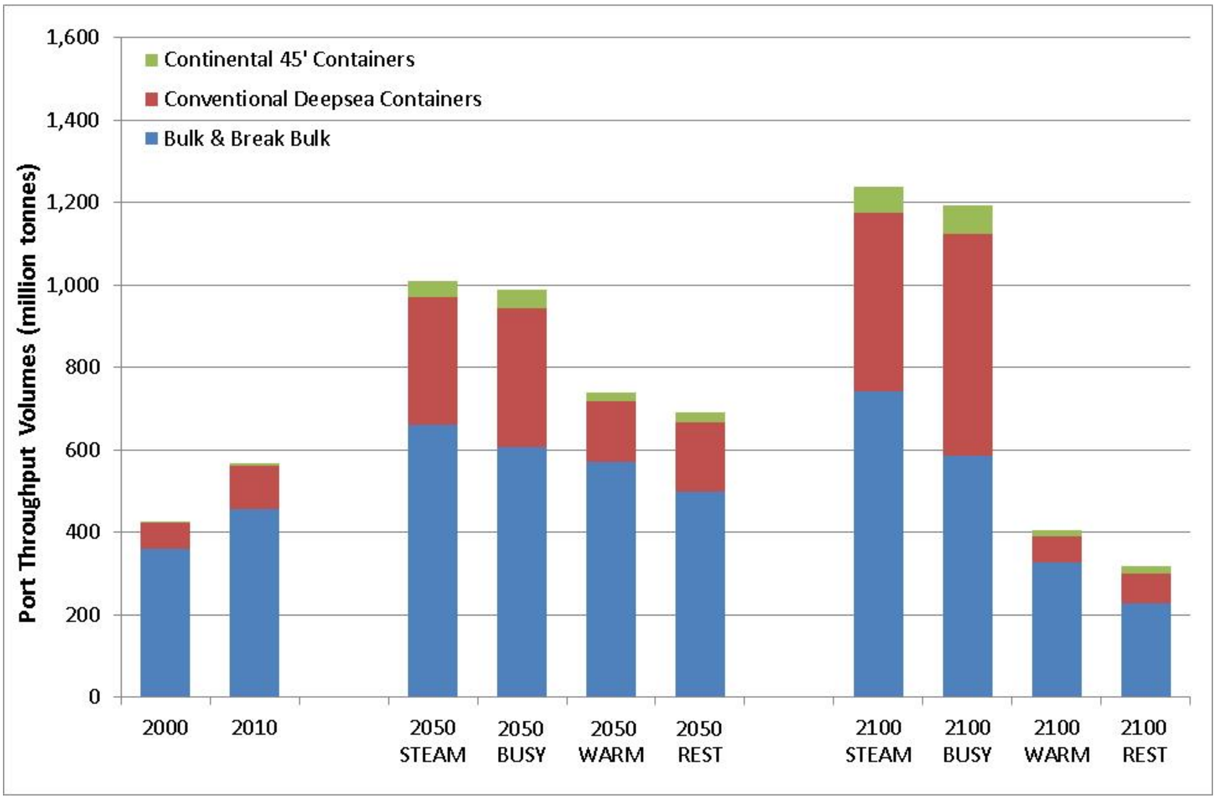
The next step was to analyse the potential for intermodal continental container and pallet transport (as a share in the transport of the other continental general cargo volumes) for which the aim of the European Commission, to shift 50% of the road transport volumes over 300 kilometre to intermodal transport, was assumed to represent the upper limit for the size of the potential intermodal continental transport volumes. In addition it was assumed that this potential will only be fully realised in the sustainable high volume scenarios and that it will be hardly realised in the unsustainable low volume scenarios. I further applied the insights obtained in Chapter 8 to define a realistic time path for the full scale development of intermodal continental short-sea-, rail-, and barge transport. Insight in the maximum attainable size of the potential intermodal continental container and pallet transport volumes was finally obtained by comparing the converted payload data of the 'base year 2004 data files' for road transport over 300 kilometre with the converted payload data for all modes of transport combined at all distances.

The IWT volumes for bulk and break-bulk cargoes as well as for conventional container cargoes were obtained by assuming a certain market share for IWT in these categories. The continental full load cargoes that are shipped by barge were assumed to comprise of: (1) the share of IWT in the hinterland transport of continental short-sea containers; (2) the share of IWT in the transport of continental full cargo loads (i.e. full truck or container loads) over 300 km; and (3) the share of IWT in the transport of continental full cargo loads below 300 km. For each segment a separate estimate was made. In addition an estimate was made of the potential transport volumes that can be expected in case of the successful development of intermodal pallet distribution networks in the second half of the 21st century.

14.6.2 The obtained scenario quantifications

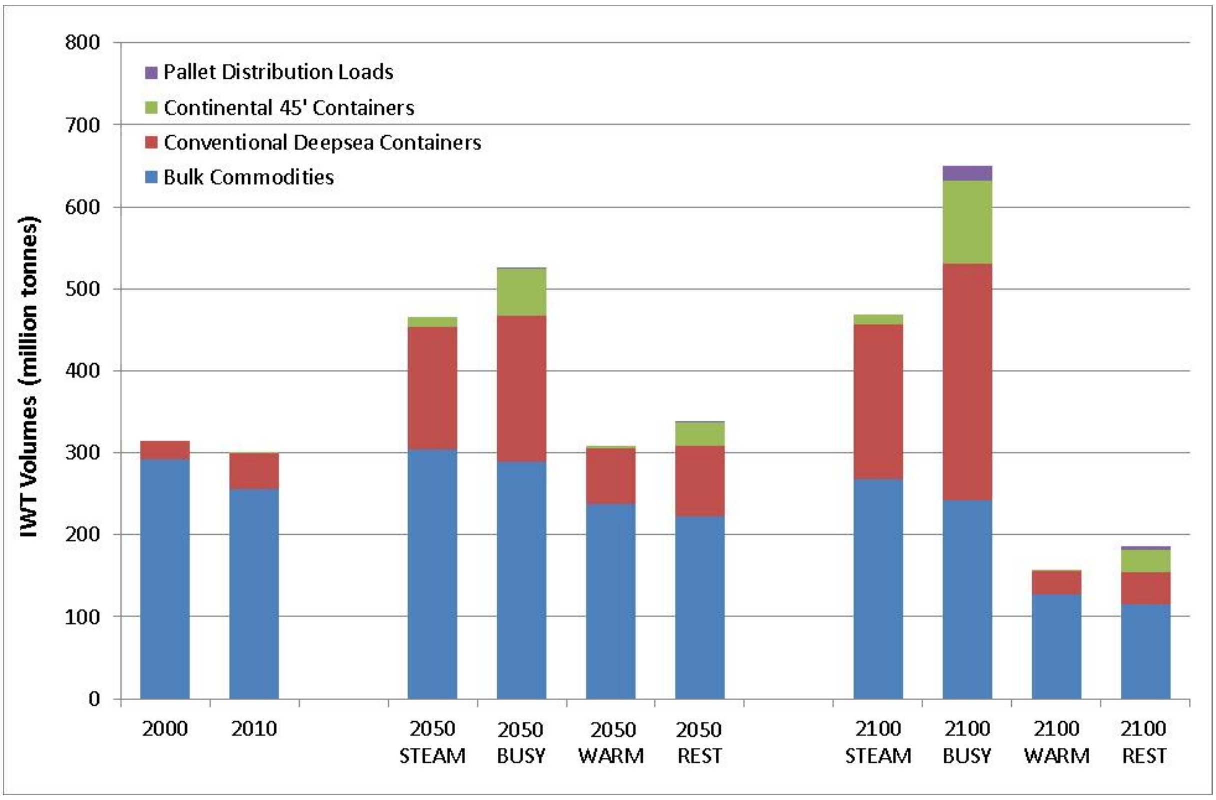
The obtained scenario quantifications for the development of the overall port throughput- and IWT volumes are summarized in Figure 14-27 and Figure 14-28. It can be observed from Figure 14-27 that that the port throughput volumes for bulk and container cargoes are likely to keep growing in the first half of the 21st century, while they may either continue to grow or start to decline in the second half of the century up to the year 2100. Figure 14-28 shows a similar trend for the container volumes that are shipped by IWT, though the IWT of bulk and break-bulk cargoes is expected remain more or less stable in the first half of the century, after which it is likely show a gradual decline.

A sensitivity analysis in which the STEAM and BUSY scenarios are compared with the STEAMING-ON (ST.-ON) and WATER-PRESSURE (WA.-PR.) scenarios is provided in Figure 14-29 and Figure 14-30. From these figures it can be observed that the highest port throughput and IWT volumes occur in the two additional STEAMING-ON and WATER-PRESSURE scenarios. This implies that these scenarios are most suitable to explore the outer corners of plausible future developments. The differences in the overall port throughput and IWT volumes between the STEAM and STEAMING-ON scenarios as well as between the BUSY and WATER-PRESSURE scenarios are almost negligible for the period up to the year 2050. This is logical because the effects of climate change are also expected to remain quite limited in this period. The effects of climate change may however become quite substantial in the second half of the century towards the year 2100. The differences between the transport volumes in the STEAM and STEAMING-ON scenarios are then becoming quite substantial, in particular for IWT. The year 2100 differences between the transport volumes in the BUSY and WATER-PRESSURE scenario are not that large, but one should realise that the WATER-PRESSURE scenario has major implications for the provided IWT infrastructure, as it amongst others presumes the river Rhine to be fully canalised.



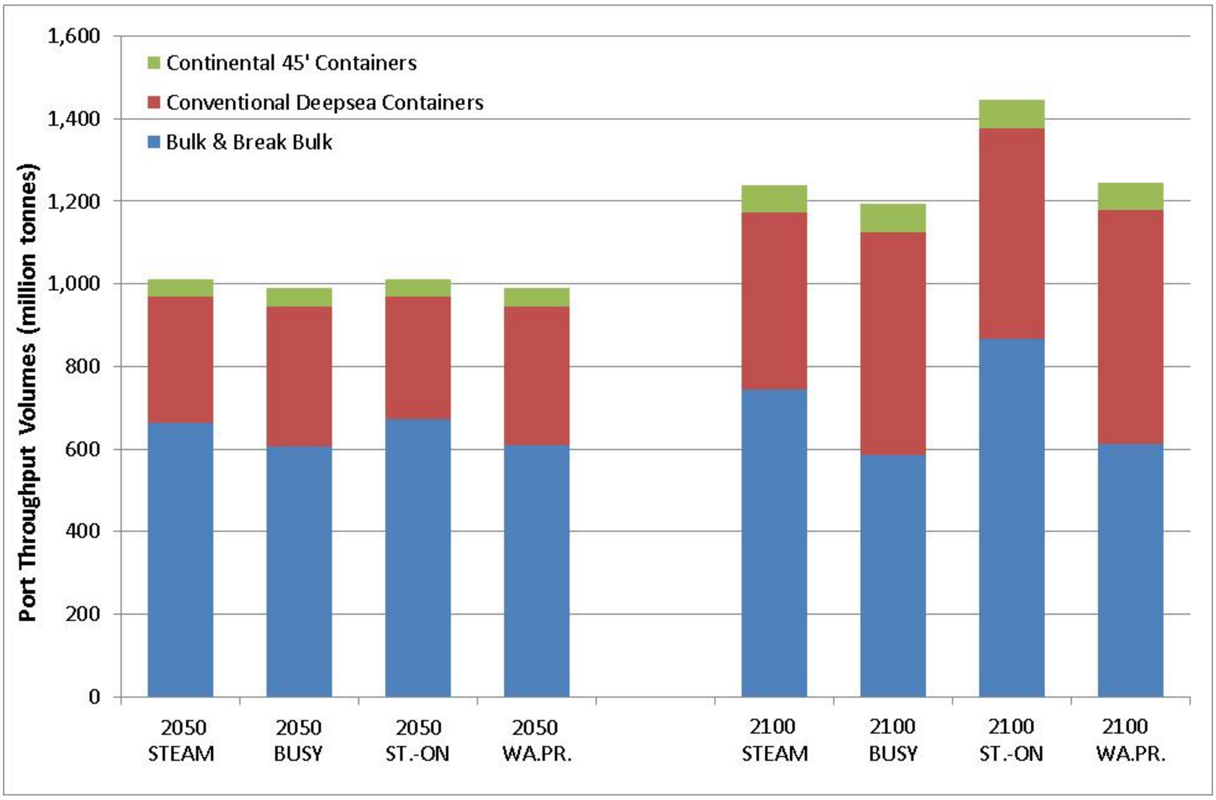
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-27: Anticipated Port Throughput Volumes in the official Delta Scenarios



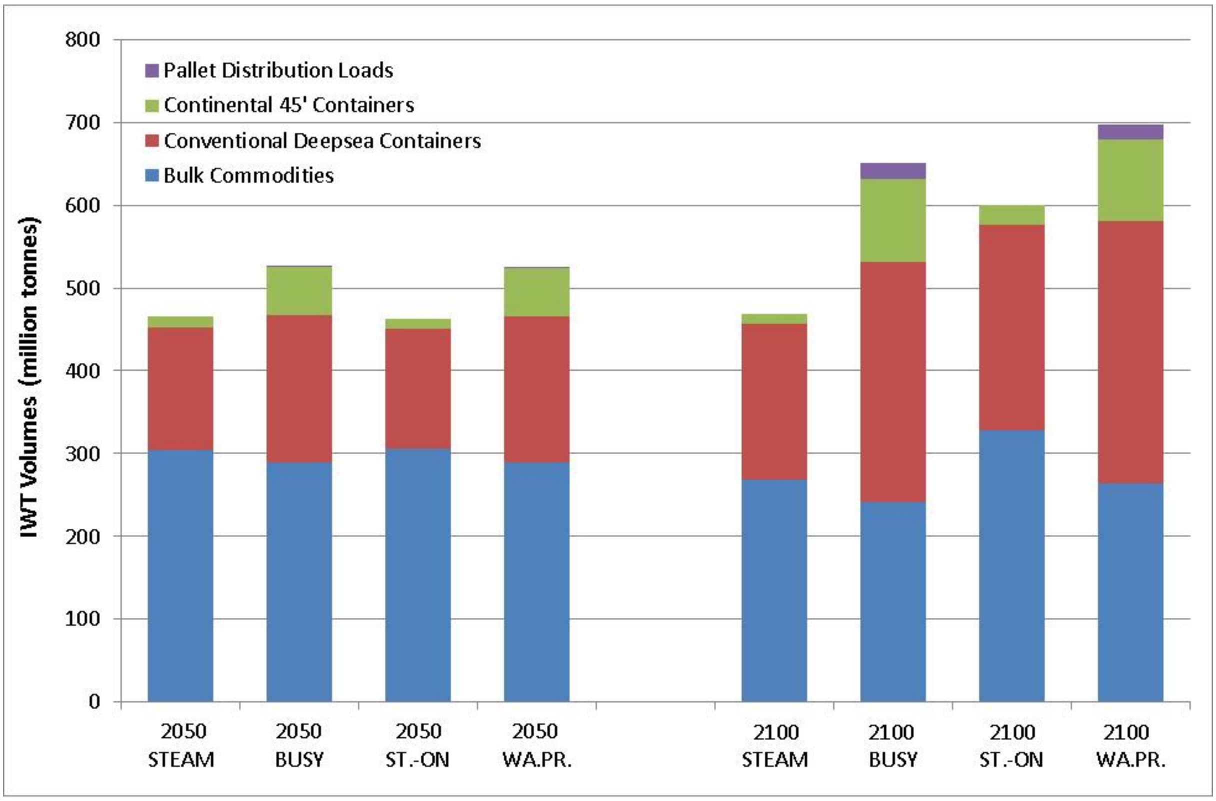
Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-28: Anticipated IWT Volumes in the official Delta Scenarios



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-29: Sensitivity of the Delta Scenarios with respect to Port Throughput



Source: Historical trend based on CBS data obtained from Rijkswaterstaat.

Figure 14-30: Sensitivity of the Delta Scenarios with respect to IWT Volumes

14.6.3 Reflection on the applied post-neo-classical economic growth paradigm

As discussed in Chapter 4, I do not agree with the mainstream neo-classical view that labour productivity and economic output can remain growing at an exponential rate for yet another very long period of time. I have therefore based the shipping scenarios on the post-neo-classical labour productivity and economic growth projections of Chapter 7, instead of on the official GDP scenarios that were developed in line with the exponential views on economic growth by the CPB (Netherlands Bureau for Economic Policy Analysis). The differences between the two approaches are considerable. The official projections are roughly about 25% to 50% higher for the year 2050 and about 100% to 200% (i.e. a factor 2 to 3) higher for the year 2100. Given the almost one-to-one relation between the overall level of economic output and the overall level of transport it is obvious that the decision to base the shipping scenarios on the post-neo-classical economic growth projections has very much affected the outcome of the obtained scenario quantifications. If I would have based the shipping scenarios on the official economic growth scenarios of the CPB, I would have presumably obtained transport scenarios that are a factor 2 to 3 higher than those presented in this chapter.

I discussed the obtained scenario quantifications with a few experts of the Dutch Government, Deltares, and the Rotterdam Port Authority, who regarded them realistic and more or less in line with their expectations. In addition they mentioned that experts from other disciplines are also struggling with the high economic growth scenarios, that tend to result in unrealistic very long term scenarios for issues such as land use and fresh water demand. The fact that it seems to be impossible to obtain sensible very long term projections for issues such as land use, water demand, and transport on the basis of the prevailing exponential economic growth scenarios supports my view that a new post-neo-classical economic growth paradigm should be adopted.

The consulted experts advised not to enter into a tough and lengthy discussion on the rate of labour productivity and economic growth prior to the completion of this thesis, as such a discussion would have endangered the completion of this thesis too much. However, with the publication of this thesis I intend to intensify the debate on the appropriate paradigm of economic growth, in the hope that the outcome of this debate will be in time for the next generation of Delta Scenarios, as well as for the evaluation of other important very long term policy issues, such as those related to pensions, energy demand, and climate change.

14.6.4 Answer to Methodological Sub Question 6

In answer to MSQ 6, I conclude that this thesis provides sufficient insights for the quantification of the six shipping scenarios that were defined in Chapter 13. The obtained scenario quantifications show that the exploration of the outer corners of plausible future developments can be improved by using the WATER-PRESSURE and STEAMING-ON scenarios instead of the official BUSY and STEAM scenarios, as these scenarios result in larger overall transport volumes and/or imply major changes to the IWT infrastructure. The obtained scenario quantifications are highly affected by the decision to apply the post-neo-classical economic growth paradigm (see Chapter 4 and 7). If I would have adopted the mainstream neo-classical paradigm of ongoing exponential economic growth, this would have resulted in low and high transport scenarios that are respectively a factor 2 to 3 higher than the numbers that I obtained. The fact that the obtained shipping scenarios were considered sensible by a number of consulted transport experts, and the fact that other disciplines also seem to be struggling with the high exponential economic growth scenarios, supports my view that a new post-neo-classical economic growth paradigm should be adopted.

Literature:

Bruggeman, W., E. Dammers, G.J. van den Born, B. Rijken, B. van Bemmel, A. Bouwman en K. Nabielek, J. Beersma, B. van den Hurk, N. Polman, Vincent Linderhof, C. Folmer, F. Huizinga, S. Hommes, and A. te Linde (2013) *Deltascenario's voor 2050 en 2100, Nadere uitwerking 2012-2013*, Deltares, KNMI, PBL, CPB, and LEI.

Groothedde, B. (2005) *Collaborative logistics and transportation networks, a modelling approach to hub network design*, Trail Research School, Delft.

Grübler, A. (1990) *The Rise and Fall of Infrastructures: Dynamics of Evolution and Technological Change in Transport,* Physica-Verlag Heidelberg.

Huizinga, F.H., and K. Folmer (2012) *CPB notitie betreft: Invulling macro beeld Delta scenario's*, Centraal Planbureau.

Luman, R. (2013) *Herstel binnenvaart uit zicht - wacht de droge ladingvaart een warme of koude sanering?,* ING Economisch Bureau.

Platz, T.E. (2009) *The Efficient Integration of Inland Shipping into Intermodal continental Transport Chains: Measures and Decisive Factors*, TRAIL Thesis Series Volume T2009/11, Trail Research School, Delft.

Quispel, M. (2013) *Recente ontwikkelingen en toekomstverwachting binnenvaart,* presentation at Binnenvaartcongress Hardinxveld Giesendam, 25 March 2013.

Van Dorsser, J.C.M. (2012) *Scheepvaartscenario's voor Deltaprogramma, 100 jaar later...,* Rijkswaterstaat, https://deltaprogramma.pleio.nl/file/download/15938322.

Van Dorsser, J.C.M., M.A. Wolters, and B. van Wee (2012) *A Very Long Term Forecast of the Port Throughput in the le-Havre – Hamburg range up to 2100*, European Journal of Transport and Infrastructure Research, vol. 12, no. 1, pp.

Van Hassel (2011) *Decreased Supply on the Small Inland Waterway Network: Causes and Consequences,* in Sys C., and T. van Elslander eds. (2011) *Future Challenges for Inland Navigation, A Scientific Appraisal of the Consequences of Possible Strategic and Economic Developments up to 2030,* UPA University Press Antwerp.

Websites:

Maddison (accessed: 2010) *Historical Data on Population and GDP,* [www.ggdc.net/Maddison]

The Conference Board (accessed: 2009, 2012). *Total Economy Database.xls,* [http://www.conferenceboard.org/economics/database.cfm]

15 Conclusions and Recommendations

"*I hear babies crying, I watch them grow. They'll learn much more than I'll never know. And I think to myself what a wonderful world. Yes I think to myself what a wonderful world.*"
- Song text written by Bob Thiele, recorded by Louis Armstrong, and released as a single in 1968

15.1 Introduction

Infrastructures are essential to the well-functioning of modern economies, but once in place they are hard to change due to their high capital intensity and very long technical lifetime. Infrastructure investments therefore need to be carefully planned in order to avoid suboptimal performance and costly adjustments in the future. This also holds for Rijkswaterstaat, the agency within the Ministry of Infrastructure and Environment that is responsible for the hydraulic structures on the main inland waterway system in the Netherlands. This thesis aims to investigate how Rijkswaterstaat can develop a workable method for taking the very long term development of the Dutch IWT system into account in the evaluation of integrated infrastructure development strategies with a very long term impact. In line with this objective the following main research question was defined (see Chapter 1).

Main Research Question (MRQ)
- How can Rijkswaterstaat develop a workable method for taking the very long term development of the Dutch Inland Waterway Transport (IWT) system into account in the evaluation of integrated infrastructure development strategies with a very long term impact?

This thesis started with a preliminary research part in which four general sub questions were addressed concerning: (1) the historical development and present characteristics of the Dutch IWT system; (2) the present way of dealing with long term effects in transport scenarios; (3) the very long term perspective on the development of the world economy; and (4) the options to take the inevitable high levels of uncertainty into account that come with a very long term planning horizon. Thereafter followed the main research part in which six methodological sub questions were addressed concerning: (1) the proposed policy framework; (2) the very long term external factors that act on the IWT system; (3&4) the options to model the IWT system at the network level; and (5&6) the options to prepare a qualitative and quantitative set of very long term scenarios for the development of the Dutch IWT system.

In addition to the main research question, it also addressed two important additional research objectives that are relevant to a much broader range of policies issues.

The first additional research objective, that concerns virtually all policies with a very long term impact, followed from the gained insight that there seems to be something wrong with the prevailing paradigm of ongoing exponential economic growth. I aimed to make clear that a different paradigm should be adopted – and addressed the implications of using an alternative economic growth paradigm on the outcome of the very long term transport projections, as well as on the appropriate level of the risk free discount rates that are to be applied when discounting very long term effects.

The second additional research objective, that feeds into the scope of the broader Delta Project in the Netherlands, concerns the development of a set of very long term shipping scenarios up to the year 2100. This objective was added in the year 2012 after I received a request to contribute to the Delta Scenarios and responded with a full scenario report (see Van Dorsser, 2012). My report not only contained four official shipping scenarios, that are now incorporated in the broader Delta Scenario report of Bruggeman et al. (2013), but also two additional scenarios that I added as a sensitivity analysis, because I consider them more appropriate to explore the outer corners of plausible future developments.

The answers to the four general- and six methodological sub-questions have already been provided in the concluding summary sections of Chapter 2 to 14 and will not be repeated in this chapter. This chapter provides an overarching view that answers the main research question, elaborates on the findings with respect to the two additional research objectives, and concludes with a number of recommendations. Section 15.2 starts with a discussion on the main conclusions from the preliminary research part of this thesis; Section 15.3 addresses the main research question; Section 15.4 addresses the findings with respect to the development of the shipping scenarios for the Dutch Delta Programme; Section 15.5 provides an overall reflection on the findings with respect to applied paradigm of economic growth and the corresponding very long term discount rates; Section 15.6 contains a number of important recommendations to Rijkswaterstaat and others; and Section 15.7 summarizes the main conclusions that can be drawn from this thesis.

15.2 Findings from the Preliminary Research Part

This section addresses the main findings from the preliminary research part of this thesis on the development and characteristics of the IWT system, the way of dealing with long term effects in transport scenarios, the very long term development of the world economy, and the options to look far ahead and deal with uncertainty in policy making.

15.2.1 The historical development and present state of the IWT system

IWT has played an important role in the transport of passengers and goods throughout the Dutch history. It was the primary mode of transport in the first half of the 19th century, but from about 1850 onwards the relative share of IWT has considerably declined in response to the emerging rail and road transport networks. By the second half of the 20th century IWT was generally perceived as a slow, old fashioned, and little service oriented mode of transport, that was bound to face a long gradual decline. This is nowadays no longer the case. IWT has attained a new momentum with the development of intermodal container transport. In addition there is still a great potential to develop intermodal continental IWT flows, which are also aimed for by sustainable European and national transport policies. Continental container barge transport is however still facing difficulties to compete with unimodal road transport, which is amongst others caused by the fact that the IWT infrastructure stems from the period before the development of the container. The present IWT infrastructure is not fully compatible with the dimensions of the continental 45 foot long, pallet wide, high cube container, that has now become the standard intermodal loading unit for continental cargoes. The extent to which intermodal continental container barge transport is able to develop therefore, amongst others, depends on the ability of infrastructure providers to adjust the IWT system in such a way that it enables efficient transport of continental containers.

15.2.2 The present way of dealing with freight transport in long term scenarios

The development of freight transport on the inland waterways depends on the development of the overall transport demand (in tonnes or tonne kilometres) as well as on the modal share for IWT. I investigated the main drivers of these two factors by analysing four recent long term transport scenario studies and concluded that: (1) the development of the overall transport demand is mainly driven by economic output (i.e. GDP), but also by trade volumes; and (2) that the modal share of IWT depends on a wider range of drivers that affect the relative cost levels of the different transport modes, such as amongst others fuel costs and infrastructure charges. In addition to the main drivers I also analysed the methodology and input data that were used for the quantification of the scenarios. With respect to the applied methodology I concluded that there is an inverse relation between the anticipated time horizon and the level of detail that can be taken into account in the applied forecast models, which implies that the farther one looks ahead the more aggregated (i.e. less detailed) the applied forecast models need to be become. With respect to the applied input data I encountered an issue with the (in my opinion much too) high economic growth projections that were used in all four evaluated long term transport scenario studies, for which an explanation is given in the next section.

15.2.3 The very long term development of the world economy

A clear definition of *'the long term'* does not exist as the perception of time depends on the inertia of the process under consideration. I defined *'the long term'* as a period of 5 to 30 years ahead and *'the very long term'* as a period of 30 to 200 years ahead. Insight into the long term development of the world economy can be obtained from analysing so called Megatrends. Megatrends relate to fundamental processes of transformation with a broad scope and a dramatic impact that take place over a time span of at least a decade. For dealing with very long term issues even longer trends need to be considered such as the about 50 years lasting 'Kondratieff waves' and the 'Secular trend' (i.e. the trend over the ages).

Kondratieff waves can be observed since the beginning of the Industrial Revolution. They are closely related to the structure of the economy, the technology base, and the social institutions (i.e. the prevailing socio-techno-economic paradigm). According to several authors the 2009 crisis marked the start of the downswing period of the present 5th Kondratieff wave. Though not explicitly stated this wave is generally considered to be driven by what I refer to as the broad concept of *'Globalisation'*. The upswing period of the next 6th Kondratieff wave is roughly expected in the period from about 2030 to 2055. Present literature indicates (often implicitly) that this wave is likely to be driven by the broad concept of *'Sustainability'*.

Despite being important for the structure of the economy, the Kondratieff waves have little effect on the overall very long term GDP trend. The very long term development of population and economic output can be related to the Secular trend over the ages. This trend started in the Middle Ages and developed through the Renaissance and Age of Enlightenment into the Industrial Age. The beginning of the 21st century is assumed to mark the end of the Industrial Age and the world is now presumed to enter a new so called Post-Industrial Nomocratic Age (in which Nomocratic stands for knowledge based). Kahn et al. (1977) placed the very long term Secular trend in an even broader perspective of the 'Great

Transition', an about 400 years lasting transition period that started at the beginning of the Industrial Revolution.

The presumption that the world economy follows an S-shaped curve of the Great Transition implies that economic output per capita and hence labour productivity are slowly moving towards a maximum attainable very long term output value. I endorse this view, but it should be noted that the mainstream neo-classical view on economic growth (that is adopted in virtually all official scenario studies including those of the OECD, EU, IPCC, and Dutch government) presumes labour productivity and economic output to remain growing at an exponential rate for at least a very long period of time (i.e. without considering any ultimate limits to labour productivity and economic output). This difference also explains why I found the economic growth projections in the analysed long term transport studies too high.

The view that there are physical limits to labour productivity growth is not just endorsed by a few 'physical' economists that also consider the mainstream view of ongoing exponential growth incorrect. Modern semi-endogenous neoclassical economists have already in the mid-1990s concluded that the assumption of constant returns to scale in the knowledge creation function (as applied in the first generation of endogenous growth models) is not in line with empirical observations and should be replaced by a function with diminishing returns to scale. This implies that modern economic theory is already 20 years recognising the fact that there are physical limits to economic growth. On top of that some economists have recently started to discuss the possibility that the economy is drawn into a Secular Stagnation. It is therefore remarkable that the mainstream view still takes exponential growth for granted.

I concluded that a different paradigm on economic growth should be adopted and defined a 'new' *post-neo-classical economic growth paradigm* that departs from the same neo-classical Solow (1956) model but imposes one additional restriction namely that the state-of-the-art labour productivity in technological frontier countries is ultimately constrained by physical limits and therefore follows some kind of S-shaped transition curve that moves towards a still unknown (and unpredictable) horizontal asymptote on the very long term (say a few hundred to a thousand years from now). This paradigm is further adopted in this thesis.

The fact that I chose to adopt a different paradigm on economic growth and developed my own GDP projections instead of using the official very long term economic growth scenarios of the CPB (Netherlands Bureau for Economic Policy Analysis) has clearly affected the transport projections that were prepared in the main research part of this thesis, but it has no effect on the methodology that I propose for the evaluation of policies with a very long term impact. The methodology that I propose in this thesis is therefore also valid in case the mainstream endogenous neo-classical view on economic growth is applied.

15.2.4 The options to deal with uncertainty in policy making

I continued this study with an investigation into the available options to deal with very long term policy issues – and concluded that sufficient methods exist for looking ahead and dealing with the inevitable high levels of uncertainty that come with a very long term planning horizon, but that the fields of looking ahead and dealing with uncertainty are still completely separated from each other and not structured in an integrated consistent manner. I have therefore proposed an integrated structure for looking ahead and dealing with uncertainty that can be used as a guideline for policy makers. This structure is indicated in Table 5-5.

For issues dealing with high or even deep levels of uncertainty (Level 3 and 4 in Table 5-5) I recommend the use of scenarios in combination with static robust and/or adaptive policies. Very long term scenarios can be quantified by applying a combination of forecasting and foresight techniques. In addition one can consider the use of highly aggregated very long term probabilistic forecasts (e.g. for the development of overall population, economic output, and total transport demand in a large region such as Western Europe), because the prediction intervals of such probabilistic forecasts can function as a clear limiting condition for the development of more detailed very long term scenarios. I have successfully applied this approach for the quantification of the shipping scenarios at the end this thesis.

Table 5-5 (repeated): Guideline for Looking Ahead and Dealing with Uncertainty

Level of uncertainty	**Proposed methods for looking ahead and visualizing the future**	**Proposed policy approach for dealing with uncertainty**	**Proposed decision criteria**
Level 1: clear enough future.	Forecasting Methodology: (advanced) trend extrapolation techniques.	Optimal policy approach: predict the future and implement an 'optimal' policy for the future.	Utility maximisation: maximisation of desired output (e.g. profit or utility).
Level 2: alternative futures (with probabilities).	Foresight Methodology: probabilistic forecasts or scenarios for which the likelihood is intended to cover the entire outcome space (e.g. scenarios based on the output of a probabilistic forecast).	Risk management approach: minimize risks (or maximize benefits) by implementing cost effective mitigation actions.	Specific risk attitude: criteria depending on specific risk attitude of the policy maker (Hurwicz optimism-pessimism criterion).
Level 3: multiplicity of plausible futures.	Futures Research Methodology: a plausible range of scenarios that is intended to explore the corners of anticipated future developments, plausible storyline scenarios, or plausible probabilistic scenarios.	Static robust policy approach: identify plausible futures and find a policy that works acceptably well across most of them (e.g. by using exploratory modelling techniques).	Regret minimization: use of Savage's mini-max criteria.
Level 4: unknown future (deep uncertainty).	Futures Research Methodology: as for Level 3, but with inclusion of wildcard scenarios to deal with 'Gray Swans'. Clear notion that 'Black Swans' may occur.	Adaptive policy approach: adapt policy over time as conditions change and learning takes place. Extend analysis with scenario discovery.	Regret minimization: as for Level 3, combined with an adaptive decision making structure.

15.3 Answer to the Main Research Question

In order to answer the main research question I defined six methodological sub questions that have been addressed in the main research part of this thesis. The first sub question concerns the development of a clear policy framework for the evaluation of proposed policies with a very long term impact on the IWT system. The following sub questions concern the various items in the policy framework as well as the development of a deductive set of very long term storyline scenarios for the development of the Dutch IWT system. This section starts with an outline of the proposed policy framework, continues with a discussion on the various items in the framework, and concludes with the options to implement the framework. The findings with respect to the development of the scenarios are discussed in Section 15.4.

15.3.1 Outline of the proposed policy framework

In principle there is not much difference between the methodological framework that can be applied for the evaluation of policies with a long term and a very long term impact. In both cases one can apply Agusdinata's (2008) XPIROV policy framework, that is based on the views of Walker (2000) and Lempert et al. (2003). This framework defines the effects of proposed policies (P) and external developments (X) on the system domain (I&R) in order to evaluate the outcomes of interest (O) and value the effects (V). The only difference between the use of this framework for the evaluation of very long term instead of long term policies is that different methods are required to define the external developments, model the system, and value the effects. I have made the XPIROV framework specific for the management of IWT infrastructures. The obtained framework is presented in Figure 6-4.

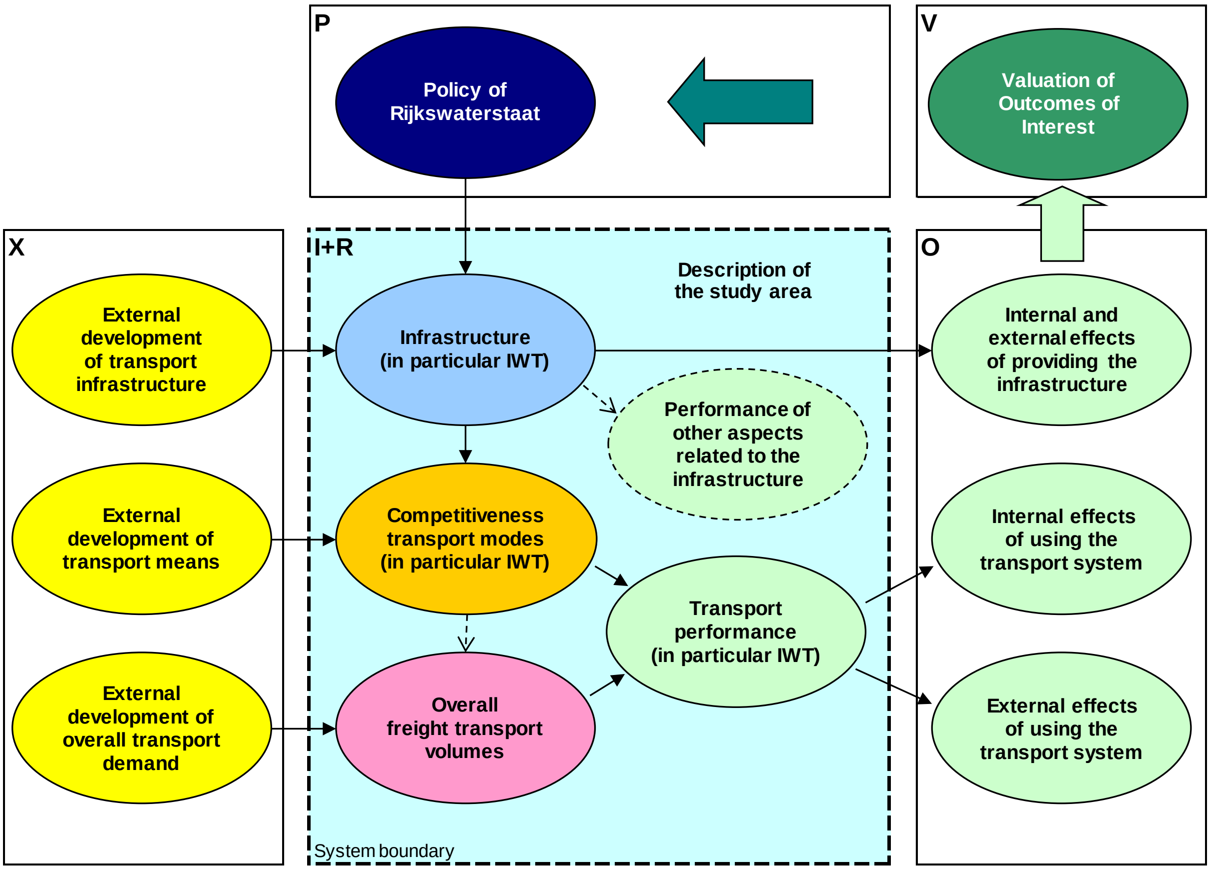


Figure 6-4 (repeated): Proposed Framework for Policies affecting the IWT System

Figure 6-4 shows that the proposed policies and external developments both feed into the system domain, that contains the modelling heart of the policy framework, and defines the policy relevant outcomes of interest to which a value is finally assigned by the policy maker.

15.3.2 The various items in the proposed policy framework

I have studied all the items in the proposed policy framework, though some items gained more attention than others. The section below provides a brief discussion of the results:

Proposed policies (P): The preparation of integrated infrastructure development strategies, that consider the necessary replacement of hydraulic structures as an opportunity to improve the network at a systems level, requires a different working approach than presently applied. Rijkswaterstaat therefore executed a case study to investigate the options to prepare such integrated infrastructure development strategies in practice. This case study, that concerns the Dutch catchment area of the River Meuse, made clear how an integral replacement strategy can be prepared for a large integrated area instead of a single hydraulic structure. I have discussed the findings of this case study in this thesis, but paid no further attention to the preparation of such integrated infrastructure development strategies.

External developments (X): Literature reveals four major external factors for the very long term development of the Dutch IWT system, which are: (1) the very long term development of the overall freight transport demand (in tonnes and tonne kilometres); (2) the development of new transport infrastructure networks, as well as the development of the IWT infrastructure itself; (3) the negative effects of climate change on the navigability of the inland waterways; and (4) the possible effects of major changes to the cost structure of transport on the modal share for IWT. I have conducted an in depth study into the primary drivers of these external developments. Table 15-1 shows how insight in these drivers was obtained and what can be expected of these developments.

Table 15-1: Insight in the Very Long Term External Drivers of the IWT System

Primary driver	How has insight been obtained	What developments can be expected
Very long term development of the overall freight transport demand.	Insight in the very long term development of the Regional (i.e. NL, BE, LU, DE, and FR) transport demand is obtained from a probabilistic transport forecast that applies a simple one variable GDP – transport relation to my own probabilistic post-neo-classical GDP projection.	The total transport demand in the Region is likely to remain growing in the first half of the 21st century. In the second half of the 21st century it may either continue to grow, stabilise or decrease. The year 2100 transport volumes are expected to be about 1 to 3 times larger than for the year 2000.
Very long term development of existing and new transport infrastructure networks.	Insight in the development of existing and new transport infrastructure networks is obtained from the pervasive socio-techno-economic drivers of the very long term Kondratieff waves. The year 2009 crisis marked the downswing period of the 5th Kondratieff wave that was driven by globalisation. The world is now moving towards the 6th Kondratieff wave that is presumably driven by sustainability.	In line with this shift of driver a strong focus on the development of intermodal transport infrastructures can be expected in more sustainable scenarios. This enhances options for the development of intermodal continental transport flows on the inland waterways. In addition the strong focus on sustainability can also enhance further upgrades and expansions of the existing West European IWT infrastructure.
Very long term effects of climate change on the performance of the IWT system.	Global climate scenarios are converted into regional climate scenarios that feed into hydraulic models that define the effects of climate change on the river discharge volumes and water levels. The effects on the draft and loading capacity of the barges are defined by taking into account the barge loading characteristics	The effects of climate change on the IWT system may still remain quite moderate if no fundamental changes to the regional air circulation system takes place, but they can also be very severe if it does. In the worst case, all year round navigation on the Rhine is no longer feasible unless far reaching mitigation measures are taken.
Very long term effects of major changes to the cost structure of inland transport on the modal share for IWT.	Insight in the possible effects of major shifts in the modal split can be obtained by investigating a broad envelope of possible changes to the cost levels of the primary cost factors, such as: land, labour, energy, materials, capital, and tax levels as well as to a few other main cost drivers.	I investigated the effects of a broad envelope of different cost levels on the options for the development of intermodal continental container transport by barge. Depending on the assumed primary cost levels continental container barge transport can either flourish or not develop at all.

System domain (I&R): The system domain contains the model structure for the evaluation of the effects of proposed policies and very long term external developments on the performance of the IWT system at the network level. The modelling of very long term transport flows at the network level does however require a different approach than the approach that is generally applied in long term transport forecast models, because it is impossible to prepare sensible forecasts for detailed aspects up to the year 2100. To solve this issue I have proposed a new hybrid model structure in which the strengths of the aggregated foresight and detailed forecast approaches are combined by projecting aggregated foresight trends onto the output of a classical four stage transport model.

The implementation of this hybrid model structure is still complicated by a number of factors. First off all the aggregated foresight trends act at different stages of the classical four stage transport model. This implies that the aggregated very long term projections need to be imposed onto the intermediate results of the applied long term transport (forecast) model during the execution of the model. This complication can be solved relatively easy by developing an additional model layer that arranges the interaction between the very long term foresight trends and the applied long term transport model.

Much more complicated is the fact that I do not consider the existing long term transport models capable of taking the expected very long term development of intermodal continental container and pallet transport (as well as multimodal bulk transport) properly into account. Considerable research efforts will still be required to make the existing long term transport models suitable for dealing with these possible new transport flows. As the required research and modelling efforts to solve this issue are beyond the scope of this thesis I concluded the discussion on the modelling of the system domain with a comprehensive research agenda for the further development of the desired very long term transport model.

Outcomes of interest (O): When defining the outcomes of interest a distinction can be made between 'direct' and 'indirect' effects on the one hand and 'internal' and 'external' effects on the other hand. For the assessment of integrated infrastructure development strategies with a very long term impact I suggest to include at least: (1) the direct internal effects, that are related to the provision and use of the infrastructure; (2) the direct negative external effects, that take place during the lifetime of the investment (or throughout the execution of the proposed policy); and (3) the direct irreversible negative external effects, that are passed on to future generations (that no longer benefit from the provided infrastructure). It is my personal opinion that a responsible policy maker should take all direct irreversible negative external effects into account in the evaluation of a proposed policy. I think these effects should not be cut off at any future time horizon. Even if the discounted value of the effects is almost negligible it is still important to realise that these effects continue to occur, in particular when considering the fact that there may be something wrong with the applied discount rates.

Valuation System (V): The valuation of policies with a very long term impact can be based on the principles of a social cost benefit analysis (SCBA). There is abundant literature on the use of SCBAs and for the Netherlands clear guidelines have been developed. For this reason I have not further discussed this subject in detail. However, the very long time horizon under consideration does raise a number of issues that need to be addressed.

The most important issue is related to the general practice of future discounting. The presently applied discount rates imply that benefits and disbenefits over 20 to 30 years virtually disappear in the valuation of the effects. This implies that policies aiming for very long term benefits are not considered of any value today. Other issues concern: the notion that the very long time horizon under consideration requires very aggregated performance indicators to describe the outcomes of interest; the notion that the value system may change over time and that this may result in changing costs and benefits per unit of output; and the notion that the no-regret decision criterion is generally considered the most suitable option for dealing with the high uncertainty levels that stem from applying a very long time horizon.

With respect to future discounting it is important to note that over the past two decades there has been a growing belief amongst some scientists that at least the irreversible negative external effects should be discounted at far lower rates. Stern (2006) for instance proposed a set of lower diminishing social discount rates for irreversible negative effects that are now adopted by the British government, but others like Nordhaus (2007) oppose firmly against these rates. I have also studied the issue of future discounting and concluded that adopting the post-neo-classical paradigm on economic growth has major implications for the applied discount rate. I found that, if the post-neo-classical paradigm on economic growth is adopted, the risk free discount rate is bound to go down to zero on the very long term. In line with these new insights I have proposed an alternative discount scheme that is recommended as a sensitivity to the official discount rates. This discount scheme is presented in Table 6-1.

Table 6-1 (repeated): Proposed Discount Scheme

Discounting period	Risk free base rate for investments	Project rate including 3.0% risk premium	Rate for irreversible negative effects
0-30 years	2.50%	5.50%	0.50%
31-75 years	1.78%	4.78%	0.36%
76 - 125 years	1.06%	4.06%	0.21%
126 - 200 years	0.49%	3.49%	0.10%
200 - 300 years	0.15%	3.15%	0.03%
300+ years	0.00%	3.00%	0.00%

***Note: The risk free investment rate is based on (1) a value of 2.5% for the first 30 years which is similar to the value required by the Dutch Government, and (2) the assumption that 200 years from now 95% of the Great-Transition S-curve of labour productivity and economic growth will be completed.**

With respect to the proposed discount scheme it should be noted that the reason for applying a diminishing risk free base rate that gradually goes down to zero on the very long term is free of any ethical considerations, as it directly reflects the consequences of adopting the post-neo-classical economic growth paradigm. This does not hold for the lower discount rates that are suggested in case of irreversible negative external effects. These are based on the risk free discount rate in combination with the ethical consideration not to judge potential damage for the one exposed by a lower weight (or discount rate) due to the fact that he lives in the distant future. However, even if one disagrees with the ethical considerations, the neutral (no ethics involved) conclusion, that the risk free discount rate should gradually go down to zero on the very long term, will still have major implications on the outcome of SCBAs for issues with a very long term impact, because much more weight is given to the very long term effects.

15.3.3 Towards implementation of the proposed policy framework

The scope of this PhD project was too large to include the implementation of the proposed policy framework. Especially because it turned out that still a considerable amount of research and modelling efforts will be required to develop a functional very long term transport model. However, the fact that I have been able to identify the expected development of the primary very long term drivers that act on the system, as well as the fact that I have been able to show how a very long term transport model can be developed by combining the strengths of the forecasting and foresight methods into a single model approach, implies that it should (at least in theory) be possible to take the effects of proposed policies and external developments with a very long term impact on the IWT system into account in the policy making process of Rijkswaterstaat. This alone is already a major achievement as I encountered quite some scepticism with respect to preparation of very long term projections during the execution of the research. What still lacks is a functional very long term transport model, for which I drafted an outline and proposed a research agenda. In my opinion the results of this thesis therefore justify a further continuation of the research work.

15.3.4 Answer to the Main Research Question

In answer to the Main Research Question, I conclude that *"a workable method for taking the very long term development of the Dutch Inland Waterway Transport (IWT) system into account in the evaluation of integrated infrastructure development strategies with a very long term impact"* can be developed by implementing the XPIROV policy framework. The only difference between the use of this framework for the evaluation of very long term instead of long term policies is that different methods are required to define the external developments, model the system, and value the effects. This study shows that it is possible to develop insight in the external developments, but that still a considerable amount of additional research and modelling efforts will be required to obtain a workable very long term transport model. In addition it is argued that it is necessary to base the very long term transport projections on a different economic growth paradigm and apply much lower diminishing discount rates for the valuation of very long term and ultra-long term effects.

15.4 Conclusions on development of Shipping Scenarios

The qualitative and quantitative storyline scenarios for the very long term development of the Dutch IWT system were prepared in conjunction with the shipping scenarios for the Dutch Delta Programme. This section concludes on the selection of the key drivers, the obtained storylines and scenario quantifications, as well as on the implications of using the post-neo-classical economic growth paradigm for the quantification of the scenarios.

15.4.1 The selection of the key drivers

The broader Delta Scenarios were developed around the four quadrants that are created by the intersection of the axes of two key drivers, being: (1) socio-economic developments; and (2) the effects of climate change. However, when I started to develop the scenarios I concluded that a third driver should have been added, that concerns the speed of the transition towards a more sustainable society. The official Delta Scenarios implicitly assume that a strong focus on sustainability results in a reduction of the negative effects of climate change, but this may not be the most logical reasoning. I would argue that the inertia of climate change is much larger that the inertia of the transition towards a more sustainable society. It is therefore questionable to what extent future policies can still affect the rate of climate change. In particular in case of high economic growth I would suggest to adopt the inverse causal relation, that the inevitable rapid change of the climate causes a strong societal drive to become sustainable. On the other hand it may still be possible that the effects of climate change remain quite moderate despite an ongoing emission of greenhouse gasses[158]. I therefore argue that the outer corners of plausible future developments would have been better explored if two different corner points

[158] This scenario is now becoming less likely (see IPCC, 2013), but I still consider it very well suited to explore the outer corners of plausible future developments, as intended by the Delta Scenario Study.

were chosen, and for that reason I added two additional scenarios that were presented as a sensitivity analysis to the official Delta Scenarios. The positioning of the four official scenarios (WARM, REST, STEAM, and BUSY) as well as the two additional scenarios (STEAMING-ON and WATER PRESSURE) is indicated in Figure 15-1.

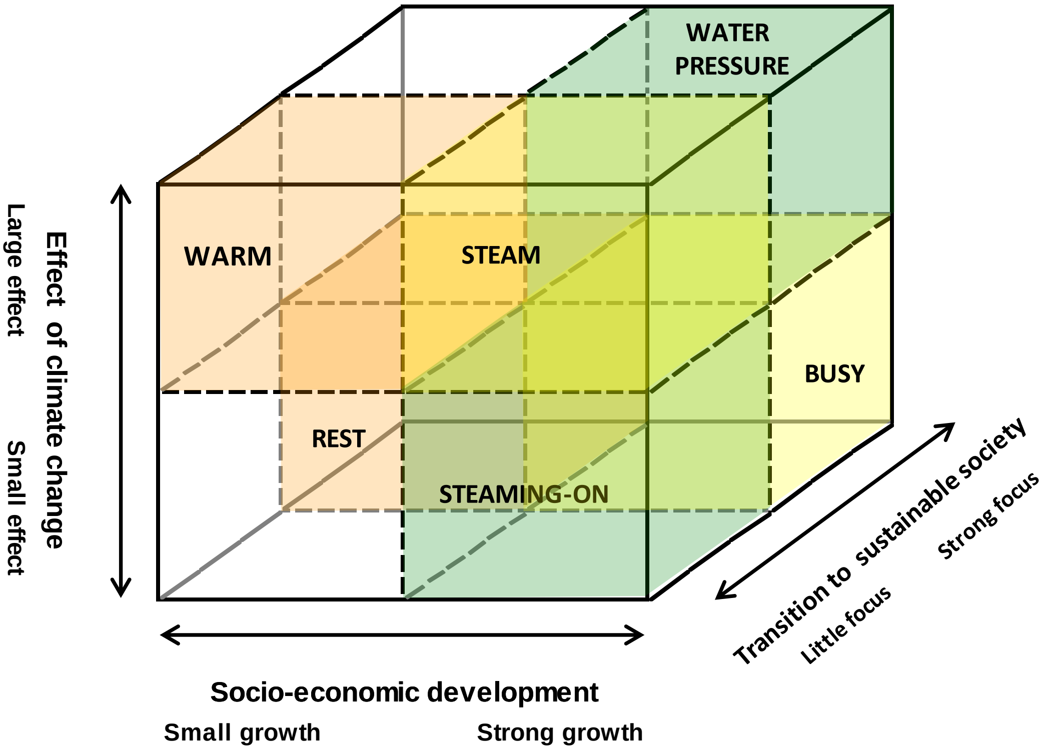


Figure 15-1: Positioning of the four official and two additional Delta Scenarios

15.4.2 The storylines of the shipping scenarios

The storylines of the shipping scenarios were prepared in line with the considerations that: (1) high economic growth results in high transport volumes; (2) climate change has a moderate effect on IWT up to the year 2050 and a potentially large effect in the period thereafter up to the year 2100; and that (3) a swift transition towards a sustainable society reduces the overall transport volumes because it causes a strong decoupling of economic output and transport, enhances the development of intermodal barge transport (also for continental cargoes), and fosters investments in an upgrade of the West European IWT system. These considerations resulted in the following six storylines:

1. The **BUSY** scenario combines a high level of economic output with a strong societal drive to become sustainable and the non-occurrence of major effects of climate change. The strong focus on sustainable development enhances the use of environmentally friendly intermodal transport solutions for transport of continental cargoes (e.g. in continental pallet wide high cube 45 foot containers). For the seaports this implies a strong growth of the continental short sea shipping volumes. On the inland waterways it implies that IWT will not only maintain a strong position in the transport of bulk commodities and conventional deepsea containers, but also gains a strong market share in the transport of continental full load cargoes (i.e. full truck and container loads). The strong focus on intermodal transport enhances companies to shift their logistics operations to the waterfront. This considerably reduces the intermodal

pre- and end-haulage costs and thereby enables the development of advanced IWT pallet distribution networks in the second half of the century.

2. The **STEAM** scenario combines a high level of economic output with a virtual absent focus on sustainability and large effects of climate change on sea level rise and river discharge. A strong growth of the overall transport volumes takes place throughout the century. However, from about the year 2050 onwards the Dutch ports start to lose market share to other ports in the Le-Havre – Hamburg range due to the poor navigability of the river Rhine (as well as the Waal and Gelderse IJssel) in the months July to October. The absolute port throughput volumes nevertheless keep growing. Inland shipping loses an even larger market share in response to the effects of climate change, but due to the strong growth of the overall transport volumes the absolute IWT volumes will still continue to grow. Despite an as good as absent focus on sustainability the strong growth of the transport volumes enables the market to develop some cost effective intermodal continental container barge lines. The potential development of intermodal pallet distribution networks does not take place.

3. The **REST** scenario combines a low level of economic output with a strong focus on sustainability and the non-occurrence of major effects of climate change. The overall transport volumes still continue to grow throughout the first half of the century but decline in the second half of the century due to reduced economic output and ongoing decoupling of economic output and transport. The strong societal drive to develop sustainable transport solutions enables the IWT sector to increase its market share. Apart from bulk cargoes and conventional deepsea containers the IWT sector also captures a fair share of the continental full cargo loads. The focus on intermodal transport enhances companies to shift their logistics operations to the waterfront. This eventually reduces the intermodal pre- and end-haulage costs considerably and thereby enables the development of some advanced IWT pallet distribution networks in the second half of the century.

4. The **WARM** scenario combines a low level of economic output with a virtual absent focus on sustainability and large effects of climate change on sea level rise and river discharge. The port throughput volumes initially show a moderate growth, but this growth turns into a decrease in the second half of the century. This decrease in transport volumes is mainly caused by reduced economic output and worsened IWT connections to the hinterland. Inland shipping loses an even larger market share in response to the effects of climate change. Very little options exist to develop cost effective intermodal continental container barge transport. The potential development of intermodal pallet distribution networks does not take place.

5. The **STEAMING-ON** scenario is related to the STEAM scenario but differs to the extent that major effects of climate change do not occur despite the ongoing emission of greenhouse gasses and an absent focus on sustainability. The main difference with the STEAM scenario is therefore that the overall growth of the Dutch port throughput- and IWT transport volumes is not tempered by the negative effects of climate change on the accessibility of the seaports and the navigability of the main IWT connections towards the hinterland.

6. The **WATER-PRESSURE** scenario is related to the BUSY scenario, but differs to the extent that despite a strong societal focus on sustainability the effects of climate

change cannot be avoided. The world has reacted too late to avoid major effects of climate change from taking place. Large efforts are put into the reduction of carbon emissions in order to avoid the impact of global warming to become even worse. Substantial investments are made to maintain and improve the performance of the more environmentally friendly modes of transport such as IWT. These investments amongst others include: a substantial increase in the dimensions of the inland waterways; the development of a number of missing links; and the canalisation of the river Rhine (to guarantee safety against flooding and mitigate low water levels in the dry season). In response to these measures the quality of the IWT system is improved compared to the BUSY scenario and IWT volumes are therefore slightly higher.

It should be noted that some of the storylines could not have been developed without taking broader European and national transport- and climate change adaptation policies into account. A good example is the canalisation of the river Rhine in the WATER-PRESSURE scenario. This scenario could have not been developed without taking such general policies into account. I therefore argue that general policies should be included in the preparation of very long term scenarios. Taking general policies into account does not imply that they need to be adopted in the specific plans for the area under consideration by the policy maker. They are only meant to describe the possible development in the rest of the world.

15.4.3 The obtained scenario quantifications

In absence of a workable transport model I still managed to quantify the very long term scenarios for the development of the Dutch port throughput- and IWT volumes on the basis of the insights that were developed in this thesis. The fact that I was able to quantify these scenarios does however not imply that there is no need to develop a more advanced very long term transport model. In some cases I had to make assumptions that are incorrect, but still expected to provide some guidance – and in addition I was only able to quantify the scenarios at the aggregated level. A more detailed transport model is therefore required to improve the quantitative estimates and provide the necessary insights at the network level. The obtained scenario quantifications for the development of the total Dutch port throughput volumes and the total Dutch IWT volumes are indicated in Figure 15-2 and 15-3.

Figure 15-2 shows that the overall port throughput volumes are roughly expected to grow by a factor 1½ to 2½ over the first half of the 21st century, of which the largest growth is caused by the growth in the conventional deepsea containers. In the second half of the century the port throughput volumes may either drop to a level comparable to the level at the beginning of the century or continue to grow at a reduced annual growth rate until it reaches a volume up to about 3 times the size of the port throughput volumes in the year 2000.

Figure 15-3 shows that the IWT volumes are roughly expected to grow by a factor 1 to 1¾ over the first half of the 21st century. Towards the end of the century the volumes are either expected to drop to a level that is about half the size of the IWT volumes at the beginning of the century or to continue to grow to a volume up to about 2 times the volume at the begin of the century. The growth of the IWT volumes is very much related to the growth of the deepsea- and continental container volumes. The bulk volumes are either expected to decrease or to remain at the initial level that they had at the beginning of the century.

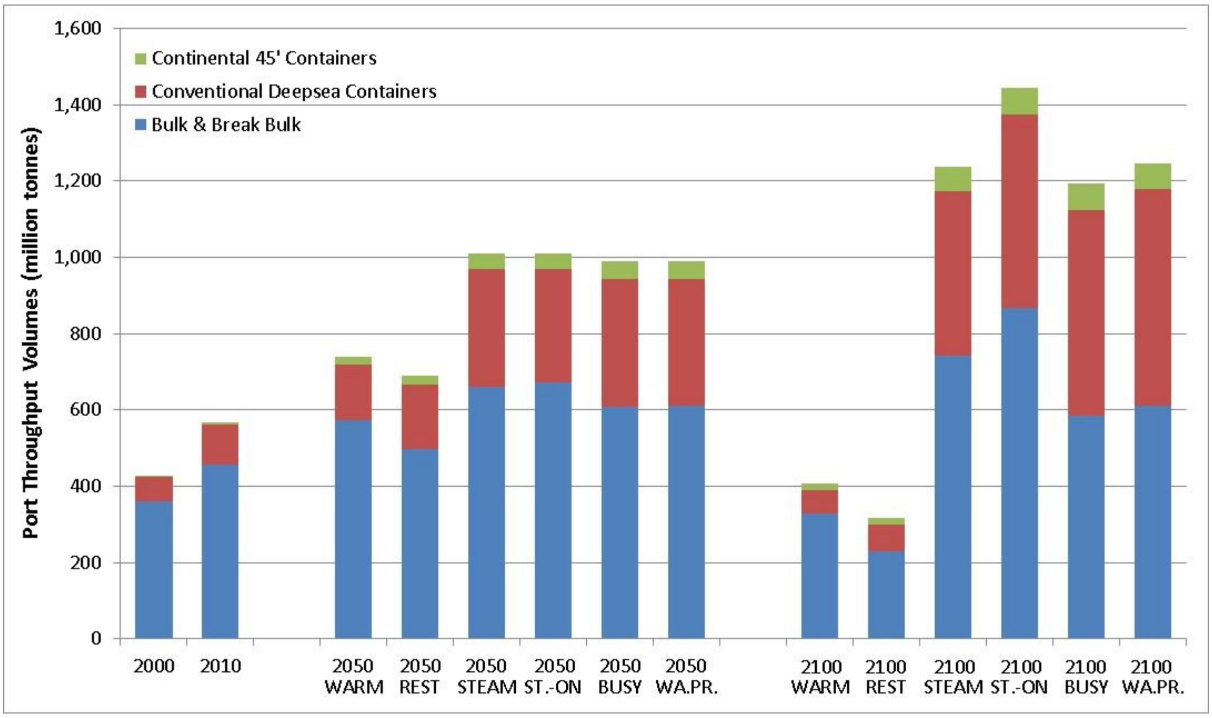


Figure 15-2: Scenarios for development of Dutch Port Throughput Volumes

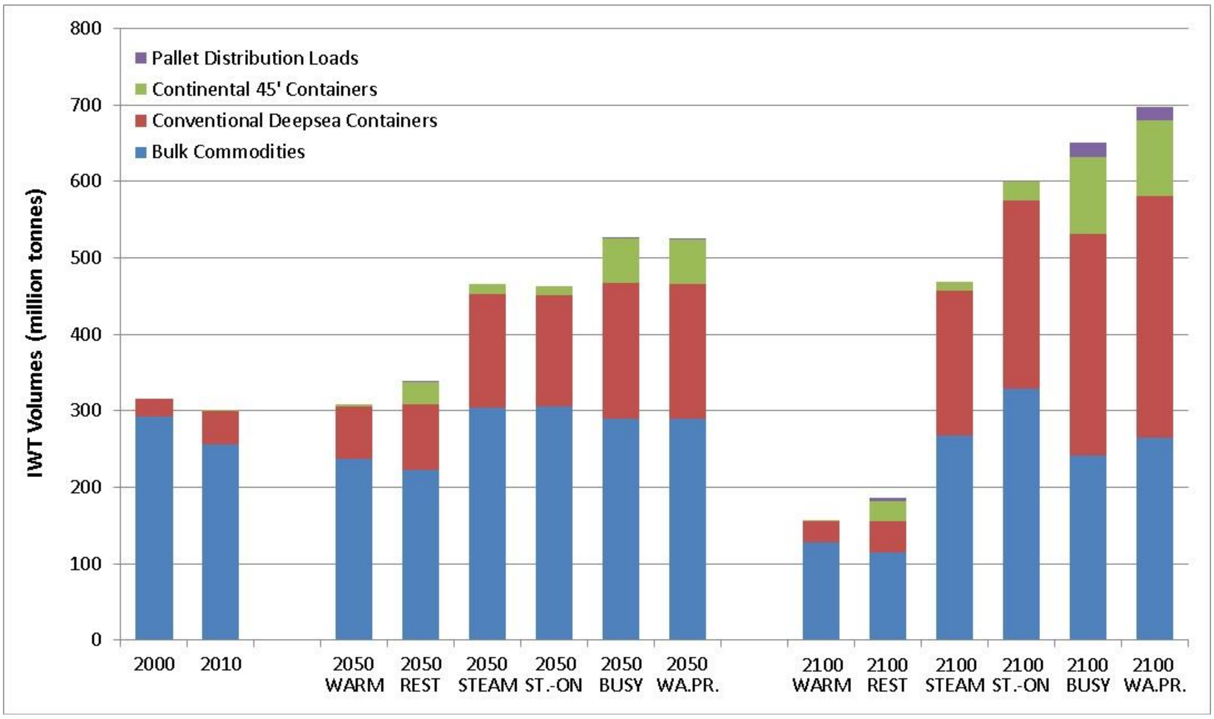


Figure 15-3: Scenarios for development of Dutch IWT Volumes

15.4.4 The implications of using the post-neo-classical economic growth paradigm

The obtained scenario quantifications are based on the aggregated probabilistic transport forecasts that were developed in the main research part of this thesis. These forecasts were obtained by applying the GDP–transport relation to a probabilistic GDP forecast that was developed in line with the post-neo-classical view on the growth of labour productivity and economic output (as discussed in the preliminary research part of this thesis).

The differences between the GDP estimates that I apply and the official GDP scenarios of the CPB are considerable. The official GDP projections are roughly about 25% to 50% higher in the year 2050 and about 100% to 200% (i.e. a factor 2 to 3) higher in the year 2100. Given the almost one-to-one relation between the overall level of economic output and the overall level of transport it is obvious that the choice to base the shipping scenarios on post-neo-classical economic growth projections has very much affected the outcome of the obtained scenario quantifications. If I would have based the shipping scenarios for the year 2100 on the official economic growth scenarios of the CPB, I would have obtained transport scenarios that are roughly a factor 2 to 3 higher.

I have discussed the outcome of the transport scenarios with a few experts of the Dutch Government, Deltares, and the Rotterdam Port Authority, who regarded the scenarios realistic and more or less in line with their long term expectations. This provides some further justification for the use of my post-neo-classical growth projections, but more important they have also mentioned that experts from other disciplines are also struggling with the high exponential economic growth scenarios of the CPB, that tend to result in unrealistic very long term scenarios for issues such as land use and fresh water demand. The fact that it seems to be impossible to obtain sensible very long term projections for issues such as land use, water demand, and transport on the basis of exponential economic growth scenarios supports my view that a different economic growth paradigm should be adopted.

15.5 Reflection on Economic Growth and Future Discounting

In the 1970s the development of labour productivity and economic output was still considered to be related to an about 400 years lasting transition S-curve that started at the beginning of the Industrial Revolution some 200 years ago. However, in the 1980s the economic society started to develop endogenous growth models, that assumed constant returns to scale in the knowledge creation function and no longer regarded labour productivity and economic output to be bounded by any physical limits. In line with these models the mainstream view became that the economy in advanced nations is slowly moving towards a fixed equilibrium growth rate on the very long term. As a result virtually all official long- and very long term scenarios are now developed in line with the assumption of ongoing exponential growth. This also holds for the Dutch WLO scenarios (up to the year 2040) and Dutch Delta Scenarios (up to the year 2100) that assume a fixed annual labour productivity growth rate of 1.2% to 2.1% throughout the century.

In my opinion the mainstream neo-classical views of ongoing exponential growth cannot be maintained throughout a very long time period, let alone throughout an ultra-long time period. The preparation of very long term projections as well as the evaluation of very- and ultra-long lasting effects requires a different view for which I proposed to adopt a post-neo-classical economic growth paradigm in Chapter 4 (see also Section 15.2.3).

Those endorsing the mainstream paradigm (that is generally perceived as the more optimistic view) are however likely to have great difficulty to accept that a different view on economic growth is required. In the hope to persuade them I conclude this thesis with ten arguments why, in my opinion, a different post-neo-classical (or physical/semi-endogenous) paradigm on very- and ultra-long term economic growth should be adopted. These arguments are:

- **Argument 1:** Considering an ultra-long time scale of ten thousands of years, human history shows only a few relatively short periods in which substantial economic growth took place. In general economic growth is more the exception than the rule.

- **Argument 2:** Mainstream economists, that base their view on the first generation of endogenous neo-classical economic growth models, do not claim economic growth to go on forever. They just don't consider what will happen a few hundred years from now (i.e. when I expect economic output to move towards its final limit state).

- **Argument 3:** Empirical data from Appendix B shows that the applied exponential growth functions for the development of labour productivity in the evaluated transport scenarios of Chapter 3 fit the post 1950 historical data much less than the linear- or diminishing growth functions over the same time period[159].

- **Argument 4:** Economists that endorse the view that there are physical limits to labour productivity growth make clear that the primary drivers of economic growth since the beginning of the industrial revolution are gradually losing their effect in the western world – and economists that belong to a relatively new conceptually distinct field of ecological economics make clear that the exceptional growth over the past century was a result of the ample availability of easily exploitable fossil fuels and other non-renewable resources for which the better mining areas are gradually depleting.

- **Argument 5:** Modern economists in the field of endogenous growth modelling have already concluded some 20 years ago that the assumption of constant returns to scale in the knowledge creation function is not in line with empirical observations and needs to be replaced by a diminishing growth function. In response they have developed a second generation of endogenous growth models that are called the semi-endogenous growth models, for which the mathematical description complies with the physical view that the economy follows some kind of very long term transition S-curve.

- **Argument 6:** Modern semi-endogenous neo-classical economists have indicated that the constant about 2% exponential growth rate of the U.S. economy over the past 150 years is a result of an exceptional increase in the level of education and the number of researchers, that has offset the effects of diminishing returns to scale. However, this strong growth in the number of researchers cannot be continued forever.

- **Argument 7:** If the growth rates that are applied in the high scenario of the Dutch Delta Programme (as defined up to the year 2100) are extended throughout the remainder of this millennium, this would imply that some 770 years from now the entire output of today's Dutch economy is produced by just one person. I do not consider this realistic.

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[159] For completeness it should be noted that this difference cannot yet be observed for the United States, where the historical fit of the linear and exponential growth function is almost similar. I think that it may still take a few decades before this effect can also be observed clearly in U.S. data on labour productivity, because the economic output of the U.S. has recently increased 'artificially' by the shale gas and shale oil revolution – and because the U.S. dollar may be 'overvalued' as it tends to be considered a safe haven in economically uncertain times.

- **Argument 8:** There exists a relation between the very long term economic growth rate and the very long term discount rate. In case the very long term growth rate goes down to zero (labour productivity stabilises at its ultimate level) the very long term risk free discount rate will also go down to zero. The use of a zero risk free discount rate implies that very long term irreversible negative external effects will have to be discounted at a zero discount rate. This finding directly bridges the gap between the irreconcilable views of those applying discount rates to justify economic activities with irreversible negative external effects and those advocating sustainable operations in which one does not trade a one-time benefit to the present generation for ultra-long lasting disbenefits to future generations. The post-neo-classical views on economic growth therefore enable these two groups to argue from the same paradigm.

- **Argument 9:** I used GDP projections that were developed in line with the post-neo-classical economic growth paradigm for the development of my very long term transport forecasts and scenarios. The obtained scenarios were considered realistic by the consulted experts. Most likely this would have not been the case if I would have applied the mainstream exponential economic growth paradigm.

- **Argument 10:** I understood, during one of the meetings on the development of the shipping scenarios for the Dutch Delta Programme, that other scenario developers are also facing severe issues with the high exponential growth rates that are applied in the broader Delta Scenario study. In the same meeting I was nevertheless, for practical reasons, advised not to enter into a tough and lengthy discussion on the development of labour productivity and economic growth with the CPB. It was instead suggested to reduce the transport volumes to the level that I would consider more realistic by applying an 'artificial' high rate of decoupling between GDP and transport. I was informed that this approach has also been applied for the quantification of the WLO scenarios. It therefore seems to be impossible to develop realistic very long term scenarios on the basis of the prevailing endogenous neo-classical GDP projections.

I think these are sufficient arguments for adopting the proposed post-neo-classical paradigm on economic growth, but I can imagine a certain reservation as adopting this paradigm will have major effects on the outcome of very long term projections (that will be much lower) and the level of the appropriate discount rate that is applied when discounting very- and ultra-long term effects (that will also be much lower). For those that have such reservations I would suggest to study the modern semi-endogenous growth theory starting with the work of Jones (1995). Otherwise I would suggest to at least consider the possibility that a two centuries long period of exponential growth could now come to an end.

15.6 Recommendations

On the basis of the conclusions in this chapter I would like to make a few recommendations to Rijkswaterstaat as well as to a number of other institutions and communities.

15.6.1 Recommendation 1: continue with the research on this subject

I recommend Rijkswaterstaat to continue the research on the development of a workable method for taking the very long term effects of proposed policies and external developments into account in the evaluation of policies with a very long term impact. For instance by appointing a few new PhD researchers and/or post docs to work on the further development of the very long term transport model for the IWT system. I think that such efforts are justified because the benefits of such a methodology are likely to outweigh the costs, and because I have concluded that it should (at least in theory) be possible to develop such a method.

15.6.2 Recommendation 2: investigate the options to solve the modelling issues

I recommend the transport modelling community to investigate the options to solve the identified issues with the modelling of the inter- and multimodal transport flows, which are mainly related to: (1) the applied description of the IWT network by means of a number of individual waterway classes instead of the true infrastructure dimensions; (2) the applied commodity classification, that does not reflect on the transport characteristics of the goods; and (3) the unimodal way in which transport data are gathered, that does not provide the necessary insights in the true origins and destinations of the transport flows.

In line with this recommendation I advise Rijkswaterstaat to think of its possible role as a catalyst for the suggested model improvements that are beneficial to a wider range of stakeholders. I can imagine that it is worth considering a joint European research project on each of these topics.

15.6.3 Recommendation 3: consider a three dimensional scenario framework

I recommend the Delta Commissioner to consider a three instead of a two dimensional framework for the development of the next generation of very long term Delta Scenarios. Different assumptions on the causal relation between the speed of the transition towards a sustainable society and the effects of climate change are likely to improve the exploration of the outer corners of plausible future developments.

15.6.4 Recommendation 4: reconsider dimensions of Canal Seine – Nord Europe

I recommend the French government to reconsider the dimensions of the planned Canal Seine – Nord Europe. The development of cost effective intermodal continental container transport (in continental pallet wide high cube 45 foot containers) on this canal requires the allowable barge dimensions to be sufficient to load four pallet wide containers next to each other as well as three high cube containers on top of each other.

15.6.5 Recommendation 5: reconsider the applied economic growth paradigm

I recommend economists, scenario developers, and politicians (including governments and institutes such as for instance the IMF, ECB, OECD, IPCC, and CPB) to replace the commonly applied mainstream paradigm of ongoing exponential economic growth by a 'new' post-neo-classical (or physical/semi-endogenous) paradigm that assumes labour productivity (and hence economic output) to grow towards a fixed maximum attainable output level on the ultra-long term (after which it may possibly fall into decline) – because the underlying assumption of constant returns to scale in the knowledge creation function that causes exponential growth is not only considered incorrect by some alternative views on economic growth that endorse the existence of physical limits, but has also been put aside some 20 years ago by the modern semi-endogenous neo-classical economic growth theory.

In line with this recommendation I advise Rijkswaterstaat to get involved in the development of the very long term economic growth scenarios for the Netherlands as it is clearly in the interest of Rijkswaterstaat to work with realistic transport scenarios that do not assume the overall transport volumes to grow towards unrealistic high volumes on the very long term. In my opinion such very long term transport scenarios cannot be based on very long term economic growth scenarios that take ongoing exponential growth for granted.

15.6.6 Recommendation 6: concerning the applied very long term discount rates

I recommend economists, policy makers, and researchers doing policy relevant research to take note of the fact that – if one adopts a post-neo-classical (or physical/semi-endogenous) view on economic growth – this also implies that the very long term risk free and social discount rates are eventually bound to go down to zero on the ultra-long term. I would therefore recommend to at least conduct a sensitivity analysis in which a post-neo-classical discount scheme is applied (such as the one presented in Table 6-1). Note that conducting a sensitivity analysis on the applied discount rates is also recommended by the official Dutch guidelines for social cost benefit analyses (see Romijn and Renes, 2013).

15.7 Main Conclusions

- Rijkswaterstaat desires to develop a workable method for taking the very long term development of the inland waterway transport system into account in the evaluation of integrated infrastructure development strategies with a very long term impact.
- This thesis investigates the options to look far ahead into the future of the IWT system and concludes that insight can be obtained in: the development of the aggregated very long term transport demand; the development of new transport infrastructure networks; the effects of climate change on IWT; and the effects of changes in the relative costs of transportation on the modal share for IWT. It should therefore, at least in theory, be possible to develop a workable method for taking the very long term development of Dutch inland waterway transport system up to the year 2100 into account.
- The implementation of the desired method still requires the development of a very long term transport model, for which I drafted an outline and presented a research agenda. The research and modelling efforts that are required to develop this very long term transport model are nevertheless beyond the scope of this thesis.
- In absence of a very long term transport model that defines the transport flows at the network level, I still managed to develop an aggregated set of very long term scenarios for the Dutch port throughput- and inland waterway transport volumes. The obtained scenarios are now incorporated in the official shipping section of the Dutch Delta Scenarios (see Van Dorsser, 2012; and Bruggeman et al., 2013).
- Virtually all official very long term GDP scenarios are now based on the mainstream neo-classical paradigm of ongoing exponential growth. I consider this paradigm wrong because the underlying assumption of constant returns to scale in the knowledge creation domain has never been in line with the physical views on economic growth (that assume the economy to grow along some kind of transition S-curve) and has already been put aside some 20 years ago by the broadly accepted semi-endogenous neo-classical economic growth theory, that assumes diminishing returns to scale.
- I therefore consider it necessary to define a ‘new’ post-neo-classical (or physical/semi-endogenous) growth paradigm that assumes labour productivity and economic output to follow some kind of very long term transition S-curve. The use of the mainstream instead of the post-neo-classical economic growth paradigm would have resulted in very long term GDP- and transport scenarios that would have been about 25% to 50% higher in the year 2050 and about a factor 2 to 3 higher in year 2100.
- Another important implication of endorsing the post-neo-classical views on economic growth is that one should also apply much lower discount rates for the evaluation of very- and ultra-long term effects, because the use of this paradigm implies that the risk free and social discount rates are bound to go down to zero on the very long term.

Literature:

Agusdinata, B. (2008) *Exploratory Modeling and Analysis: A promising method to deal with deep uncertainty,* TRAIL Thesis Series Volume T2008/17, Trail Research School, Delft, The Netherlands.

Bruggeman, W., E. Dammers, G.J. van den Born, B. Rijken, B. van Bemmel, A. Bouwman en K. Nabielek, J. Beersma, B. van den Hurk, N. Polman, Vincent Linderhof, C. Folmer, F. Huizinga, S. Hommes, and A. te Linde (2013) *Deltascenario's voor 2050 en 2100, Nadere uitwerking 2012-2013,* Deltares, KNMI, PBL, CPB, and LEI.

IPCC (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jones, C. I. (1995a) *R&D-based models of economic growth*, Journal of Political Economy, vol. 103, no. 4, pp. 759-783.

Jones, C. I. (1995b) *Time Series Tests of Endogenous Growth Models*, Quarterly Journal of Economics, vol. 110, no. 2, pp. 495-525.

Lempert, R.J., S.W. Popper, and S.C. Bankes (2003) *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis.* RAND, Santa Monica.

Nordhaus, W.D. (2007) *A review of the Stern review on the economics of climate change, Journal of economic literature*, vol. 45, pp. 686-702.

Romijn, G, and G. Renes (2013) *Algemene leidraad voor maatschappelijke kosten-batenanalyse*, CPB and BPL, Den Haag, The Netherlands.

Solow, R.M. (1956) *A Contribution to the Theory of Economic Growth*, The Quarterly Journal of Economics, vol. 70, no. 1, pp. 65-94.

Stern, N. (dir.) (2006) *The Stern Review Report: the Economics of Climate Change*, London, HM Treasury, October 30, 603 p.

Van Dorsser, J.C.M. (2012) *Scheepvaartscenario's voor Deltaprogramma, 100 jaar later...,* Rijkswaterstaat, https://deltaprogramma.pleio.nl/file/download/15938322.

Walker, W.E. (2000) *Policy Analysis: A Systematic Approach to Supporting Policymaking in the Public Sector*, Journal of Multi-Criteria Decision Analysis, vol. 1, no. 3, pp. 11-27.

16 Epilogue

"How lovely is it to do nothing, and then to rest from doing nothing."
- H. Zille, German Illustrator and Photographer (1922)

Dear reader, together we have reached the end of an interesting investigation into the future of not only ourselves, but also our children and our grandchildren. The insights that were developed in this thesis are many and one may have to read this thesis several times to grasp all the new insights that have been presented. I myself am not able to store all the details of this thesis in my head, but all is written on paper now, so it won't get lost.

At the beginning of this thesis I cited Kahn et al. (1977)[160] who wrote that: *"We frequently find that what is well known is poorly understood, and what is taken for granted is taken without thought. We also disagree with much of the thinking and discussion in academic, intellectual and literary establishments today. Therefore, for both the common and academic wisdom we offer uncommon analysis. The exercise may please some, jar others and perhaps upset more than a few. But we are confident that it will open a new perspective on the issues we discuss"*. For a long time I questioned if it would not be inappropriate to start with such a quote, but throughout this thesis it turned out to be a red line, and for that reason I kept it in.

Scientific work is generally intended to provide an original contribution to knowledge, but the usual way of conducting research is not designed for major breakthroughs. The common practice of first studying what others have done in order to find a gap that can still be filled in enhances small incremental contributions, and comes with the danger of getting locked into the mind-set of the present generation of mainstream scientists without giving new ideas a fair enough chance. In addition it also enhances the embedding of erroneous views as people start to cite each other without making up their own mind first.

I am personally used to follow a different approach in which I start to think by myself and write down my views – often guided by intuition – in order to finally confront them with the prevailing views. This is definitely not the easiest way, as it creates a lot of resistance from the establishments, but for me it works out quite effectively.

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[160] Kahn, H., W. Brown, and L. Martel (1977) *The Next 200 Years, A Scenario for America and the World*, The Hudson Institute, Associated Business Programmes Ltd., 17 Buckingham Gate, London, United Kingdom.

I can imagine diehard scientists to offend against the use of intuition in scientific research, as I also did when I was much younger, but today I would argue that intuition is very well able to outperform reasoning. Paradoxically my own views on the use of intuition in scientific research are purely based on reasoning. According to Simon (1987, p.64)[161] intuition can be defined as "*analysis frozen into habit*". This implies that intuition can be regarded as extensive empirical analysis, that has not yet been formalised by means of explicit scientific logic. The challenge in ground breaking science is, from my perspective, to bring mainstream science in line with one's intuition and to simultaneously sharpen this intuition when conducting the research. This is exactly what I have tried to do.

My intuitive approach resulted in a few new insights of which the most important ones are related to the views on the very- and ultra-long term development of economic growth, for which I proposed to adopt a 'new' post-neo-classical economic growth paradigm that no longer takes ongoing exponential economic growth for granted; and a corresponding view on future discounting, for which I concluded, in line with this post-neo-classical growth paradigm, that the risk free discount rate is bound to go down to zero on the very long term. My intuitive approach also resulted in the development of, as far as I know, the first probabilistic very long term GDP projections, as well as the first highly aggregated probabilistic very long term transport projections, and finally it, amongst others, resulted in the suggestion to use a different set of key drivers for the development of the Dutch Delta Scenarios that enabled the development of two additional scenarios.

I found it quite difficult to present these new ideas in such a way that they gain sufficient acceptance. I have clearly experienced that unconventional views create a lot of opposition amongst the establishments, but on the other hand there were many people interested and willing to support which gave me the energy to move on. Though it often took me tremendous efforts to find the right words, these efforts always resulted in a better analysis, which made it worth undertaking them. It is very well possible that my views on economic growth and future discounting will remain subject to discussion for a considerable period of time, but I am confident that these views will eventually be looked upon quite positively. It simply takes time to shift from one perspective to another.

I hope that reading this thesis has been as inspiring as doing the research was for me.

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[161] Simon, H.A. (1987) *Making Management Decisions: The Role of Intuition and Emotion*, The Academy of Management Executive, vol. 1, no. 1, pp. 57-64.

A EU Transport Data

The discussion on the development of the transport system in Chapter 2, 3, and 7 of this thesis required input from long term data series on the development of the inland transport volumes within the Netherlands, its surrounding countries, and the European Union. Preferably very long term data series would have been used that cover the full length of at least one about 50 years lasting Kondratieff wave (see Chapter 4), but such long term data series were not available. It was however possible to prepare a consistent long term dataset on the overall transport performance (measured in tonne kilometres) for each individual EU-27 member state from the year 1970 to the year 2008 (the last year for which sufficient data was available at the moment that I constructed this database in the year 2010). This appendix provides some background on the many issues that were encountered during development of the dataset. The dataset itself is made available on the internet and referred to in Appendix F.

Data on inland transport (in tonne kilometre) is available from various EU sources as well as from the ITF/OECD database for the period from the year 1970 onwards, and in addition the UNECE also provides data for the period from the year 1991 onwards. I nevertheless encountered many issues with the available data and therefore compiled the three above data sources in a single consistent dataset that was further used for the research in this thesis. The obtained dataset includes short sea shipping, road transport, railway transport, IWT, and pipeline transport. Air transport is not included as its share is less than 0.1% for the EU-27.

In addition to the inland transport volumes I also included data on the development of the economy (i.e. the GDP) for the individual EU member states. This data was obtained from the Total Economy Database of The Conference Board. For some countries full data series for GDP did not exist and estimates were made by comparison with former countries, such as Yugoslavia for Slovenia and the USSR for the Baltic states. The economic data was included to make it possible to study the relation between economic output and transport.

The data from the EU, ITF/OECD, and UNECE differ considerable. In fact the EU data was not even consistent over its own publications. For this reason I evaluated, judged and compiled the data from all three sources into a consistent dataset for each individual mode of transport, EU member country, and year. I think that the obtained dataset is reasonable, but there is still considerable room for improvement (e.g. by cross-checking with data obtained from national statistics). In general the rail, IWT, and pipeline data turned out to be reasonably consistent. For road transport this was not the case. A major problem is that the EU shifted in the year 2001 (following its unification) from road transport measurements based on total haulage by national territory to road transport measurements by haulage of companies registered within the country. This implies that data on the actual road transport performance within the member states is no longer available from the year 2002 onwards.

In addition the ITF/OECD and UNECE do not specify what is meant by road transport. From the observed data I consider it possible that things are mixed up and that the presented data sometimes refers to road transport by national haulage and sometimes to the haulage of trucks registered in the country. As a result it is not clear how to interpret the data.

I was only interested in the total road haulage by national territory (and not by trucks registered in the country). As this data is no longer available I constructed my own estimates for the EU member states from the year 2002 onwards. To this end I first estimated the share of the overall road transport volumes within the EU-15 for each of the EU-15 member states on the basis of the historical trend in the 1970-2001 data, and then multiplied the relative share of the individual member states by the reported totals for the EU-15. For the new EU-12 countries only the ITF/OECD data provides a consistent dataset. It is however unclear if this data refers to haulage by national territory, national transport companies, or a combination of both. I have therefore made no adjustments to the ITF/OECD EU-12 data.

The applied approach in which I had to estimate the road volumes on the national territories by myself is far from perfect. It is very unfortunate that these numbers are no longer reported.

Literature:

European Commission (2000) *EU Transport in Figures: Statistical Pocketbook 2000*, Directorate General for Energy and Transport, Brussels. Related data: *pb pt2 July 2000.xls* obtained from DG MOVE - Directorate-General for Mobility and Transport.

European Commission (2001) *Transport and Environment: Statistics for the transport and environment reporting mechanism (TERM) for the European Union – 2001 edition,* Office for Official Publications of the European Communities, Luxembourg.

European Commission (2003) *European Union Energy & Transport in Figures 2003*, Directorate General for Energy and Transport, Brussels. Related data: *ETIF_2003 _tran_tonkm.xls* obtained from DG MOVE - Directorate-General for Mobility and Transport.

European Commission (2010) *EU energy and transport in figures: Statistical Pocketbook 2010*, Publications Office of the European Union, Luxembourg. Related data: pb_2010_32 _tkm.xls obtained from http://ec.europa.eu/transport/publications/statistics/statistics_en.htm.

Websites:

International Transport Forum of the OECD (accessed: 2010) *Historical data on Inland Freight Transport in tonne kilometres*, [www.internationaltransportforum.org].

Total Economy Database of The Conference Board (accessed: 2009, 2014) Historical GDP data, [http://www.conference-board.org/data/economydatabase/].

UNECE Statistical Database (accessed: 2010) *Transport Statistics for Inland Transport Modes in tonne kilometres*, [http://w3.unece.org/pxweb/].

B Reflection on Applied Scenario Input

The nature of forward looking projections is such that ex-ante validation by means of obtaining additional sample data is not possible. The only option to verify the quality of the obtained forecasts and/or scenario quantifications is to verify the quality of the input data and the applied methodology. This appendix reflects on the main transport drivers that were applied in the four transport studies discussed in Chapter 3. It covers the main socio-economic drivers (i.e. population and economic output) as well as the trade volumes.

B.1 Dutch WLO Scenario Input

B.1.1 Applied socio-economic data

The Dutch WLO report does not provide a clear table with the absolute values of the applied scenario drivers. I therefore had to reconstruct the scenario data. Table B-1 provides my best reconstruction of the WLO scenario data in which the economic values are converted into real Euros at constant year 2000 price levels.

Table B-1: Main Demographic and Socio-Economic Drivers in WLO scenarios

The Netherlands	Year	2000	2020	2020	2020	2020	2040	2040	2040	2040
Item	Unit	Real	GE	SE	TM	RC	GE	SE	TM	RC
Population	[million persons]	15.9	17.9	17.6	17.0	16.5	19.7	18.9	17.1	15.8
Population 20-64	[million persons]	9.9	10.4	10.2	10.0	9.8	10.5	10.0	9.2	8.6
Labour (>12 h/week)	[million persons]	7.5	8.7	8.1	8.1	7.5	9.0	7.9	7.6	6.6
Part-time factor	[% of all workers]	8%	7%*	6%*	6%*	5%*	6%	5%	5%	2%
Labour (all workers)	[million persons]	8.1	9.4*	8.7*	8.7*	7.9*	9.6	8.3	8.0	6.7
Labour Participation	[% of pop 20-64]	82%	90%*	85%*	87%*	81%*	91%	84%	87%	78%
Labour Productivity	[thousand Euros]	51.5	75.3*	68.0*	72.6*	64.2*	115.2	92.1	107.5	82.3
GDP	[billion Euros]	418	705	589	629	506	1,107	769	864	554
GDP/Capita	[thousand Euros]	26.2	39.4	33.5	37.1	30.7	56.3	40.8	50.5	35.0
Export Trade	[billion Euros]	293	677	522	550	394	1,338	799	861	474
Import Trade	[billion Euros]	270	644	488	497	369	1,323	821	791	436
GDP/Capita	[index year 2000]	1.00	1.50	1.28	1.41	1.17	2.14	1.55	1.92	1.33
GDP	[index year 2000]	1.00	1.69	1.41	1.50	1.21	2.65	1.84	2.07	1.33
Export Trade	[% of GDP]	70%	96%	89%	88%	78%	121%	104%	100%	86%
Import Trade	[% of GDP]	65%	91%	83%	79%	73%	119%	107%	92%	79%

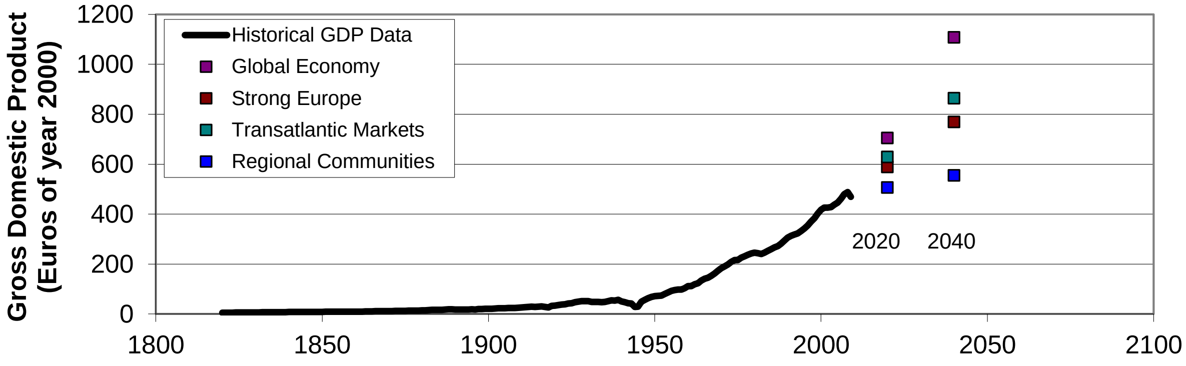
* Estimated values on the basis of the assumption that the 2020 part-time factor equals the average of 2000 and 2040.

Note: Scenarios: Global Economy (GE). Strong Europe (SE), Transatlantic Markets (TM), and Regional Communities (RC); Values in real Euros at constant year 2000 price levels; Labour participation estimated as total workers / size of population in range 20-64; Labour productivity per worker per year.

Source: CBS Statline (www.cbs.nl), Janssen et al (2006b, p.122, 128, and 133), De Jong et al. (2004, p.60), Roodenburg and Vuuren (2004, p.27), Schuur and Verkade (2010, p.2, GDP index digitized from figure), Huizinga en Smid (2004, p.16).

B.1.2 Reflection on the Dutch GDP Scenarios

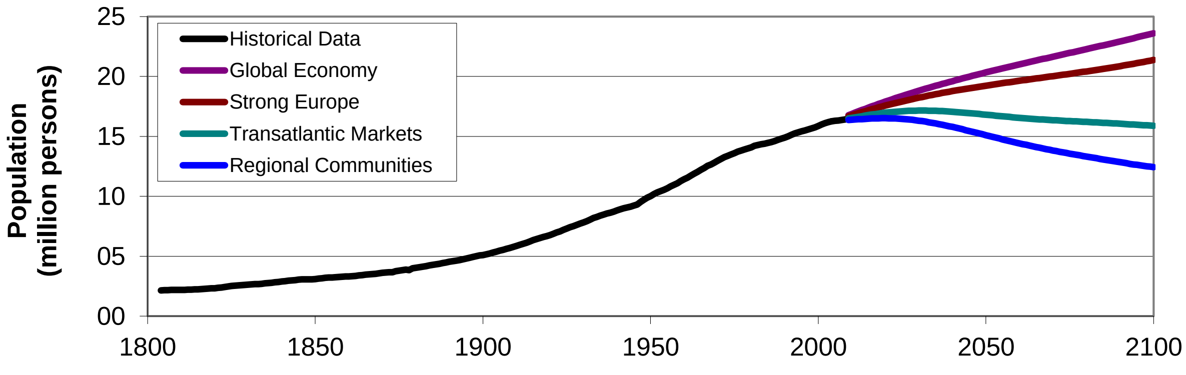
Figure B-1 shows the historical development and expected GDP in the Dutch WLO scenarios. The Global Economy and Transatlantic Markets scenarios show an extension of the historical exponential trend; the Strong Europe scenario shows a more or less linear trend; and the Regional Communities scenario shows that economic growth may reduce as a result of an aging and declining population. At first sight the scenarios appear to be quite reasonable, but it is dangerous to draw conclusions without verifying the underlying assumptions.



Source: Historical Data: Maddison (data 1820-2008), The Conference Board (data 1950-2009) and CBS Statline (data 1969-2010); Scenario Data: from Table B-I.

Figure B-1: Long term development of the Dutch GDP

By definition the economic output (i.e. GDP) of a country equals the size of the working population times the labour productivity of its workers. To verify the underlying assumptions of the GDP scenarios I evaluated the long term development of the size of the overall- and working age population, the degree of labour participation, and the output per worker. Figure B-2 indicates the assumed development of the overall population. The figure also includes an extension of the WLO scenarios up to the year 2100 as proposed by De Jong (2008).

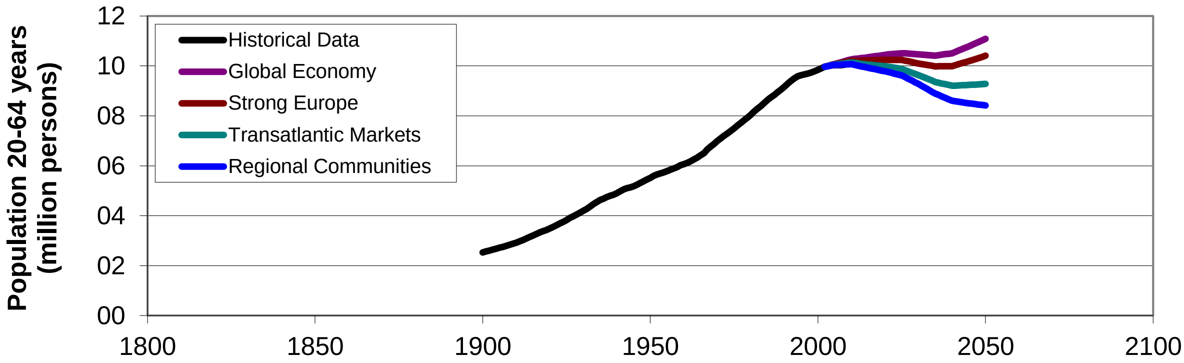


Source: Historical Data: Maddison (data 1820-2008), The Conference Board (data 1950-2009), CBS (2000, CD-ROM, data 1800-1999), and CBS Statline (data 1900-2010); Scenario Data: De Jong et al. (2004, p. 60, data up to 2050) and De Jong (2008, p. 73, extension of data up to 2100).

Figure B-2: Long term development of the Dutch Population

Other long term population projections were prepared by the UN (2004), Alho and Nikander (2004), and Scherbov et al. (2008). The WLO scenarios are in line with the UN projections (of 17.0 million in 2050 and 15.9 million in 2100) and the probabilistic projections for 2050 of Scherbov et al. (2008, mean of 17.2 million and 80% confidence interval of 14.6 – 19.8 million). The WLO population scenarios are therefore in line with other projections[162].

The breakdown of the population projection into different age categories provides insight in the size of the working age population of 20-64 years old[163]. The historical development as well as the values applied in the WLO scenarios are indicated in Figure B-3.



Source: Historical Data: CBS Statline (Data 1900-2010); Scenario Data: from Table B-1.

Figure B-3: Long term development of Working Age Population (of 20-64 years)

The development of the working age population is in line with the probabilistic population projections of Scherbov et al. (mean value of 9.5 million and 80% confidence interval of 7.9 to 11.1 million). The WLO scenarios are therefore also in line with this projection[164].

The size of the working population can be expected to follow the trend of the working age population. To verify this assumption the development of the size of the working population is indicated in Figure B-4.

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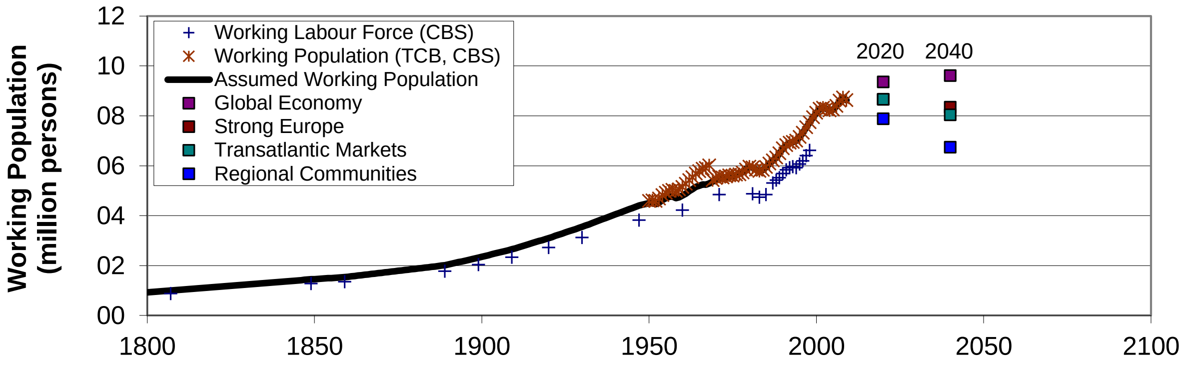
[162] The probabilistic estimates of Alho and Nikander (2004) indicate higher values for 2050 (mean of 19.2 million and 80% confidence interval of 16.5 – 22.7 million) but there are good reasons to expect that this estimate is on the high side. At the time of publishing (in 2004) new insights in probabilistic population forecasts for Europe were obtained. For example the IIASA forecast of 2003 for Western-Europe was adjusted firmly downwards in 2007. It is not unlikely that the probabilistic forecast of Alho and Nikander (published in 2004) were also on the high side. This can also be confirmed by comparing the 2010 forecast to the current 2010 value.

[163] I used this age category as an indication of the amount of working age people, but there are also younger and older people included in the overall work force.

[164] The probabilistic projections of Alho and Nikander for 2050 (mean value of 10.4 million and 80% confidence interval of 9.2 to 11.6 million) are higher than the WLO scenarios that vary from 8.4 to 11.1 million people. However, as discussed above, there are reasons to assume that this forecast is on the high side.

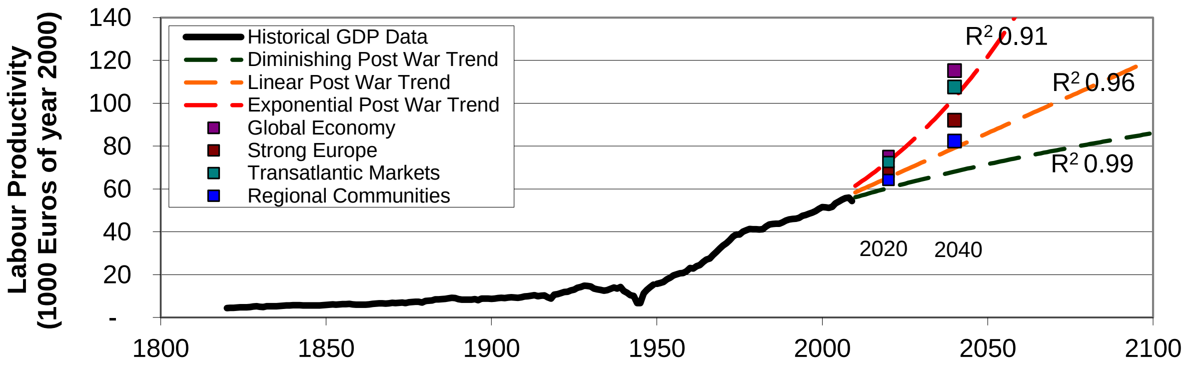


Source: Historical Data: CBS (2000, CD-ROM, data 1807-1998), CBS Statline (data 1969-2010), The Conference Board (data 1950-2009); Scenario Data: from Table B-1.

Figure B-4: Long term development of Total Working Population

From a comparison between Figure B-3 and Figure B-4 it can be concluded that the WLO scenarios more or less follow the trend set by the scenarios of the working age population. However, from Table B-I it can be observed that the assumed labour participation rate (defined as all workers of all ages divided by population of 20-64 years old) increases considerably from 82% in the year 2000 to 91% (GE), 84% (SE) or 87% (TM) in the year 2050. Only the RC scenario shows a slight decrease to 78% over the same period. According to Roodenburg and Vuuren (2004) this change is caused by a large increase in participation of females, elderly, and immigrants. However, I think that these assumptions are somewhat optimistic and would therefore be inclined to apply slightly lower participation rates.

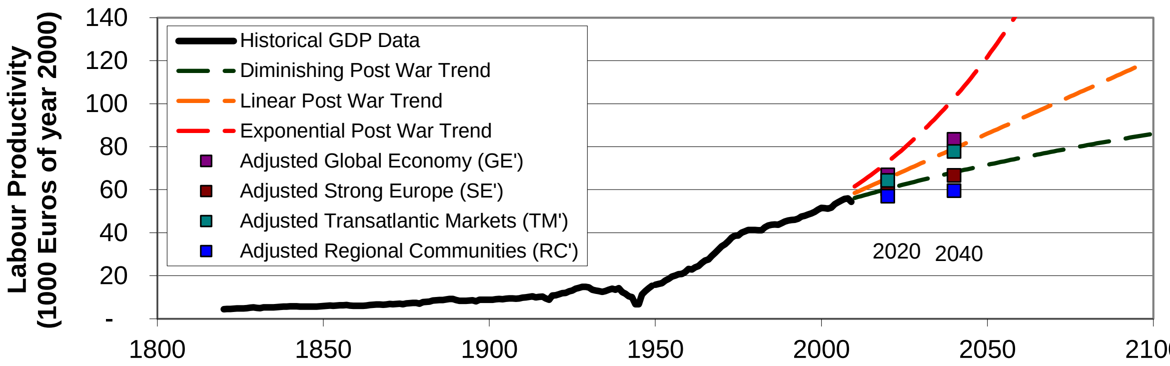
The annual labour productivity per worker can be calculated by taking the quotient of the GDP and total working population (including part-time workers). The applied scenario assumptions as well as the historical developments are indicated in Figure B-5.



Source: Historical Data: Calculated from trends of Figure B-1 and Figure B-4; Scenario Data: from Table B-1.

Figure B-5: Development of Labour Productivity (GDP per Worker per Annum)

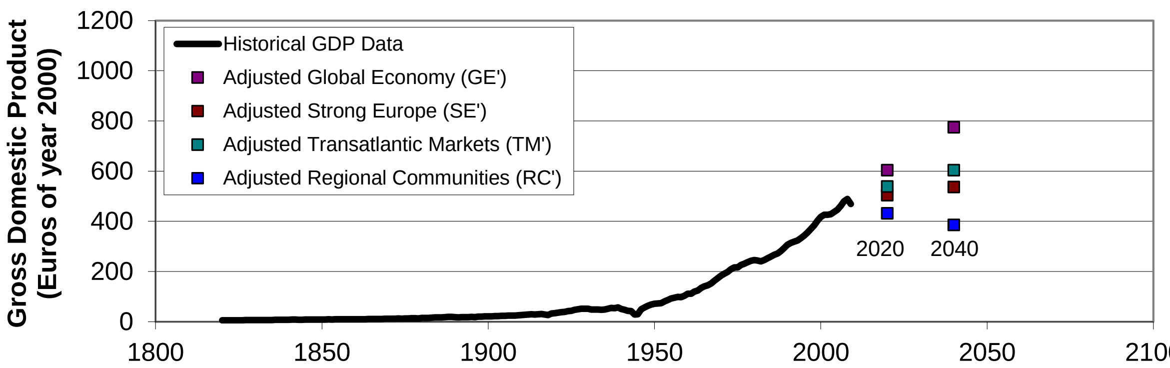
To put things in perspective a number of generic post wars trends were added to the figure. The lowest trend follows a general (diminishing growth) function a*(x–b)^c+d; the middle trend follows a linear growth function a*x+b; and the upper trend follows an exponential growth function a*e^(b*(x-c)) [165]. It appears from Figure B-5 that the WLO scenarios are developed in line with an exponential trend (this means that a more or less constant annual growth factor is applied). However, the exponential trend has a relatively poor fit compared to the other trends. The unexplained variance of the exponential function is 2.4 times larger than the unexplained variance of the linear function and 6.6 times larger than the unexplained variance of the general (diminishing growth) function. I therefore consider it unlikely that labour productivity will follow the trend as set out by the WLO scenarios. I think that the linear trend is already somewhat on the optimistic side. To provide a realistic forward view one should, in my opinion, adjust the WLO scenarios towards the linear and/or diminishing trends. My adjusted assumptions on labour productivity are indicated in Figure B-6.



Source: Historical Data: from Figure B-5; Adjusted Scenario Data: from Table B-4.

Figure B-6: Adjusted assumptions on Labour Productivity

I have prepared a new estimate of the GDP output on the basis of a three percent point lower labour participation rate (which I find more appropriate) and the adjusted labour productivity assumptions. The adjusted GDP scenarios are indicated in Figure B-7.



Source: Historical Data: from Figure B-1; Adjusted Scenario Data: from Table B-4.

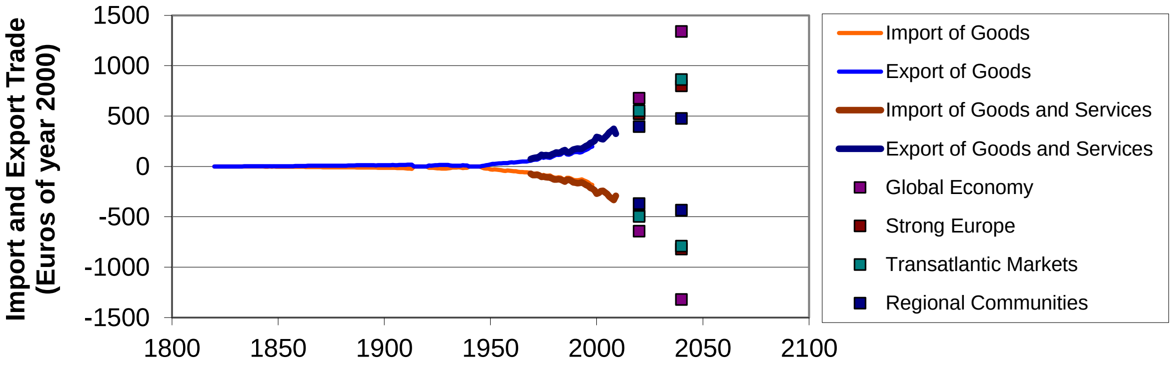
Figure B-7: Adjusted Gross Domestic Product (GDP) Scenarios

[165] The curves were fitted through post war data of 1950 to 2010. The x in the function represents the predicted year. The following coefficients were obtained: general diminishing function: a= 60.858, b=1928.8, c=0.2251, d=-107.6; linear function: a=0.691, b=-1330; exponential function: a=0.8103, b=0.0171, c=1756.8.

From a comparison between the original and adjusted WLO scenarios it can be observed that the economic output (GDP and GDP per Capita) is about 15% lower in 2020 and 30% lower in 2040. This will also lead to considerably lower trade and transport scenarios.

B.1.3 Reflection on the Dutch Trade Scenarios

Figure B-8 shows that the trade volumes (in real terms at constant Euros of the year 2000) have been growing at an exponential rate since the end of the World War II.

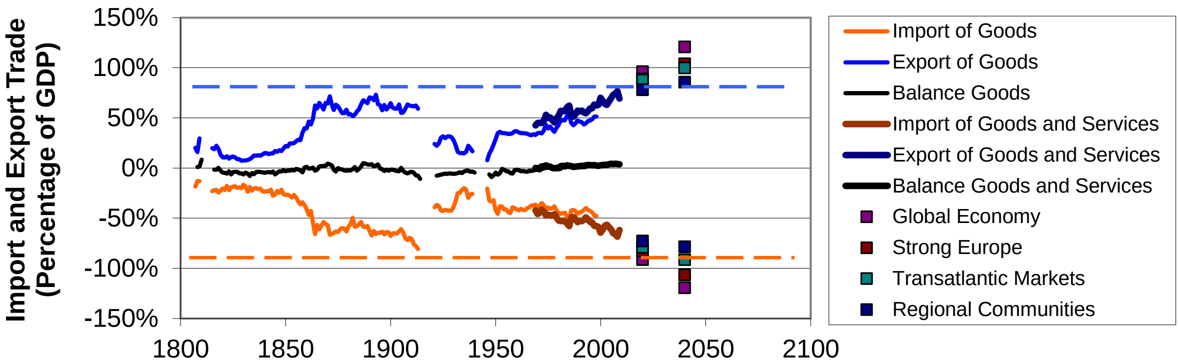


Source: Historical Data: CBD (2000, CD-ROM, data 1800-1999), CBS Statline (data 1969-2010), Maddison (1820-2008), Own Calculations; Scenario Data: from Table B-1.

Figure B-8: Import and Export Trade Volumes

Figure B-8 indicates that the WLO scenarios assume a continuation of the exponential post war trend. The Global Economy scenario assumes the imports and exports to increase by respectively a factor 4.9 and 4.6 (compared to the year 2000 level). This is much higher than the expected growth of the GDP by a factor 2.1. The Regional Communities scenario (with countries having a strong regional focus) assumes the trade volumes to increase by a factor 1.6. This is also much higher than the expected growth of the GDP by a factor 1.3.

I think that it is short-sighted to assume international trade volumes to remain growing at a much faster rate than the economic output volumes. Historical data shows long periods of time with a more or less constant 'trade to GDP factor' (see period 1870-1914 in Figure B-9 for the Netherlands and period 1872-1912 in Figure B-20 for Germany). In these periods the long term growth rate of the trade volumes equals the long term growth rate of the economy.



Source: Historical Data: CBD (2000, CD-ROM, data 1800-1999), CBS Statline (data 1969-2010), Own Calculations; Scenario Data: from Table B-1.

Figure B-9: Import and Export Trade as a factor of GDP

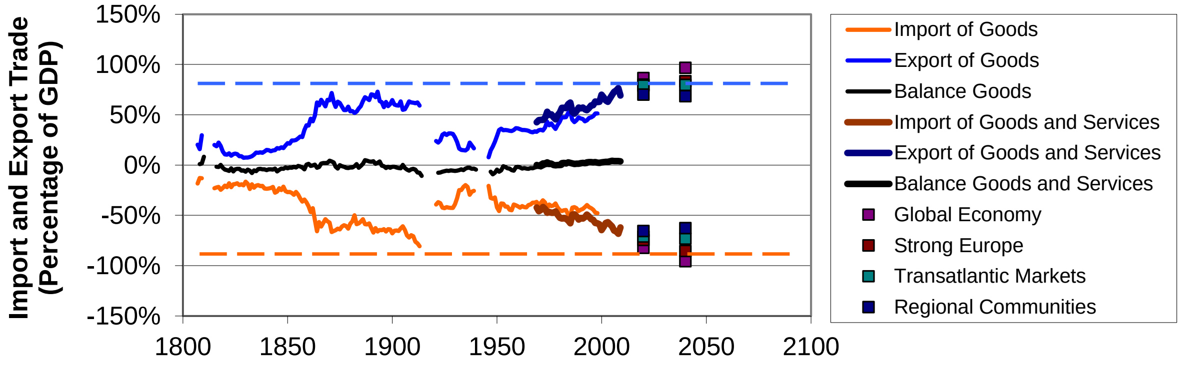
I would argue that the level of openness of the economy (reflected by the trade to GDP factor) is defined by the nature of the country and its geopolitical situation at the time. In absence of major geopolitical changes the trade to GDP factor can be expected to remain more or less constant. This was for instance the case for the Netherlands in the period 1870 to 1914.

Suppose that someone was asked in 1865 to prepare a long term forecast for the future development of trade volumes based on 50 years of historical data. Most likely this person would have forecasted the trade volumes to double within a decade. This however did not happen as soon thereafter the Netherlands reached its natural limits to trade, in which no additional trade can be generated without adding value by producing goods or services. A similar argument can be held today. There are good explanations for the relatively high growth of international trade since the 1960s. The trade barriers of the Cold War were removed and the European Union has become a single political and monetary entity with free movement of people, money and goods. The European economy opened up and is now highly interrelated. In response Dutch trade volumes flourished and the trade to GDP factor rose to its high current level, that is almost similar to the high level in the period from 1870 to 1914.

In order to prevent us making the same hypothetical mistake as in 1865 it is important to realise that the Dutch economy is now already very open. It is questionable if it can become much more open than today. I consider it very well possible that the Dutch economy is once again reaching its natural (saturation) levels of openness. In that case the trade scenarios cannot be based on extrapolation of the historical trend. Instead, it should be based on insight with respect to the development of the openness of the economy. I would therefore suggest the following methodology for the development of trade scenarios:

1. Define the expected relative openness of the economy (i.e. the trade to GDP factor) on the basis of expected geopolitical trends described in the scenarios;
2. Define the scenarios for the development of the GDP (see Section B.1.2);
3. Define the trade volumes by multiplying the GDP by the trade to GDP factor.

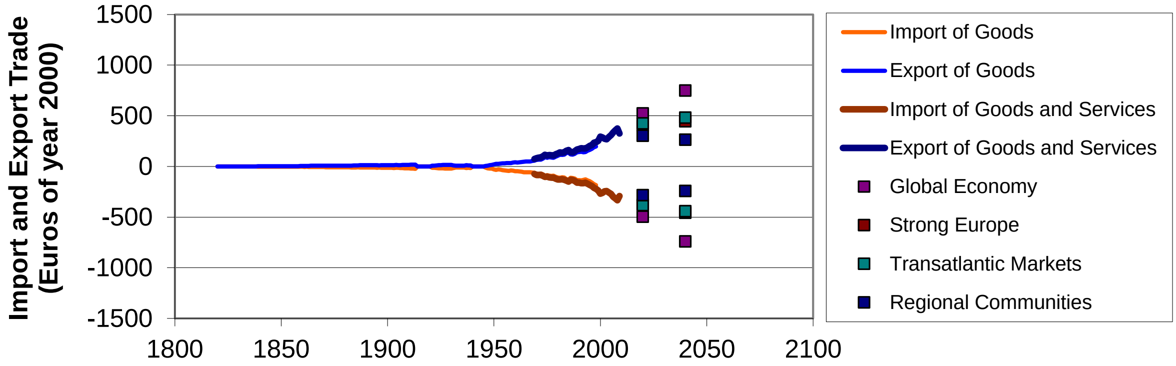
I do not pretend that I am able to forecast the precise level for the openness of the economy, but I find it important to show the implications of a stabilizing trade to GDP fraction on the overall trade assumptions made in the WLO scenarios. I think that the current assumptions (see Figure B-9) are too high. At least for the Regional Communities scenario I would expect a reduction compared to the 2008 situation. I therefore suggest to apply 10% reduction for 2020 and a 20% reduction for 2040 in all scenarios (see Figure B-10).



Source: Historical Data: CBD (2000, CD-ROM, data 1800-1999), CBS Statline (data 1969-2010), Own Calculations; Adjusted Scenario Data: from Table B-4.

Figure B-10: Adjusted Import and Export Trade as a factor of GDP

Further research on the development of the trade to GDP factor will be required to judge if these assumptions are sensible, but the suggested numbers at least put things in perspective. On the basis of the adjusted trade to GDP factors and the adjusted GDP scenarios a new set of the trade scenarios was obtained. The adjusted trade scenarios are indicated in Figure B-11.



Source: Historical Data: CBD (2000, CD-ROM, data 1800-1999), CBS Statline (data 1969-2010), Maddison (1820-2008), Own Calculations; Adjusted Scenario Data: from Table B-4.

Figure B-11: Adjusted Import and Export Trade Scenarios

A summary of the adjusted WLO scenarios is provided in Table B-2. From a comparison with the original scenarios it can be concluded that the expected trade volumes are 23% lower for the year 2020 and 44% lower for the year 2040.

Table B-2: Adjusted WLO scenario output and comparison

The Netherlands Item	Year Unit	2000 Real	2020 GE'	2020 SE'	2020 TM'	2020 RC'	2040 GE'	2040 SE'	2040 TM'	2040 RC'
Population	[million persons]	15.9	17.9	17.6	17.0	16.5	19.7	18.9	17.1	15.8
Population 20-64	[million persons]	9.9	10.4	10.2	10.0	9.8	10.5	10.0	9.2	8.6
Labour Participation	[% of pop 20-64]	82%	87%	82%	84%	78%	88%	81%	84%	75%
Labour (all workers)	[million persons]	8.1	9.0	8.4	8.4	7.6	9.3	8.0	7.8	6.5
Labour Productivity	[thousand Euros]	51.5	66.8	60.3	64.3	56.9	83.3	66.6	77.7	59.5
GDP	[billion Euros]	418	604	503	538	432	774	536	603	385
GDP/Capita	[thousand Euros]	26.2	33.7	28.6	31.7	26.2	39.4	28.4	35.3	24.3
Export Trade	[billion Euros]	293	522	402	424	303	748	446	481	264
Import Trade	[billion Euros]	270	497	376	383	283	740	458	442	243
GDP/Capita	[index year 2000]	1.00	1.29	1.09	1.21	1.00	1.50	1.08	1.34	0.93
GDP	[index year 2000]	1.00	1.44	1.20	1.29	1.03	1.85	1.28	1.44	0.92
Export Trade	[% of GDP]	70%	86%	80%	79%	70%	97%	83%	80%	68%
Import Trade	[% of GDP]	65%	82%	75%	71%	66%	96%	85%	73%	63%
Comparisson with origional WLO figures										
GDP	[% reduction]		14%	15%	14%	15%	30%	30%	30%	30%
Export Trade	[% reduction]		23%	23%	23%	23%	44%	44%	44%	44%
Import Trade	[% reduction]		23%	23%	23%	23%	44%	44%	44%	44%

Note: Values in real Euros at constant year 2000 price levels.

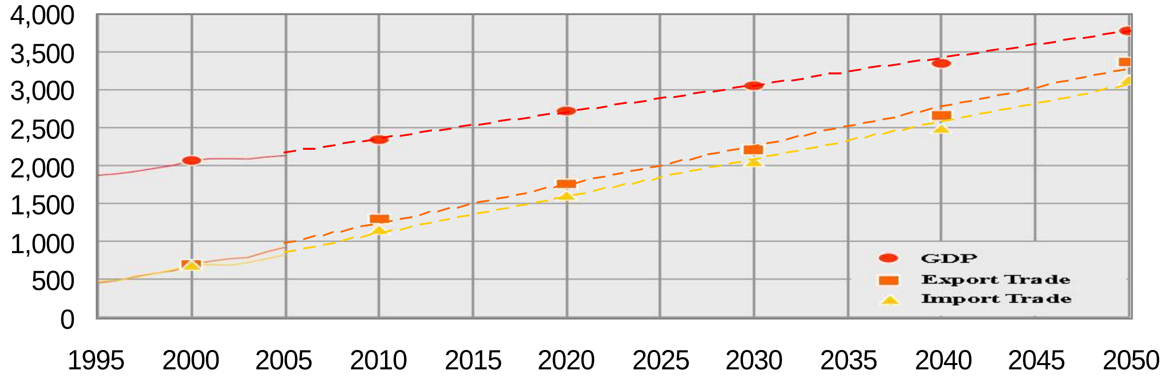
Source: Table B-1, Own Calculations.

I think that the adjusted scenarios provide a better representation of the future state of the GDP and trade volumes. The most important message following from the adjusted scenarios is that the unprecedented growth of the second half of the 20th century may come to an end. I do not expect labour productivity rates to remain growing at an exponential rate. In addition I argue that there are limits to the openness of the economy and that these limits need to be taken into consideration when developing long term trade scenarios.

B.2 German Scenario Input

B.2.1 Applied Socio-Economic Data

The transport volumes in the German scenario study are based on the development of the GDP, as well as on the development of the volumes of import-, export- and transit trade. The applied assumptions on GDP, imports and exports are indicated in Figure B-12.



Note: Figure in billion Euros at constant 2000 price levels

Source: Ickert et al. (2007, p.43), adjusted layout, linear trend lines added.

Figure B-12: Development of GDP and Import/Export Trade Volumes

From Figure B-12 it appears that the estimate was based on just 10 years of historical data (1995-2005). Though it was argued to be impossible to look further back in time due to the reunification of Germany in the year 1990, I still find it inappropriate to use such short time series for such a long term projection. I think that there are better ways to deal with the reunification like using a combination of former DDR and BRD data, which I will apply for the figures in this section. Table B-3 provides a reconstruction of the applied scenario data.

Table B-3: Main Demographic and Socio-Economic Drivers in German Scenario

Germany	Year	1995	2000	2001	2010	2010	2020	2030	2040	2050
Item	**Unit**	**Historic Data ⇨**				**Scenario Data ⇨**				
Population	[million persons]	81.9	82.5	82.5	82.5	82.8	82.6	81.1	78.4	75.1
Population 20-64	[million persons]			51.1		51.0	50.1	45.7	42.9	40.8
Labour Population*	[million persons]	41.0	42.5	42.7	43.6	*43.6*	*41.8*	*39.9*	*38.1*	36.3
Unemplyment rate	[% of available labour]	8.2%	7.8%	7.9%	7.2%	*8.5%*	*7.5%*	*6.4%*	*5.3%*	4.2%
Labour (all workers)	[million persons]	37.6	39.1	39.3	40.4	*39.8*	*38.6*	*37.4*	*36.1*	34.8
Labour Participation	[% of pop 20-64]			76.9%		*78.2%*	*77.2%*	*81.9%*	*84.2%*	85.3%
Labour Productivity	[thousand Euros]	49.7	52.7	53.1	55.6	*58.7*	*70.3*	*81.5*	*92.6*	108.5
GDP	[billion Euros]	1,869	2,064	2,090	2,247	2,338	2,717	3,050	3,346	3,776
GDP/Capita	[thousand Euros]	22.8	25.0	25.3	27.2	28.2	32.9	37.6	42.7	50.3
Export Trade	[billion Euros]	448	688			1,294	1,754	2,205	2,658	3,364
Import Trade	[billion Euros]	464	681			1,154	1,606	2,047	2,487	3,129
Transit Trade	[billion Euros]	6,612	9,871			18,153	27,932	37,919	47,937	60,475
GDP/Capita	[index year 2000]	0.91	1.00	1.01	1.09	1.13	1.31	1.50	1.70	2.01
GDP	[index year 2000]	0.91	1.00	1.01	1.09	1.13	1.32	1.48	1.62	1.83
Export Trade	[% of GDP]	24%	33%			55%	65%	72%	79%	89%
Import Trade	[% of GDP]	25%	33%			49%	59%	67%	74%	83%
Transit Trade	[% of GDP]	354%	478%			776%	1028%	1243%	1433%	1602%

* According to Ickert et al. (2007, p.44) the labour force (all workers) equals 34.8 million at 4.2% unemplyment in 2050. For 2050 this results in a Labour population of 36.3 million. Labour population in 2010 equals the historic value. 2020-2040 were interpolated. The unemplyment rate is linear interpolated from the reported 2003 value of 9.3% to the reported 2050 value of 4.2%. Italic numbers are based on these assumptions.

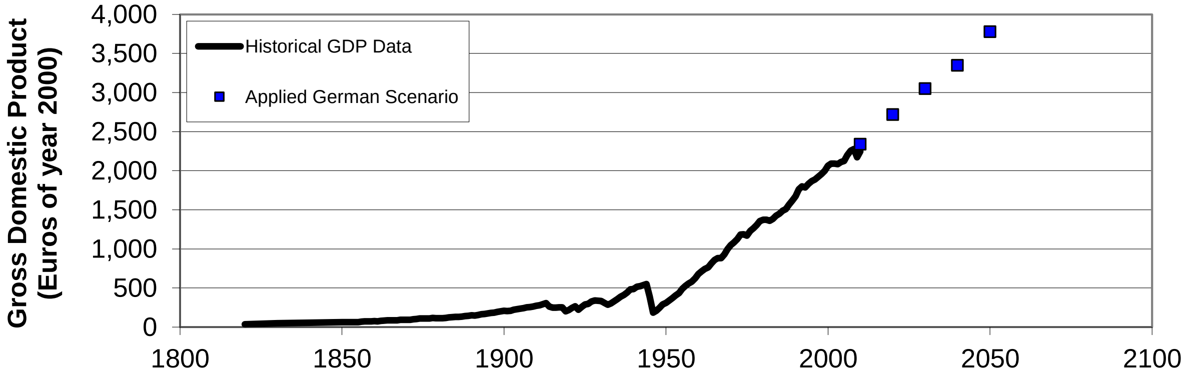
Note: Transit Trade includes: Exports and Imports with Austria, Belgium, Switzerland, Czech Republic, Denmark, France, Hungary, Italy, The Netherlands, Poland, Sweden and the United Kingdom; Values in real Euros at constant year 2000 price levels.

Source: Statistisches Bundesambt (2003, p), Ickert et al. (2007, p.44, p.48), Own Calculations.

It was necessary to reconstruct the data because the applied methodology and assumptions were not reported by Ickert et al. (2007). From Figure B-12 one can expected the GDP and trade scenarios to be developed in line with a linear extrapolation of the present trend. The underlying assumptions with respect to labour participation and annual output per worker were not discussed, but Ickert et al. (2007, p.44) indicated that the combined labour force is expected to comprises of 34.8 million workers in 2050 at an unemployment rate of 4.2%. This number made it possible to reconstruct the data. It is therefore still possible to reflect on the socio-economic assumptions that were applied in the German scenario.

B.2.2 Reflection on the German GDP Scenario

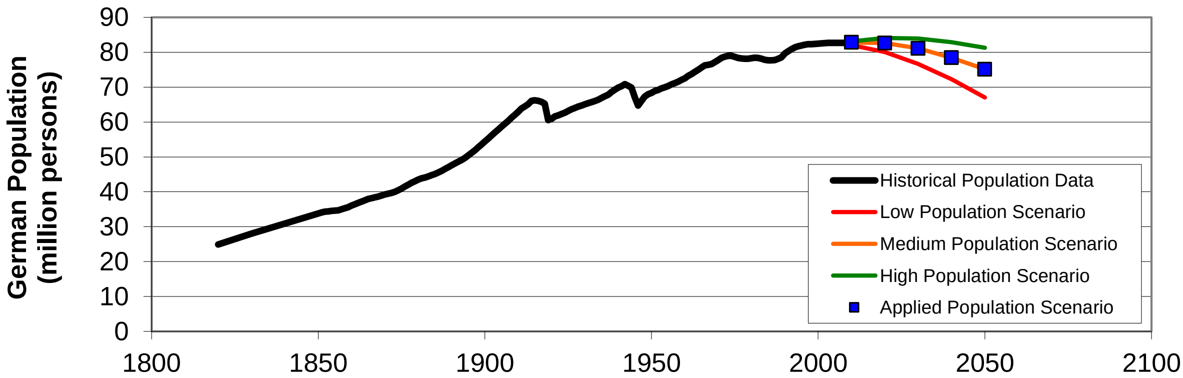
In order to put the development of the German GDP in a historical perspective a long term dataset was obtained. The historical data and applied scenario are indicated in Figure B-13.



Source: Historical Data: Maddison (data 1820-2008), The Conference Board (data 1950-2010), Ickert et al. (data base year 2000); Scenario Data: Ickert et al. (2007).

Figure B-13: Long term development of the German GDP

The applied scenario assumes that the linear historical trend of the GDP over the past 60 years (1950-2010) can be extrapolated towards 2050. This section analyses if this approach can also be justified on the basis of demographic developments and labour productivity assumptions.

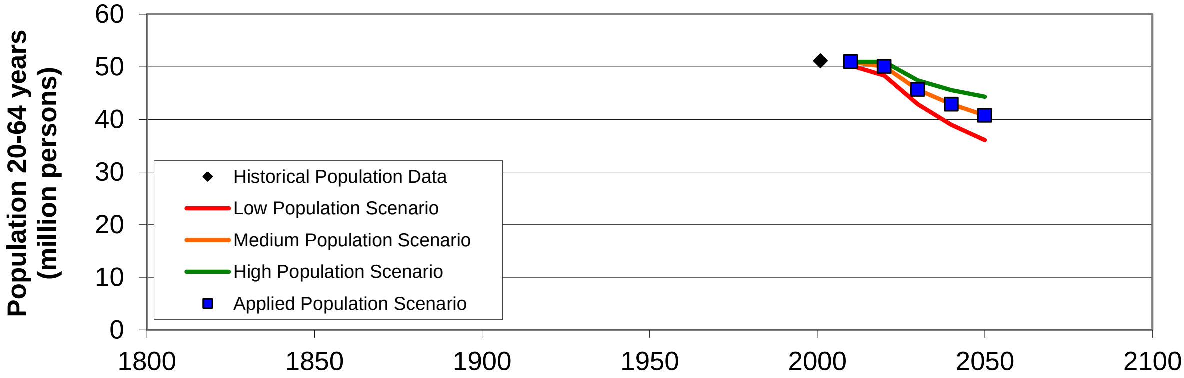


Source: Maddison (2009, data 1820-2008), The Conference Board (2010, data 1950-2010), Statistisches Bundesambt (2003, population scenarios), Ickert et al. (2007, applied scenario).

Figure B-14: Long term development of the German Population

Figure B-14 shows the long term population scenarios of the Statistisches Bundesambt (2003). The medium scenario (variant 5) was adopted in the German scenario study. The 2050 value of 75.1 million is lower than the UN (2004) projection of 79.1 million and the probabilistic projection of Alho and Nikander (mean of 80.3 million and an 80% confidence interval of 66.3 to 97.2 million), but quite similar to the probabilistic forecast of Scherbov et al. (2008, mean of 73.4 and 80% confidence interval of 61.1 to 86.1 million). Taking into account the fact that the medium scenario overestimated the real size of the population in 2010; the fact that the forecast of Alho and Nikander (2004) is expected to be on the high side; and the fact that the revised 2050 forecast of the UN (2008, http://esa.un.org /unpp/) is only 70.5 million – I think that the population scenarios are still quite reasonable.

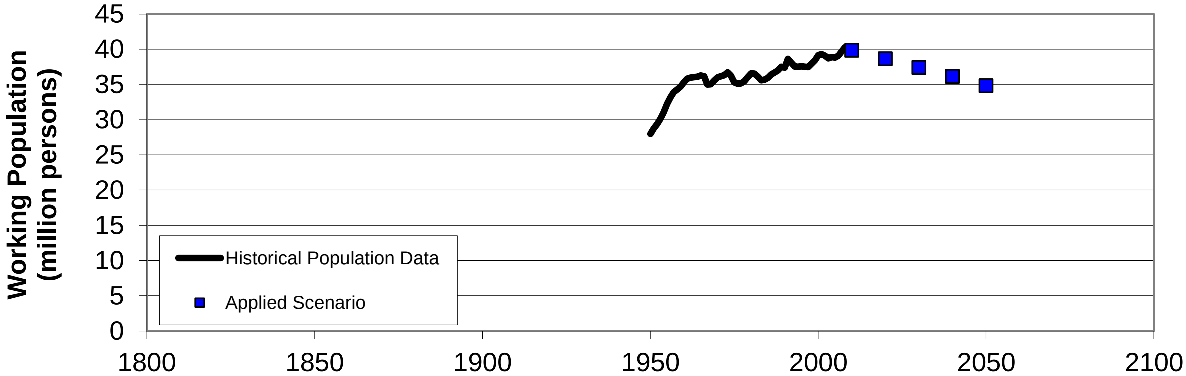
The Statistisches Bundesambt (2003) also provided an estimate of the working age population of 20-64 years old. These scenarios are indicated in Figure B-15. It can be observed that the scenarios are in line with the probabilistic forecast of Scherbov et al. (2008, mean of 38.4 million and 80% confidence interval of 31.0 to 46.4 million).



Source: Data obtained from Statistisches Bundesambt (2003).

Figure B-15: Long term development of Working Age Population (20-64 years)

Figure B-15 shows that the working age population can be expected to decrease considerably as a result of the retirement of the baby boom generation. In line with this development the size of the working population can also be expected to decrease. The historical development and assumptions made in the German Scenario are indicated in Figure B-16.

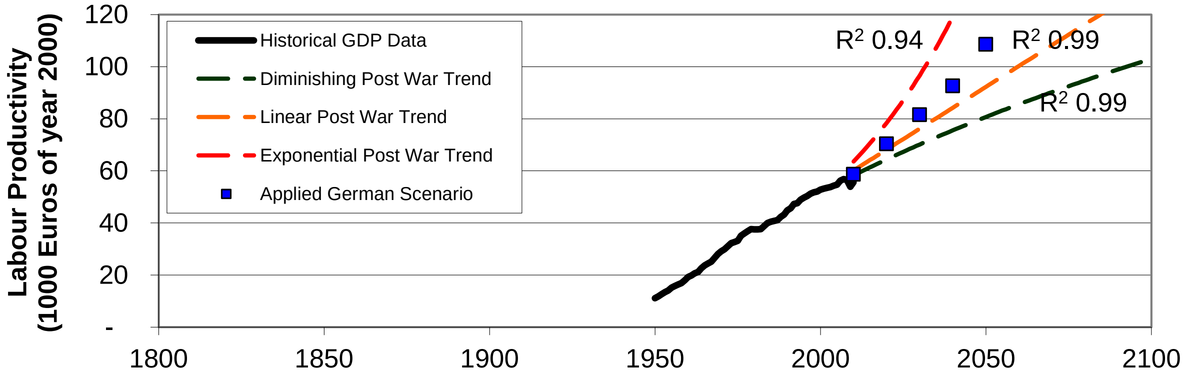


Source: The Conference Board (2010, data 1950-2010), Ickert et al. (2007, p.44 data 2050.

Figure B-16: Long term development of Total Working Population

The working population follows the decreasing trend set by the working age population, but not to a similar extent. Table B-3 shows that the assumed labour participation rate (defined as all workers of all ages divided by population of 20-64 years old) increases considerably from 76.9% in 2001 to 85.3% in 2050. To some extent this increase can be justified by a decrease in the unemployment rate, but I still expect the assumptions to be somewhat optimistic.

The labour productivity per worker can be derived from the GDP and working population projections. The historical development and assumed scenarios are indicated in Figure B-17.



Source: The Conference Board (2010, data 1950-2010), Statistisches Bundesambt (2003, population scenarios), Ickert et al. (2007, p.44 data 2050), Own Calculations.

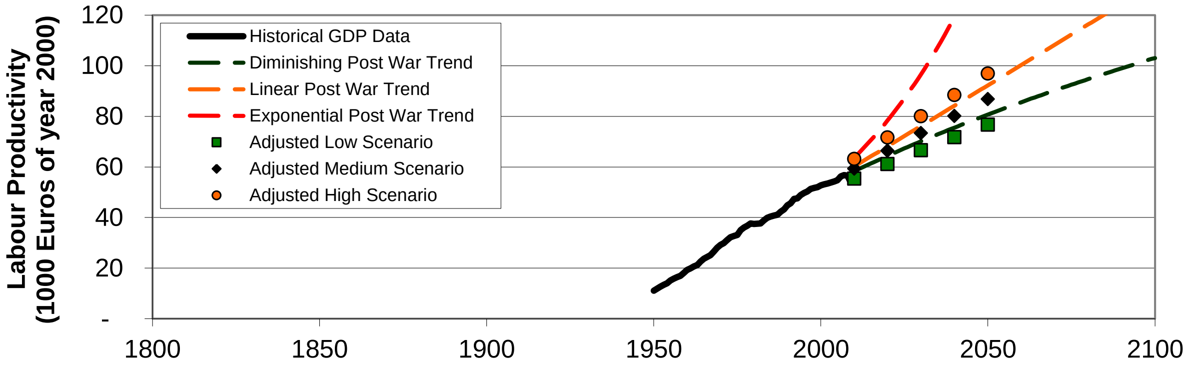
Figure B-17: Development of Labour Productivity (GDP per Worker per Annum)

To put things in perspective a number of generic post wars trends were added to the figure. The lowest trend follows a general (diminishing growth) function a*(x–b)^c+d; the middle trend follows a linear function a*x+b; and the upper trend relates to an exponential growth function of the shape a*e^(b*(x-c))[166]. It appears from the figure that the German scenario is developed in-between the linear and exponential trend. However, the exponential trend has a relatively poor fit compared to the other trends. The unexplained variance of the exponential function is 6.0 times larger than the unexplained variance of the linear function and 12.1 times larger than the unexplained variance of the general diminishing growth function.

I think it is unlikely that labour productivity and GDP will follow the trend indicated by the German scenario. I have therefore developed three new scenarios for Germany on the basis of: the low, medium, and high population scenarios of the Statistisches Bundesambt (2003); revised assumptions on labour productivity; and slightly adjusted assumptions on labour participation. The population scenarios correspond to the variants 1, 5 and 9 of which variant 5 reflects to the middle scenario that was also used in the German scenario study.

I assumed the labour productivity rates to be in line with the linear and diminishing trend. I defined the low scenario as 95% of the diminishing trend; the high scenario as 105% of the linear trend; and the medium scenario as the average of both trends. The adjusted labour productivity assumptions are indicated in Figure B-18.

[166] The curves have been fitted through the post war data of 1950 to 2010. The x in the function represents the predicted year. The following coefficients have been applied for: the diminishing general function: a=243.2, b=1882.2, c=0.1557, d=-459.2; the linear function: a=802, b=-1552; and the exponential function: a=0.5933, b=0.0209, 1786.7.

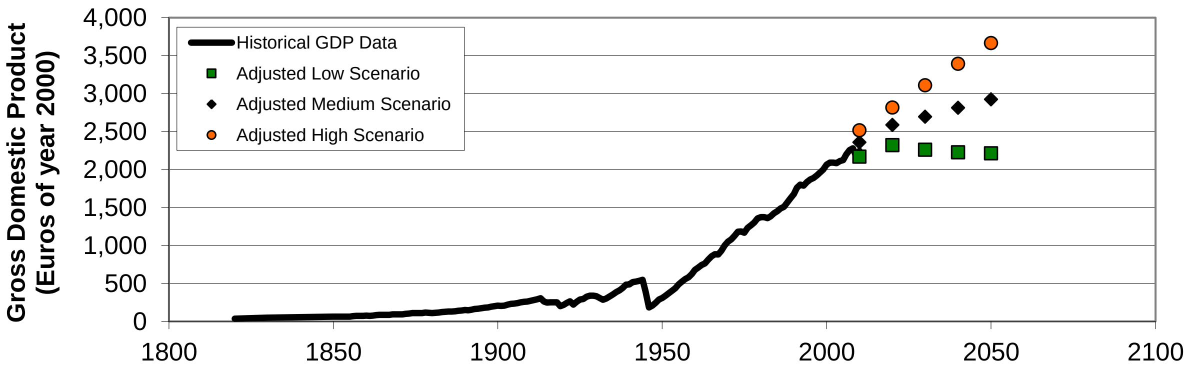


Source: Historical Data from Figure B-13, Adjusted Scenario Data from Table B-6.

Figure B-18: Adjusted assumptions on Labour Productivity

I find the labour participation rates that are applied in the original scenario a little optimistic. For the low scenario I therefore assume a linear growth of the labour participation rate up to 80% in 2050. In the high scenario the original labour participation rate (up to 85.3% in 2050) was applied. The medium scenario assumes the average of both assumptions.

On the basis of the various population estimates, adjusted participation rates, and adjusted assumptions on labour productivity a new set of three adjusted scenarios was developed. The outcome of these scenarios is indicated in Figure B-19.



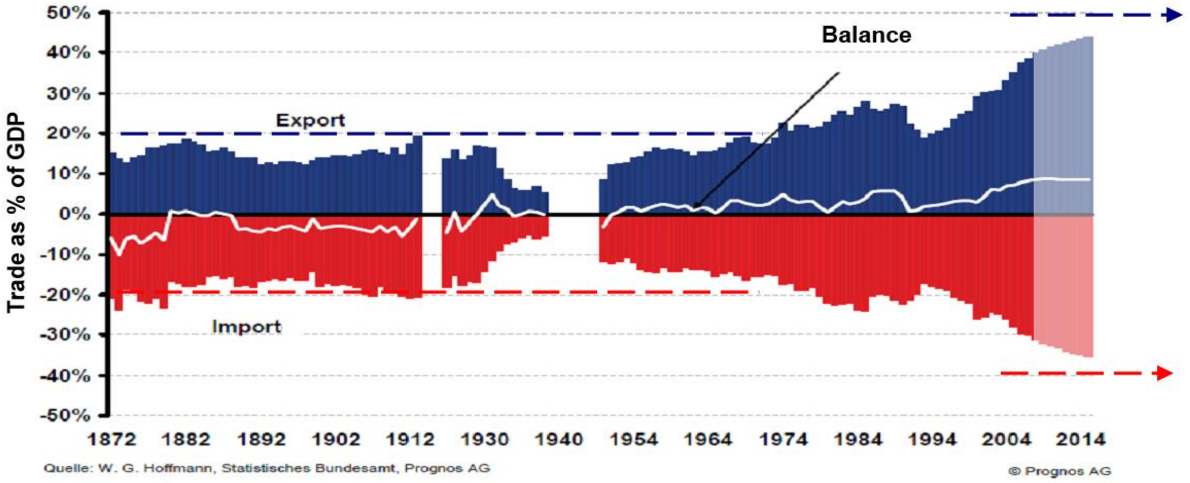
Source: Historical Data from Figure B-13, Adjusted Scenario Data from Table B-6.

Figure B-19: Adjusted Gross Domestic Product (GDP) Scenarios

The original German scenario (see Figure B-13) has to be reduced by 12% in 2030 and by 23% in 2050 to obtain the adjusted medium scenario. If the original scenario is compared with the high and low adjusted scenarios, it can be expected to be -2% to 26% too high in 2030 and 3% to 41% too high in 2050. Though I cannot prove that my adjusted scenarios are right, they at least indicate the possibility of a trend breach in the linear growth of the GDP, that cannot be observed from the original German scenario (see Figure B-13).

B.2.3 Reflection on the German Trade Scenarios

With respect to the development of import and export trade it was assumed by Ickert et al. that the exports increase from 43% of the GDP in 2005 to 89% of the GDP in 2050. For the imports a similar increase from 38% to 83% was assumed. From Figure B-12 it appears that this assumption is likely to be based on a linear extrapolation of the historical trend between 1995 and 2005, but it is dangerous to base a long term trend on such a relatively short time range. I obtained longer time series showing data back to 1872. The data are presented in Figure B-20. The numbers from the year 2006 onwards were forecasted by Prognos AG.



Source: Gramke (http://www.toenissteiner-kreis.de/pdf/vortrag_gramke.pdf, 2006), adjusted.

Figure B-20: Historical Development and Forecast of the Export/Import factor of GDP

Figure B-20 shows the historical development of the imports and exports in relation to the GDP. It can be observed that over a long time period of about a century (1872-1972) there has been a natural limit to the maximum levels of imports and exports of about 20% of the GDP. As a result of European integration the trade volumes increased to a higher level until the reunification of Germany in 1990, which enhanced a strong national focus that caused a temporary drop in the relative size of the international trade volumes. At the same time the European Union became larger and Europe became more integrated. This European integration caused a major upward shift in the trade to GDP factor. Considering the fact that Europe is already very integrated and the fact that further options to expand to the east are limited – a new long term equilibrium can now be expected (as also forecasted by Prognos AG and indicated with the arrows in the figure). To verify that the trade to GDP factor is indeed stabilising more recent data was obtained. This data is listed in Table B-4.

Table B-4: German Import/Export Trade Statistics

German Trade	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Nominal GDP	2,012	2,063	2,113	2,143	2,164	2,211	2,242	2,327	2,432	2,481	2,397
Real GDP (base 2000)	1,995	2,064	2,092	2,092	2,088	2,103	2,122	2,198	2,259	2,275	2,169
Conversion Factor	99%	100%	99%	98%	96%	95%	95%	94%	93%	92%	90%
Nominal Imports	445	538	543	518	534	575	625	722	770	806	673
Nominal Exports	510	597	638	651	664	731	780	883	964	983	807
Real Imports	441	539	537	506	516	547	591	682	715	739	609
Real Exports	506	598	632	636	641	696	739	834	895	901	731
Index Real Imports	0.82	1.00	1.00	0.94	0.96	1.02	1.10	1.27	1.33	1.37	1.13
Index Real Exports	0.85	1.00	1.06	1.06	1.07	1.16	1.24	1.39	1.50	1.51	1.22
Import Fraction of GDP	0.22	0.26	0.26	0.24	0.25	0.26	0.28	0.31	0.32	0.32	0.28
Export Fraction of GDP	0.25	0.29	0.30	0.30	0.31	0.33	0.35	0.38	0.40	0.40	0.34

Source: IMF – World Economic Outlook Database (2011), Eurostat Database (2011), own calculation of real imports, exports, indices and factors of GDP.

On the basis of Figure B-20 and Table B-4 I would argue that the trade to GDP factor is indeed stabilizing. My expectations are therefore different from those of Ickert et al. (2007)

who assume an ongoing linear growth of the trade to GDP factor. To illustrate the effect of these different views on the development of the trade to GDP factor I made a few additional scenario assumptions. The first assumption deals with the trade volumes in the base year 2010. For the low scenario I have assumed the imports and exports to be respectively 1.13 and 1.22 times the year 2000 value. This corresponds to the indices of the recession year 2009. For the high scenario the imports and exports were related to the indices of the strong pre-recession year 2008. It was further assumed that the year 2050 trade to GDP factor ranges between 35%-45% for imports and between 45%-55% for exports (based on Figure B-19). A new set of adjusted scenarios was constructed on the basis of these assumptions. Table B-5 provides a summary of the adjusted scenarios. The medium adjusted scenario is 26%-27% lower in 2010, 45%-50% lower in 2030, and 57%-63% lower in 2050. In general the adjusted 2050 trade volumes are 40%-70% lower for exports and 47%-75% lower for imports.

Table B-5: Adjusted scenario output and comparison

Germany	Scenario and Year	Adjusted Low			Adjusted Medium			Adjusted High		
Item	**Unit**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**	**2010**	**2030**	**2050**
Population	[million persons]	82.0	76.7	67.0	82.8	81.1	75.1	83.1	83.9	81.3
Population 20-64	[million persons]	50.2	42.9	36.1	51.0	45.7	40.8	51.0	47.4	44.3
Labour Population*	[million persons]	42.8	36.2	30.1	43.5	*39.2*	*35.2*	*43.6*	*41.5*	39.5
Unemplyment rate	[% of available labour]	8.5%	6.4%	4.2%	8.5%	*6.4%*	*4.2%*	*8.5%*	*6.4%*	4.2%
Labour (all workers)	[million persons]	39.2	33.9	28.8	39.8	36.7	33.7	39.9	38.8	37.8
Labour Participation	[% of pop 20-64]	78.0%	79.0%	80.0%	78.1%	80.4%	82.7%	78.2%	81.9%	85.3%
Labour Productivity	[thousand Euros]	55.4	66.6	76.6	59.3	73.3	86.7	63.1	80.0	96.8
GDP	[billion Euros]	2,169	2,258	2,211	2,358	2,693	2,924	2,517	3,107	3,663
GDP/Capita	[thousand Euros]	26.5	29.4	33.0	28.5	33.2	38.9	30.3	37.0	45.1
Export Trade	[billion Euros]	841	945	995	939	1,210	1,462	1,037	1,495	2,015
Import Trade	[billion Euros]	777	835	774	856	1,027	1,170	934	1,150	1,648
GDP/Capita	[index year 2000]	1.06	1.18	1.32	1.14	1.33	1.56	1.21	1.48	1.80
GDP	[index year 2000]	1.05	1.09	1.07	1.14	1.30	1.42	1.22	1.51	1.77
Export Trade	[% of GDP]	39%	42%	45%	40%	45%	50%	41%	48%	55%
Import Trade	[% of GDP]	36%	37%	35%	36%	38%	40%	37%	37%	45%
Comparisson with origional scenario										
GDP	[% reduction]	7%	26%	41%	-1%	12%	23%	-8%	-2%	3%
Export Trade	[% reduction]	35%	57%	70%	27%	45%	57%	20%	32%	40%
Import Trade	[% reduction]	33%	59%	75%	26%	50%	63%	19%	44%	47%

Note: Values in real Euros at constant year 2000 price levels.

Source: Table B-5, Own Calculations.

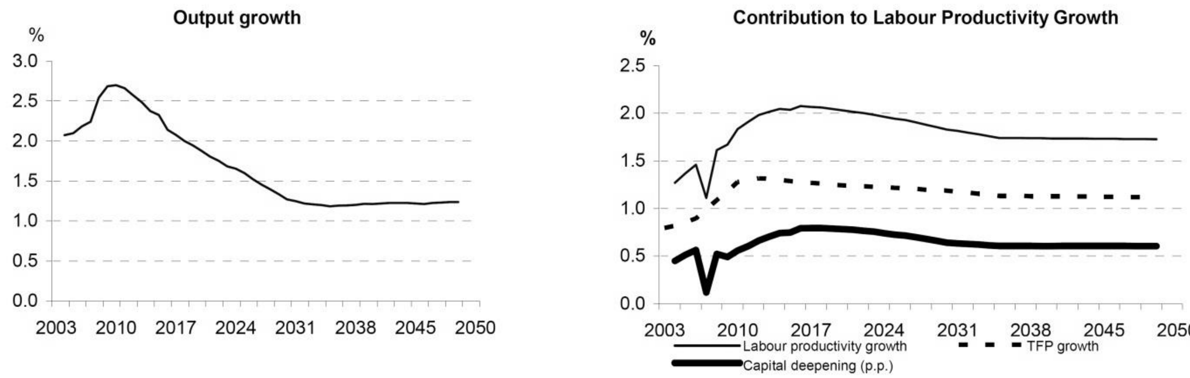
B.3 The EU Scenario Input

On a European level two scenario studies were evaluated. These are the TRIAS (Krail et al., 2007) and TRANSvisions study (Petersen et al., 2009). For both studies the assumptions were not reported in sufficient detail to allow for an evaluation of the labour participation and productivity assumptions. The TRANSvisions study has nevertheless indicated that the socio-economic assumptions (for the EU27) are based on the *"Long-term labour productivity and GDP projections for the EU25 Member States"* of the Directorate-General for Economic and Financial Affairs (Carone et al., 2006). This section therefore starts with a review of the latter EC FIN projections for the EU25. Thereafter a reference scenario for the EU27 is developed that is used to verify the population and GDP assumptions that were applied in the TRIAS and TRANSvisions studies.

B.3.1 Applied Socio-Economic Data in EC FIN Estimate

Carone et al. (2006, p.28) base their estimates on economic theory that suggests that: *"In the long-run, according to the neo-classical growth model (Solow model), the economy should reach its equilibrium (also called steady state or balanced growth path), where both the ratio of capital stock to labour expressed in efficiency units, K/(L.E) and output to labour expressed* *in efficiency units (or output per effective worker), remain constant over time".* The Solow model implies that the economic output per worker depends on the level of capital relative to each worker (for which there is an optimum referred to as steady state or balanced growth path) and the rate of technological progress. Once a country has reached its balanced growth path it can only increase its output per worker by raising the state of technology referred to as Total Factor Productivity (TFP). In other words the GDP output per worker increases as a result of technological growth and deepening of the capital stock (see also Chapter 4).

The economic output projections are based on assumptions regarding the size of the working population (as fraction of working age population) and labour productivity growth (caused by technological growth and capital deepening). The assumptions on economic output and labour productivity growth as applied in the EC FIN estimate are indicated in Figure B-21.



Source: Carone et al. (2006, p.63), adjusted layout.

Figure B-21: EU25 Economic Growth and Labour Productivity Assumptions

The EC FIN estimate does not provide the levels of economic output and labour productivity. In order to reconstruct the scenarios I digitized the above growth factors and applied them to the levels reported by The Conference Board (values in international 1990 GK$[167], data obtained in 2011). The number of workers was defined by dividing the levels of economic output by the average annual output per worker. Demographic data on the total population and working age population (20-64 years old) was taken from Scherbov et al. (2008)[168]. The result of the reconstruction of the EC FIN scenario for the EU25 is indicated in Table B-6.

From the table it can be observed that the EC FIN scenario assumes a significant increase in the labour participation rate. The fraction of total workers (of all ages) divided by the working age population (20-64 years old) is expected to increase from 74% in 2010 to 80% in 2050. There are reasons to expect the labour participation rate to increase, but I think the assumed increase is rather optimistic. I therefore suggest to use slightly lower figures.

[167] The 1990 GK$ is a monetary unit at constant prices comparable e.g. year 2000 Euro's (see also Chapter 7).

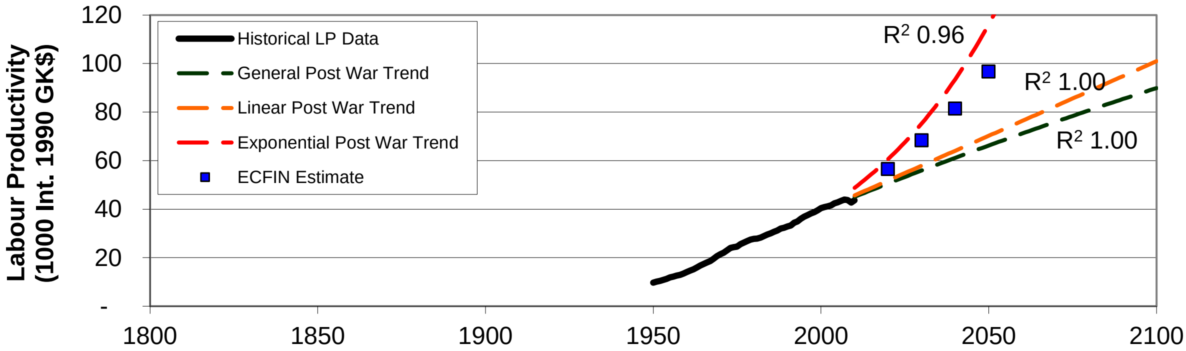
[168] The demographic assumptions in the EC FIN study are based on the EUROPOP 2004 projections of Eurostat, which were not available. However, Scherbov et al. (2008) converted these scenarios into probabilistic projections. Scherbov's mean value was reported to be similar to the medium population EUROPOP 2004 projection. The EUROPOP 2004 projections could therefore be taken from Scherbov et al. (2008).

Table B-6: Main Demographic and Socio-Economic Drivers in EU25 EC FIN estimate

EU25 - Scenarios Item	Year Unit	2010 Base	2020 Base	2030 Base	2040 Base	2050 Base
Population	[million persons]	466	470	470	463	448
Population 20-65	[million persons]	285	279	265	249	233
Labour participation	[% of pop 20-64]	74%	77%	78%	79%	80%
Labour (all workers)	[million persons]	212	216	208	197	188
Labour Productivity	[Int. 1990 GK$]	46,184	56,469	68,382	81,435	96,719
GDP	[billion 1990 GK$]	9,777	12,212	14,241	16,060	18,147
GDP/Capita	[Int. 1990 GK$]	20,977	25,965	30,332	34,711	40,488
GDP	[Index year 2000]	1.24	1.55	1.81	2.04	2.30
GDP/Capita	[Index year 2000]	1.27	1.58	1.84	2.11	2.46

Source: Carone et al. (2006), Scherbov et al. (2008), The Conference Board, Own Calculations

Figure B-22 shows the assumptions with respect to the development of labour productivity (defined as GDP per worker) in relation to the historical trend. I fitted three generic post war trends to put the assumption in perspective. The lowest trend follows a general (diminishing growth) function a*(x–b)^c+d; the middle trend follows a linear function a*x+b; and the upper trend relates to an exponential growth function of the shape a*e^(b*(x-c))[169].



Source: Historical Data: The Conference Board, Own Calculations; Scenario Data: from Table B-6; Trend lines and adjusted scenario assumptions: Own Calculations.

Figure B-22: Development of Labour Productivity in the EU25

It appears from the Figure B-22 that the EU25 scenario is more or less developed in line with the exponential trend. However, this exponential trend has a relatively poor fit compared to the other trends. The unexplained variance of the exponential function is 9.9 times larger than the unexplained variance of the linear function and 10.0 times larger than the unexplained variance of the general (diminishing growth) function. In my opinion the labour productivity scenario assumptions are therefore not realistic. I think it would be better to base the labour productivity assumptions on the average of the linear and general (diminishing growth) trend. The adjusted assumptions on labour productivity are indicated in Figure B-23.

169 The curves were fitted through post war data of 1950 to 2010. The x represents the predicted year. The following coefficients were applied for the diminishing general function: a=158.5, b=1746.7, c=0.2416, d=-564.0; the linear function: a=0.6145, b=-1198; and the exponential function: a=0.3481, b=0.0217, 1782.3.

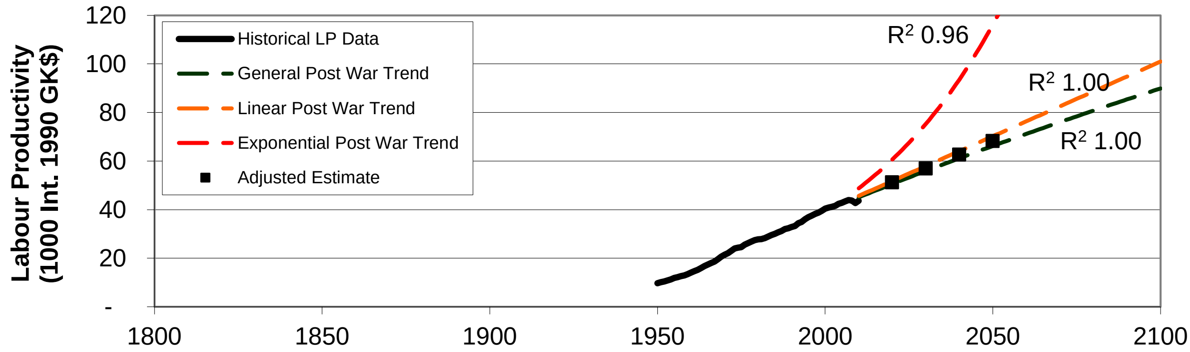
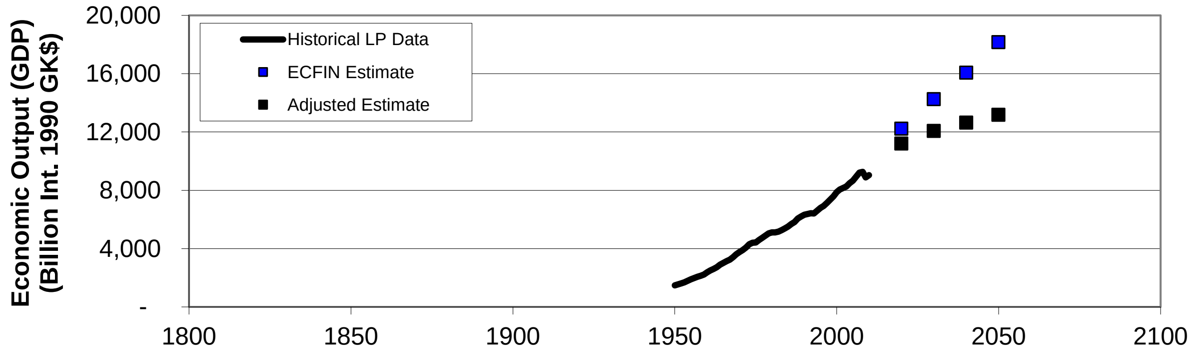


Figure B-23: Adjusted assumptions on Development of Labour Productivity

I developed a new GDP estimate on the basis of the adjusted labour productivity assumption and a slightly decreased assumption on labour participation. The effect of the adjusted scenario assumptions on the overall GDP estimate is indicated in Figure B-24. The details of the adjusted scenario are indicated in Table B-7.



Source: Historical Data: The Conference Board, Own Calculations; Scenario Data: from Table B-6; Trend lines and adjusted scenario: from Table B-7.

Figure B-24: Original EC FIN and Adjusted GDP scenarios for the EU25.

Table B-7: Demographic and Socio-Economic Drivers in Adjusted EU25 Estimate

EU25 - Adjusted Item	Year Unit	2010 Adjusted	2020 Adjusted	2030 Adjusted	2040 Adjusted	2050 Adjusted
Population	[million persons]	466	470	470	463	448
Population 20-65	[million persons]	285	279	265	249	233
Labour participation	[% of pop 20-64]	74%	76%	77%	78%	78%
Labour (all workers)	[million persons]	211	212	204	194	182
Labour Productivity	[Int. 1990 GK$]	45,351	51,178	56,930	62,611	68,226
GDP	[billion 1990 GK$]	9,567	10,862	11,634	12,138	12,406
GDP/Capita	[Int. 1990 GK$]	20,527	23,095	24,780	26,235	27,680
GDP	[Index year 2000]	1.21	1.38	1.48	1.54	1.57
GDP/Capita	[Index year 2000]	1.25	1.40	1.50	1.59	1.68
Comparison with the original scenario						
GDP	[% reduction]	2%	9%	17%	23%	29%

Source: Table B-6, Own Calculations.

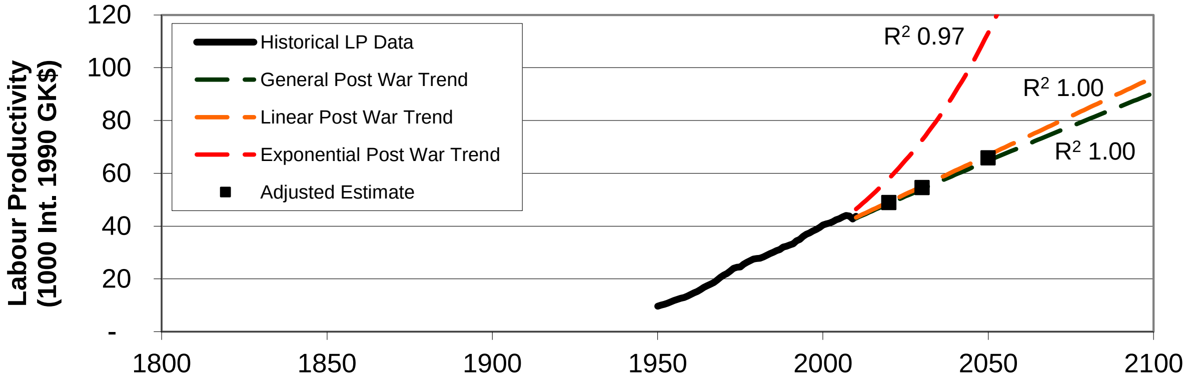
From a comparison of the original and adjusted scenarios it can be concluded, that in my opinion, the original EC FIN scenarios for the EU25 are about 9% too high in 2020 and about 29% too high in 2050. On the basis of my empirical findings (i.e. the fit with the three different post war trends) I no longer expect exponential growth to hold on throughout the next four decades. I think a linear or diminishing trend is much more likely to occur.

B.3.2 Reflection on GDP assumptions applied in TRIAS and TRANSvisions Study

The details provided by the TRIAS and TRANSvisions studies (for the EU27) are insufficient to provide a breakdown of the socio-economic assumptions on working population, labour participation and labour productivity. I therefore prepared a reference scenario for the EU27 (EU25+2) to evaluate the assumption made in the TRIAS and TRANSvisions studies.

Step 1: Development of the EU27 reference scenario

Demographic scenarios for the two additional countries Romania and Bulgaria were obtained from Scherbov et al. (2008) and the labour participation rate was assumed to be similar to those of the EU25. Figure B-25 indicates the re-estimated labour productivity assumptions[170]. The overall assumptions for the EU27 reference scenario are summarised in Table B-8.



Source: Historical Data: The Conference Board, Own Calculations; Trend lines and adjusted scenario assumptions: Own Calculations.

Figure B-25: Adjusted Assumptions on Labour Productivity for the EU27

Table B-8: Assumptions applied in the EU27 Reference Scenario

EU27 Item	Year Unit	2005 Real	2020 Adjusted	2030 Adjusted	2050 Adjusted
Population	[million persons]	493	497	495	470
Population 20-64	[million persons]		296	281	245
Labour Participation	[% of pop 20-64]		76%	77%	78%
Labour (all workers)	[million persons]	215	225	216	191
Labour Productivity	[Int. 1990 GK$]	40,926	48,847	54,541	65,811
GDP, EU27	[billion int. 1990 GK$]	8,799	10,998	11,801	12,563
GDP/Capita	[Int. 1990 GK$]	17,848	22,108	23,849	26,734

Source: Scherbov et al. (2008), The Conference Board, Table B-7, Own Calculations.

[170] Adjusted coefficients are: for the diminishing general function: a=113.2, b=1558.2, c=0.3188, d=-752.3; the linear function: a=0.5898, b=-1142.3; and the exponential function: a=0.3048, b=0.0223, 1784.2.

Step 2: Assumptions applied in TRIAS and TRANSvisions scenarios
The socio-economic assumptions that were applied in the TRIAS scenarios were not reported in tabular form but could be measured from figures showing the levels of economic output per country, the level of exports per sector (for both goods and services), and indices referring to the development of issues like population, GDP, and trade exports. The data were digitised from the figures and converted into levels. The results are summarised in Table B-9.

Table B-9: Demographic and Socio-Economic Data applied in TRIAS study

EU27 Item	Year Unit	2000 Real	2010 Applied	2020 Applied	2030 Applied	2040 Applied	2050 Applied
Population	[million persons]	485	494	498	497	485	471
GDP	[billion Int. 1990 GK$]	7,997	9,371	11,539	14,569	18,237	22,694
Exports	[billion Int. 1990 GK$]	2,460	3,505	5,049	6,534	8,141	10,040
Export/GDP	[factor]	0.31	0.37	0.44	0.45	0.45	0.44
Population	[Index 2000]	100	102	103	102	100	97
GDP	[Index 2000]	100	117	144	182	228	284
Exports	[Index 2000]	100	143	205	268	333	412

Source: Data digitized from Krail et al. (2007), Own Calculations.

The applied levels for population and GDP in the TRANSvisions META-MODELS were reported for the years 2005, 2020, 2030, and 2050 in the TRANSvisions Task 2 report. For comparison the GDP data was converted from constant year 2000 Euros into international 1990 GK$. The reconstructed scenario data is summarised in Table B-10.

Table B-10: Demographic and Socio-Economic Data applied in TRANSvisions study

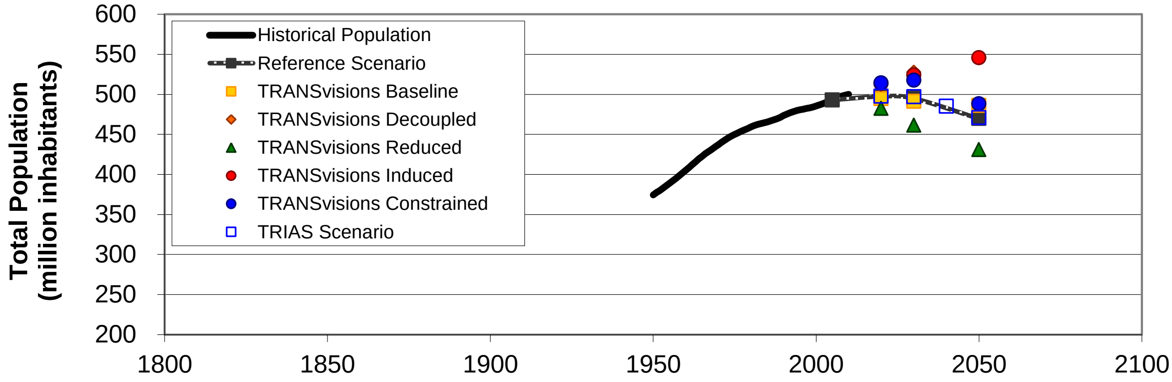
EU27 Population, GDP*	Year Unit	2005 Real	2020 Applied	2030 Applied	2050 Applied
Baseline Scenario	[million persons]	492	495	491	486
Decoupled Scenario	[million persons]	492	513	527	546
Reduced Scenario	[million persons]	492	483	461	431
Induced Scenario	[million persons]	492	514	524	546
Constrained Scenario	[million persons]	492	514	517	488
Baseline Scenario	[billion Int. 1990 GK$]	8,799	12,706	15,483	21,754
Decoupled Scenario	[billion Int. 1990 GK$]	8,799	13,671	17,051	25,943
Reduced Scenario	[billion Int. 1990 GK$]	8,799	11,168	12,122	15,263
Induced Scenario	[billion Int. 1990 GK$]	8,799	14,504	17,835	28,324
Constrained Scenario	[billion Int. 1990 GK$]	8,799	15,012	16,645	15,957

*GDP data converted from year 2000 Euros to Int. 1990 GK$ by applying factor 8,799/9,853 (year 2005 values).

Source: MCRIT (2009, p.190-200), Own Calculations.

On page 100 of the Task 2 report it was noticed that the year 2050 exports in the baseline scenario have a year 2000 index of 532 compared to an index of 410 applied in the TRIAS study. This is the only available information on trade volumes that were reported by the TRANSvisions study. I was therefore unable to include the export data in Table B-10.

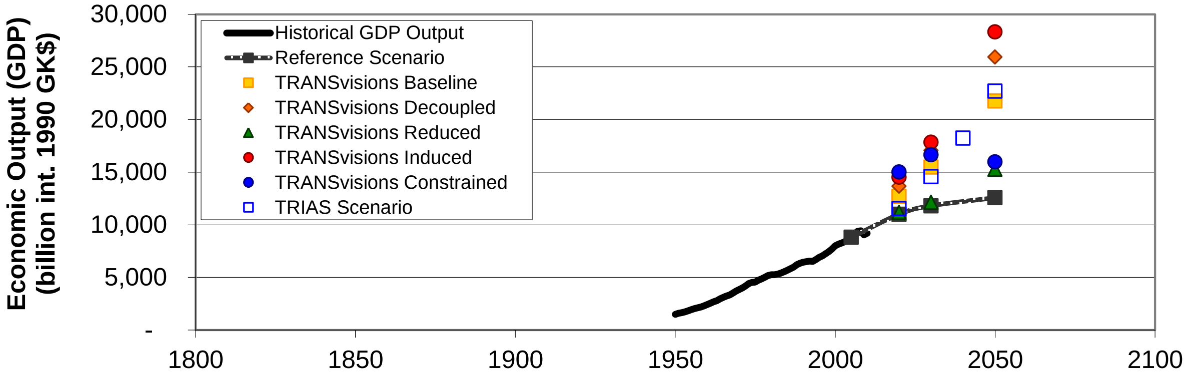
Step 3: Comparison of TRIAS and TRANSvisions scenarios with the reference scenario
The assumptions on overall population and economic output as applied in the TRIAS and TRANSvisions scenario studies were compared with the reference scenario. The results of this comparison are indicated in Figure B-26 and Figure B-27.



Source: Historical Data: The Conference Board; Scenarios: from Table B-9 and Table B-10.

Figure B-26: Comparison of population data with reference scenario for EU27

It can be concluded that both the baseline scenario of the TRANSvisions study as well as the single scenario of the TRIAS study follow the same demographic trend as in the reference scenario. In addition the TRANSvisions scenarios are not much biased towards the baseline trend. The applied scenarios are therefore in line with my expectations.



Source: Historical Data: The Conference Board; Scenarios: from Table B-9 and Table B-10.

Figure B-27: Comparison of GDP output with reference scenario for EU27

The economic output scenarios for the EU27 are indicated in Figure B-27. There is not much difference between the baseline scenario of the TRANSvisions study and the single TRIAS scenario. However, both scenarios deviate considerably from the reference scenario. The evaluated scenarios are 3% to 51% higher in 2030 and 21% to 125% higher in 2050. The reference scenario is 24% lower than the TRANSvisions baseline scenario in 2030, 42% lower than the TRANSvisons baseline scenario in 2050, and 45% lower than the single TRIAS scenario in 2050. I therefore consider the applied GDP scenarios much too high.

B.3.3 Reflection on Trade assumptions applied in TRIAS and TRANSvisions Study

Table B-9 shows that the TRIAS study assumes the export trade to GDP factor to stabilise at a rate of about 0.45 from 2020 onwards. The assumed stabilisation of the trade to GDP factor is in line with my expectations. If the trade to GDP factor is assumed to be correct, the trade volumes will be off by a similar percentage as the GDP.

B.4 Conclusions on the applied Scenario Input

The nature of forward looking projections is such that ex-ante validation by means of obtaining additional sample data is not possible. The only option to verify the quality of the obtained forecasts and/or scenario quantifications is to verify the quality of the input data and the applied methodology. This appendix provided a reflection on the main transport drivers (i.e. GDP and trade volumes) that were applied in the four transport studies that were discussed in Chapter 3. It includes an analysis of: demographic developments, working population (labour participation), labour productivity, economic output, and trade volumes.

For the evaluation of the demographic scenario assumptions I relied on a comparison with other demographic studies. I concluded that the assumptions on overall population and working age population are in line with other projections. For the evaluation of the applied assumptions concerning the size of the working population I have calculated the labour participation factor (defined as the total workforce divided by the population of 20-64 years old). A substantial increase in the labour participation factor over time has been assumed throughout the scenarios. This increase was justified by a strong expected increase in the participation of females, elderly, and immigrants. However, I think that these assumptions are somewhat optimistic and would therefore be inclined to use slightly lower numbers.

The labour productivity assumptions were put into a historical perspective by extrapolating three different trends including: an exponential trend, a linear trend, and a general diminishing trend. The regression statistics indicate that labour productivity is not likely to continue to grow at an exponential rate (fixed annual growth percentage). The unexplained variance in the exponential relation is generally 2½ to 12 times higher than for the linear and diminishing trends. However, despite the poor fit of the exponential relation all four evaluated scenario studies appear to follow an exponential trend. This contradicts my empirical findings. I think that labour productivity is more likely to grow according to a linear or general (diminishing growth) trend over the next 40 years. As a result I expect the assumed economic output in all the evaluated scenarios be too optimistic. If I am right the long term GDP estimates of the baseline scenarios for the year 2040 and 2050 are typically a factor 1.3 to 1.8 too high[171]. Given the fact that GDP is one of the main drivers of the transport system, the long term scenario quantifications are also likely to be on the high side.

Trade volumes can be regarded as the mathematical product of the level of economic output (GDP) and the openness of the economy (that is reflected by the trade to GDP factor: trade volume/GDP). Given a stable international geopolitical stetting the trade to GDP factor can be expected to remain constant over time. Over the past half century the integration of countries into the European Union and the effects of globalisation resulted in an increased openness of the economy. For this reason the trade volumes have been growing much faster than the GDP. However, the European Union cannot expand much further and the world has now become a global village. In addition the main drivers of the next 6th Kondratieff wave are likely to somewhat counter the Globalisation trend, that was predominant in the 5th Kondratieff wave (see Chapter 4). The trade to GDP factor is therefore likely to reach its saturation level (at least for Western Europe). I do not expect the trade volumes to continue their growth at a

[171] Netherlands (2040): factor 1.4 for all scenarios; Germany (2050): factor 1.3 for baseline scenario; EU-TRIAS (2050): factor 1.7 for baseline scenario; EU-TRANSvisions (2050): 1.8 for baseline scenario.

much faster rate than the economy. This notion is realised in the TRIAS study, that assumes the trade to GDP factor to stabilize from about 2020 onwards, but it has not been realised in the Dutch and German scenario studies, that still foresee a strong growth of the trade to GDP factor. Taking into account the adjusted GDP output and the applied trade to GDP factor I expect the long term trade estimates in the baseline scenarios to be typically a factor 1.7 to 2.5 too high[172]. Given the fact that trade volumes are also an import driver for the transport system, this will further cause the long term scenario quantifications to be on the high side.

Literature:

Alho, J.M. and T. Nikander (2004) *Uncertain Population of Europe: Summary Results from a Stochastic Forecast*, Deliverable 12 of Work Package 6 of the EU 5th frame work funded research project Uncertain Population of Europe (UPE), HPSE-CY-2001-00095.

Carone, G., C. Denis, K. Mc Morrow, G. Mourre, and W. Röger (2006) *Long-term labour productivity and GDP projections for the EU25 Member States: a production function framework*, European Economy, Volume 253, European Commission, Directorate-General for Economic and Financial Affairs.

CBS (2000) *Tweehonderd jaar ststistiek in tijdreeksen, 1800-1999*, Centraal Bureau voor de Statistiek/Rijks Universiteit Groningen.

De Jong, A.H., and H.B.M. Hilderink (2004) *Lange-termijn bevolkingsscenario's voor Nederland*, Rijksinstituut Volksgezondheid en Millieu/Centraal Bureau voor de Statistiek, Bilthoven/Voorburg.

De Jong, A.H. (2008) *Vier scenario's voor de zeer lange termijn.* Bevolkingstrends: Statistisch kwartaalblad over de demografie van Nederland, Jaargang 56-4e kwartaal 2008, Centraal Bureau voor de Statistiek, Den Haag, pp. 72-81.

Hoeven, N. van der, C. Jacobs, E. Koomen, J. Aerts (2007) Beschrijving van social-economische scenario's voor het jaar 2100, Aandacht voor veiligheid.

Huizinga, F. and B. Smid (2004) *Vier vergezichten op Nederland, Productie, arbeid en sectorstructuur in vier scenario's tot 2040*. Centraal Planbureau, Den Haag.

Ickert, L., U. Matthes, S. Rommerskirchen, E. Weyand, M. Schlesinger, and J. Limbers (2007) *Abschätzung der langfristigen Entwicklung des Güterverkehrs in Deutschland bis 2050*, ProgTrans AG.

Janssen, L.H.J.M., V.R. Okker, and J. Schuur (2006a) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040*, Centraal Planbureau, Milieu- en Natuurplanbureau, and Ruimtelijk Planbureau.

Janssen, L.H.J.M., V.R. Okker, and J. Schuur (2006b) *Welvaart en Leefomgeving: een scenariostudie voor Nederland in 2040; Achtergronddocument*, Centraal Planbureau, Milieu- en Natuurplanbureau, and Ruimtelijk Planbureau.

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[172] Netherlands (2040): factor 1.7 for all scenarios (adjusted GDP and trade to GDP factor); Germany (2050): factor 2.5 for baseline scenario (adjusted GDP and trade to GDP factor); EU-TRIAS (2050): factor 1.7 for baseline scenario (adjusted GDP, GDP to trade factor assumed to be correct); EU-TRANSvisions (2050): 1.8 for baseline scenario (adjusted GDP, GDP to trade factor assumed to be correct) .

Japan Center for Economic Research (2007) *World Economic & Population Outlook 2006-2050.* Tokyo: JCER. Available from http://www.jcer.or.jp/eng/pdf/2006long_table.pdf.

Krail, M., W. Schade, D. Fiorello, F. Fermi, A. Martino, P. Christidis, B. SChade, J. Purwanto, N. Helfrich, A. Scholz, M. Kraft (2007) *Outlook for Global Transport and Energy Demand.* Deliverable 3 of TRIAS (Sustainable Impact Assessment of Strategies Integrating Transport, Technology and Energy Scenarios). Funded by European Commission 6th RTD Programme. Karlsruhe, Germany.

MCRIT (2009) *TRANSvisions Task 2 Quantitative Scenarios, final version*, Funded by DG TREN, Barcelona, Spain.

Petersen, M.S., R. Enei, C.O. Hansen, E. Larrea, O. Obisco, C. Sessa, P.M. Timms, A. Ulied (2009) *Report on Transport Scenarios with a 20 and 40 year Horizon, Final Report,* Funded by DG TREN, Copenhagen, Denmark.

Roodenburg, H. and D. van Vuuren (2004) *Arbeidsaanbod in de lange-termijnscenario's voor Nederland*, Centraal Planbureau, Den Haag.

Scherbov. S. M. Mamolo, and W. Lutz (2008) *Probabilistic Population Projections for the 27 EU Member States Based on Eurostat Assumptions*, http://www.oeaw.ac.at/vid/download/edrp_2_08.pdf

Schuur, J. and E. Verkade (2010) *De financiële crisis en de beleidsopgaven volgens WLO*, CPB Memorandum, vol. 235, Jan 19th.

Schwartz, P. (1991) *The Art of the Long View, Planning for the Future in an Uncertain World*, Doubleday, a division of Bantam Doubleday Dell Publishing Group, Inc., New York.

Smid, B. (2005) *Arbeidsproductiviteit op lange termijn in historisch en internationaal perspectief*, CPB Memorandum, vol. 107, Jan 14th.

Solow, R. M. (1956) *A Contribution to the Theory of Economic Growth*, The Quarterly Journal of Economics, vol. 70, no. 1, pp. 65-94.

United Nations (2004) *World Population to 2300,* UN Department of Economic and Social Affairs, New York.

Websites:

Centraal Bureau voor de Statistiek (accessed: 2011) *Statline Database,* [www.cbs.nl]

The Conference Board (accessed: 2010) *Total Economy Database*, [www.conferenceboard.org/economics/database.cfm]

Maddison, A. (accessed: 2009) *Historical Data on Population and GDP*, [www.ggdc.net/Maddison]

Welvaart en Leefomgeving (accessed: 2011) *WLO Scenarios*, [www.welvaartenleefomgeving.nl/]

United Nations (accessed: 2011) World Population Prospects (2008 Revision), [http://esa.un.org/unpp/]

C Reflection on Practice of Future Discounting

Chapter 6 discussed the evaluation of policies with a very long term impact. It turned out that there are still some issues with the current practice of future discounting, as the effects of policies with a very long term impact tend to be undervalued in present social cost benefit analyses (SCBAs). This appendix provides a reflection on future discounting in which I first address a number of alternative views on future discounting, that are related to the use of diminishing social discount rates, and then make clear why I think the most important reason for using much lower discount rates is still overlooked. I argue that, if technological progress and economic growth will gradually phase out on the very long term (as presumed in the post-neo-classical paradigm on economic growth), the risk free discount rate is also bound to gradually go down to zero. I therefore suggest an alternative discount scheme that can be applied as a sensitivity analysis to the official rates presently prescribed.

C.1 The Practice of Future Discounting

In today's economic reality the value of one money-unit tomorrow is perceived less valuable than the value of one money-unit today. Economists therefore apply future discounting to take these time preferences into account. For private investments it is common to perform a cost benefit analysis (CBA) in which the 'net present value' (NPV) of a perceived 'cash flow' (CF) is calculated on the basis of a fixed 'discount rate' (r) that reflects the required return on investment for the private investor. The NPV is defined by the following formula:

$$NPV(CF) = \sum_{t=0}^{t=\infty} \frac{CF_t}{(1+r)^t} \qquad \text{(Discount Formula)}$$

in which:

- PV(CF) : present value of a cash flow;
- CF_t : cash flow at time t;
- r : the applied discount rate;
- t : number of time periods ahead.

Future discounting is also applied in SCBAs to value the effects of a certain project for the entire society. For this purpose the Dutch Ministry of Finance (2009) prescribes a risk free discount rate of 2.5% and a project specific risk mark-up of 3.0%. This implies that in general a fixed discount rate of 5.5% is applied in Dutch SCBAs. Only in cases where it concerns important irreversible negative effects a lower risk mark-up of 1.5% can be applied, which implies that in such cases an overall discount rate of 4.0% is used.

For the evaluation of very long term policy effects the use of a single fixed discount rate (as prescribed by the Dutch government) is questionable. A number of experts consulted by Mouter et al. (2012, p.43) pointed out that long term aspects tend to be undervalued in SCBAs. The experts indicated that they have considerable problems with the rate at which negative external effects are discounted in Dutch SCBAs, because: *"As a consequence of the applied discount rate (dis)benefits over 20 to 30 years are virtually negligible"*. According to these experts this practice is not in line with policies that aim for robust sustainable long term solutions. As a result of the high presently prescribed discount rates sustainable project alternatives, that aim for long term benefits, are likely to be scored too low in SCBAs.

The past decades there has been a growing belief that irreversible negative effects should be discounted at much lower rates, in particular when it concerns very long term irreversible negative effects. Weitzman (1998), Gollier (2002), Davidson, (2004), and Stern (2006) provided valuable insights in very long term future discounting, but in my opinion the most important argument is still overlooked. In line with the post-neo-classical view on economic growth (see Chapter 4), I think that the risk free discount rate is eventually bound to go down to zero. This calls for a new perspective on future discounting.

C.2 Considerations regarding the Use of Social Discount Rates

Scientific literature provides a number of important arguments for the use of lower social discount rates. These arguments will be discussed in this section.

<u>Social discount rates concern consumption instead of investments</u>
Discounting principles were initially developed to support investment decisions. A positive NPV implies that the project is feasible from the financial perspective of the investor. It indicates that the internal rate of return (IRR) of the project is higher than the minimum rate of return that is required by the investor. When considering the implications of irreversible negative external effects that are passed on to future generations, such as the effects of climate change, a different approach will be required. Davidson (2004, translated) questions if *"the time horizon for investments on the international capital market is still meaningful for climate investments with a time horizon of many centuries"*. He argues that climate policies are hardly concerned with direct government investments. Most policies concern measures that enhance consumers and producers to reduce greenhouse gas emissions themselves. Sooner or later these costs will be passed on to the public, that will not only pay for it at the cost of their savings and investments[173], but mainly at the cost of reduced consumptive spending. Davidson therefore argues that, for the evaluation of very long term negative external effects, one should consider the use of social discount rates for loss of consumption.

<u>Diminishing social discount rates for loss of consumption</u>
The discussion on the level of the appropriate discount rate for irreversible negative external effects that are passed on to future generations is not new. Scientists like Schelling (1995), and Gollier (2002) have also discussed the subject of intergenerational wealth transfer. They argue that, according to the so called Ramsey-equation, the consumption based discount rate is composed of two parts. The first part relates to the pure psychological time preference. The

[173] Hence that according to macroeconomic theory savings equal investments (see e.g. Blanchard, 2000).

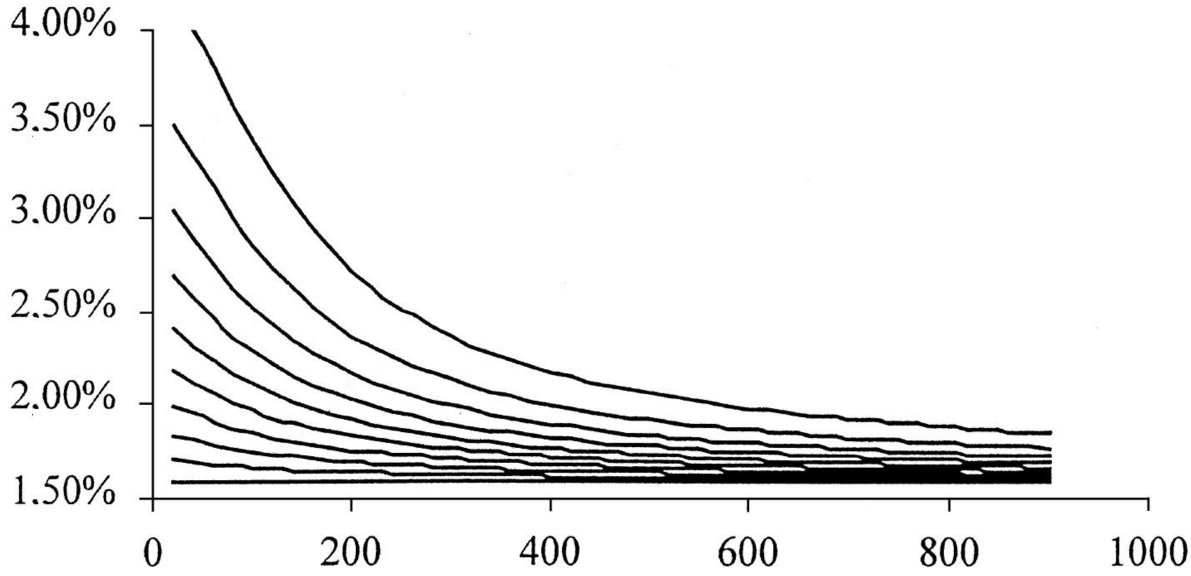
second part is related to the wealth effect of an extra unit of consumption. The Ramsey (1928) equation can be written as:

$$r = \delta + \eta \cdot g \qquad \text{(Ramsey Equation)}$$

Where **r** is the social discount rate that represents the preference of consumption today (e.g. by the present generation) compared to consumption in the future (e.g. by distant future generations); **δ** is the pure time preference for consumption today compared to consumption in the future; **g** is the per capita consumption growth between the present and future time period; and **η** is the elasticity of marginal consumption (see also Weitzman, 2007, p.706).

In the discussion on social discounting the assumption is often made that future generations will be wealthier – and therefore, that the utility of an extra unit of consumption will be less in the future than it will be today. In line with this argument Gollier (2002, p.150) indicates that: *"The second reason to discount the future is related to a wealth effect. We expect that the quantity of available consumption goods will increase over time. After all, in the western world at least, we experienced an uninterrupted growth during the two last centuries. Given decreasing marginal utility of consumption, an investment which gives one unit of consumption good in the present should not be acceptable. Investing for the future in a growing economy will increase consumption inequalities over time. Since agents have preferences for smoothing of consumption over time, this investment should be implemented only if its rate of return is large enough to compensate for this negative effect on welfare. The larger the growth rate of the economy the larger the socially efficient discount rate"*.

Gollier (2002) studied the desirable very long term social discount rate for an economy that has a long term nonnegative growth rate. He concluded that the long term discount rate tends to move towards a fixed nonnegative equilibrium state for a risk averse agent. His socially desirable (mainly) decreasing discount rates are indicated in Figure C-1.



Note: The numbers presented on the x-axis relate to the number of years that one looks ahead.
Source: Gollier (2002, p.160), adjusted size and layout.

Figure C-1: Decreasing Social Interest Rates according to Gollier

The use of diminishing social discount rates has also been advocated by *"The Stern Review Report: the Economics of Climate Change"*, that was published by Stern (2006) on behalf of the British government. The Stern Review triggered a fierce international debate on future discounting in which: Nordhaus (2007), for instance, opposed against the low level of the discount rates proposed by the Stern Review; and in which Weitzman (2007) argued that the Stern Review may get it right for the wrong reasons[174].

The discount scheme of the Stern Report has been adopted by the British government. In a supplement of the green book on discounting the British government now prescribes a diminishing social discount rate, for *"cases where the effects under examination are very long term (in excess of 50 years) and which involve very substantial and, for practical purposes, irreversible wealth transfer between generation"* (Lowe, 2008, p.5). The social discount rates prescribed by the British government are indicated in Table C-1.

Table C-1: Social Discount Rates prescribed by the British Government

Period of years	0-30	31-75	76-125	126-200	201-300	301+
Standard rate as published in the Green Book	3.50%	3.00%	2.50%	2.00%	1.50%	1.00%
Reduced rate where "Pure STP" = 0	3.00%	2.57%	2.14%	1.71%	1.29%	0.86%

Source: Lowe (2008, p.5).

Social justice and zero discount rates for loss of consumption

Despite the fact that diminishing social discount rates put more weight on very long term irreversible negative external effects than their fixed counterparts, they are still questionable from an ethical point of view. Davidson (2004) argues that it is not ethical to take future wealth growth into account in any discount factor concerning intergenerational wealth transfer of irreversible negative external effects (such as the effects of greenhouse gasses). He states that this argument is in line with the legal provision that caused damage may not be weighted lower (discounted at a higher rate) because the one exposed is living far away, has a different ethnical culture, or is much richer than the one who causes the damage.

According to Davidson (2004, translated) the *"The social (diminishing) discount theories are still questionable from an ethical point of view because they have not been developed in line with the moral choices of society which have been created and institutionalised in law, for instance for the interaction between people living today. There is no reason why the Dutch government should apply different standards for interaction between current and future generations as for interaction between people living today. At least, not if the Dutch government aims to be committed to intergenerational justice.*

[174] Weitzman indicates that there are good reasons why one should apply lower diminishing discount rates (and spend more money to slow down global warming) as proposed by the Stern report, but that the discussion should be much more about how much insurance to buy in order to offset the small chance of a ruinous catastrophe that is difficult to compensate by ordinary savings, than about consumption smoothing over generations.

What are the relevant social norms with respect to the interaction between the current and future generations that need to be adopted in cost-benefit analyses concerning climate change policy? The most important notion is that these policies in the first place deal with risks – and that the current legal system also has to balance between the benefits of avoiding risks and the costs of reducing risks. Not all risk need to be removed, as this would be impossible, but one needs to take 'reasonable' precautions.

When defining what is reasonable, the one causing the risk should not judge the potential damage for the one exposed by a lower weight (discount) due to the fact that he lives at distance or is much richer. Such are not only the laws of the Dutch government, but also those of international justice, for instance with respect to cross border air pollution. [...] The Dutch government endorses these national and international standards.

It is difficult to see how the Dutch government can strive for intergenerational justice while at the same time it judges damage from climate change (and loss of consumption) to future generations lower than for the current generation. The Dutch government therefore has good reasons to apply a social discount rate of 0%, when it comes to balancing between climate damage and loss of consumption for the current and future generations".

In line with this argument Davidson (2004) suggested to apply a 0% social discount rate for loss of consumption. The question is now how much of the economic output is consumed and how much is saved and therefore also invested.

<u>The appropriate discount rate according to Davidson</u>

Davidson (2004) argues that the fraction of consumptive spending equals the marginal consumption quote, which according to Lind (1982) is about 80%. With respect to the SCBA he therefore argues that from all the social investments in climate related policies only 20% (the marginal saving quote) will be invested at the expense of other investment opportunities. The main fraction (about 80%) concerns the benefits of avoiding climate change at costs of loss of consumption for the present generation. Davidson therefore proposes to base the discount factor on the weighted average of the investment fraction and the consumption loss fraction. He argues that it would be sensible for the Dutch government to make a clear political statement and discount the costs of climate change at a rate of 0.8%, that is obtained by applying a zero discount rate to the 80% consumption fraction, and a 4% discount rate to the 20% investment fraction.

<u>Some additional considerations with respect to the applied risk mark-up</u>

It is interesting to notice that the Dutch government prescribes the risk free discount rate to be increased with a risk mark-up in order to take into account the risk of non-performance or loss of income for the present generation. I find it odd that, in case of irreversible negative effects, the Dutch investment discount rate is still increased by 1.5% (on top of the assumed risk free discount rate of 2.5%). This implies that: *because we are uncertain about the profitability of the project for our own generation, we deem the negative effects of irreversible environmental damage to future generations less important*. I would consider it more appropriate to base the overall discount rate on a zero discount rate for the consumption fraction and the risk free discount rate of 2.5% for the savings/investment fraction. In line with this argument I would suggest to apply a discount rate of 0.5% rather than 0.8%.

C.3 Ethical Concerns with the Proposed Discount Rates

The above section highlights the fact that the international community has not yet reached consensus on the appropriate level of the applied discount rate. Some different approaches were proposed, but how ethical are these approaches? To answer this question I looked at a the hypothetical case of a nuclear power plant.

Gooding (1978, p.25) pointed out that: *"As fission reactors are generating energy, they are simultaneously generating radioactive wastes. Some decay quickly. Strontium-90 and cesium-137, for example, have half-lives of around 30 years. Others will be with us for a very long time. Iodine-129 has a half-life of 16,000,000 years, neptunium-237 of 2,130,000 years, plutonium-239 of 24,000 years and so on. These, it seems, are evils we have little choice but to leave to our children. Unless we find some secure method of isolating these wastes virtually forever, clear issues of intergenerational justice will inevitably arise"*.

This raises the following question: *How can one come to decide to invest in a nuclear plant if the half-life time of nuclear waste is easily 10,000 years, knowing that nuclear waste will have to be stored for about 250,000 years (ten-thousands of generations)?*[175]. I think that the answer to this question is quite simple: *Just neglect the consequences of nuclear waste for future generations by applying a sufficiently high discount rate*.

To show that the effects on future generations are still almost completely neglected by the presently prescribed discount rates (as well as by the much lower rates that were proposed by more progressive scientist like Davidson and Stern), I considered a simplified case for a hypothetical SCBA of a new nuclear power plant. Let's assume that: (1) the nuclear waste remains harmful forever; (2) that costs of nuclear waste preservation will remain constant over time; and (3) no environmental disasters will occur due to nuclear leakage. For this simplified case the discounted value of the everlasting negative effects can be mathematically represented by the perpetuity of the applied discount rates[176]. This simplification made it possible to estimate the NPV for the everlasting irreversible negative external effects that are taken into account in the SCBA. The results of this exercise are indicated in Table C-2.

Table C-2: NPV of the Costs of Nuclear Waste Preservation at given Discount Rates

Discount Scheme	Rates	NPV of the effect
Dutch Standard Rule	5.5%	Cost of 18 years of waste preservation
Dutch Reduced Rule	4.0%	Costs of 25 years of waste preservation
British Standard Rule	3.5%-1.0%	Costs of 31 years of waste preservation
British Reduced Rule	3.0%-0.86%	Costs of 38 years of waste preservation
Davidson's Rule	0.8%	Costs of 125 years of waste preservation
Reduced Davidson's Rule	0.5%	Costs of 200 years of waste preservation

Note: The estimates have been based on the perpetuity of the everlasting effects.

[175] For further background on the period that nuclear waste remains harmful see Feiveson et al. (2011, p.5).

[176] The perpetuity of a constant annual amount (returning in all future years) can be obtained by simply dividing the annual sum by the applied (fixed) interest rate. For example: an everlasting annual cash flow of 100 euro that is discounted at a constant fixed rate of 5% is worth 2000 euro today.

It is quite interesting to observe that the NPV of nuclear waste preservation is just 18 to 200 years while the expected preservation period of the waste is about 250,000 years. This implies that almost no weight is given to the distant future. This is also confirmed by the fact that, if the effects are cut off after 1% of the running time (i.e. 2500 years), this would not have a noticeable effect on the outcome of the NPV[177]. One can therefore conclude that, as a result of applying future discounting principles, the life of 99% of the future population dealing with this waste problem is not considered of any value at all.

How is it possible that even the more progressive economists, that aim for a fair balance between future benefits of avoided damage and current costs of reducing damage, apply discount standards that neglect the negative effects for so many future generations?

The answer to this question should, in my opinion, be related to one single very critical assumption, namely the assumption that economic growth itself is sustainable. If one endorses the mainstream exponential growth paradigm ones makes the implicit assumption that: *If the current gains from nuclear production would be invested now, and will remain being invested in the future, they will eventually more than offset the ongoing costs for preservation of nuclear waste.* I question the possibility of ongoing economic growth, in particular throughout an ultra-long time period of 250,000 years (see Chapter 4)[178]. In absence of sufficient technological-, labour productivity-, and economic growth it will be almost impossible to sustain sufficient returns on investment to keep up with the assumed discount rate.

I therefore conclude that the justification for developing a nuclear plant is solely based on one single assumption, namely the assumption of everlasting ongoing exponential economic growth, but according to the post-neo-classical paradigm on economic growth this assumption is wrong and cannot be sustained at such an ultra-long time horizon.

C.4 Why an even lower Discount Rate is Appropriate

The previous section indicated that all previously proposed standards will, in my opinion, result in an immoral balancing between the current benefits of using nuclear power and the future disbenefits of burdening distant future generations with the problems of nuclear waste conservation. It seems that there is something fundamentally wrong with the current practice of future discounting and the implicit underlying assumption that there will always remain sufficient risk free investment opportunities. This section therefore continues with two formal arguments why much lower decreasing discount rates should be applied.

Weitzman's argument for discounting at the lowest possible rate

Weitzman (1998) gives a clear argument that there is a *"'basic reason' or 'generic argument' why negative external effects reaching into the far-distant future should be discounted at the lowest possible rate"* (p.202). His argument starts with the notion that *"While there is uncertainty about almost everything in the distant future, perhaps the most fundamental uncertainty of all concerns the discount rate itself"* (p.202). He suggests that, in order to deal

177 Hence that this also implies that I would have obtained the same results if I would have dropped the first assumption, that nuclear waste remains harmful forever, and applied a finite period instead.

178 It should be noticed that today's mainstream neo-classical economist do not claim that their views will hold for such a very long period of time, they are just not concerned about the ultimate state of the economy.

with the present state of uncertainty about the far distant future discount rate, it is sensible to develop a range of **j** possible future scenarios with a probability $\mathbf{p_j > 0}$ and $\mathbf{\sum p_j = 1}$. For each of the scenarios a discount rate $\mathbf{r_j(t)}$ is applied, that is assumed to reach a final steady state limit as time goes to infinity. He refers to this limit as $\mathbf{r_j^*}$. Due to the practice of discounting itself the scenario with the lowest discount rate will become the single most dominant one.

Weitzman's *"proposition tells us that the interest rate for discounting among events within the far distant future should be its lowest possible limiting value. From today's perspective, the only limiting scenario is the one with the lowest interest rate – all of the other states at far-distant time, by comparison, are relatively much less important now because their present value has been reduced by the power of compound discounting at a higher rate"* (p. 205).

Weitzman's argument clearly points out that for irreversible negative very long term external effects (such as the effect of carbon emissions on global climate change, radioactive waste disposal, loss of biodiversity, and minerals depletion) the lowest plausible discount rate should be applied. If I assume this discount rate to be nonnegative the lowest final steady state limit rate will be equal to zero, which implies no discounting at all.

<u>Implications of applying the post-neo-classical paradigm on economic growth</u>

In line with the post-neo-classical paradigm on economic growth, that was proposed in Chapter 4, I consider economic growth as a temporary phenomenon that is related to the very long term (e.g. 400 year lasting) transition process of the industrial and knowledge revolution, in which the state of technology (i.e. TFP), labour productivity, and economic output are assumed to gradually move towards a maximum attainable level on the very long term, say a few hundred years from now. I will now argue why I think that this also implies that the risk free discount rate is bound to go down to zero on the very long term.

I previously discussed that, when it concerns irreversible negative external effects, the use of social discount rates can be considered. I will therefore start to address the implications from a social perspective, that can be linked to the so called Ramsey equation (see Section C.2). If I define the risk free discount rate as the rate at which the stakes of the present and future generations are considered equally important, this implies that no pure time preferences should be taken into account. The δ should therefore be set at 0%, which implies that r is a direct function of g (for any given risk preference η). When labour productivity growth ultimately ceases to exist in response to the diminishing returns on technological progress, as presumed in the post-neo-classical paradigm on economic growth, this implies that the per capita income growth, and hence also the per capita consumption growth (g), will ultimately go down to zero; and when $g \rightarrow 0$ this will also imply that $r \rightarrow 0$. In other words: *'The limit value of the ultimate risk free discount rate goes down to zero'*.

But even if one does not agree on the use of social discount rates one should still argue from an investment perspective that, the closer the state of technology moves towards it maximum attainable limit, the less options there will remain for further innovation. At some stage it will become increasingly difficult for companies to be distinctive, which implies that there will be a strong competition on price levels, and that the profit margins and returns on investment for the individual companies are gradually forced down. At the same time there will be little investment opportunities due to lack of innovation and absent growth of the economy. This causes a stage of excess capital (hence: investments < savings). In search for some profit the excess capital will flow into stocks and bonds, that increasingly become less profitable (i.e. higher price levels for stocks and bonds, that offer similar or lower dividend- and interest payments, will at a certain stage start to dilute the maximum attainable returns on investment). In absence of economic growth, this situation will go on until it will eventually no longer be possible to gain any risk free returns on investment. *The risk free discount rate is therefore also bound to go down to zero on the very long term from the investment perspective.*

In addition to the intuitive argumentation above, I will provide a formal proof that the risk free discount rate goes down to zero in the following text box:

Proof that risk free discount rate goes down to zero in absence of economic growth:
Let's assume a simplified economic model for a risk free world without taxation and government spending, in which the maximum attainable rate of labour productivity $\overline{LP_{max}}$[179] is bounded by physical limits (as presumed in the post-neo-classical economic growth paradigm that has been discussed in Chapter 4).

Let's further assume that the global economy moves towards a final steady state situation in which the size of the population, labour force $\bar{L}$, and the ultimate labour productivity rate $\bar{\kappa}^*$[180] reach a final constant limit value.

For such a world the global production function for the constant steady state output of the economy $\overline{Y^*}$, can be written as:
$\overline{Y^*} = \bar{\kappa}^* \cdot \bar{L}$, with
$\bar{\kappa}^* = f(L, \kappa_y^*) \leq \overline{LP_{max}}$, and
κ_y^* representing the optimal level of capital relative to labour.

The next step is to discuss the accumulation of real capital (I have not included inflation in this discussion). The amount of real capital K_t at time period t can be written as:
$K_t = K_{t-1} + S_t$

In which S_t represents the real savings (i.e. in terms of goods) in time period p. These savings are equal to the produced goods that have not been consumed or invested:
$S_t = Y_t - C_t - I_t$

The variable Y_t reflects the output of the world economy at time period t; the variable C_t reflects the world consumption at time period t; and the variable I_t reflects the investments that are made in production facilities all over the world at time period t.

With respect to the investments a further distinction can be made between replacement investments I_{R_t} that are necessary to keep economic production at its present level, and new investments I_{N_t} that increase the global level of economic output by increasing the labour productivity rate κ. The investments at time t can therefore be written as:
$I_t = I_{R_t} + I_{N_t}$

[179] The '$-$' above the letter L is used to indicate that the concerned variable has a constant value.

[180] The '*' indicates that κ has reached its optimal level of capital relative to labour, that corresponds to Solow's (1956) balanced growth path.

Having discussed the function for the accumulation of capital I will now further discuss the implications for the steady state situation. Let's define t = 0 as the moment at which the steady state situation starts, and from which growth of labour productivity and economic output no longer occurs. For each time period $t \geq 0$ it holds that:

$$Y_t = \overline{Y^*}$$

Given a stable size of the population and a fixed level of economic output one can also assume the consumption levels to stabilise at a fixed level:

$$C_t = \overline{C^*}$$

In the ultimate steady state situation all labour will be deployed at the steady state labour productivity rate $\overline{\kappa}^*$. This implies that there are no options to invest in an increase of economic output by making new investments:

$$I_{N_t} = 0$$

The only remaining investments are therefore related to the replacement of capital goods, which can be assumed to be more or less constant over time:

$$I_{R_t} = \overline{I_R^*}$$

The above assumptions imply that savings become a constant value:

$$S_t = \overline{S^*} = \overline{Y^*} - \overline{C^*} - \overline{I_R^*}$$

The steady state consumption and investment levels cannot be larger than the economic output, because this would ultimately result in negative stocks of produced consumption and capital goods. For the steady state situation it should therefore hold that:

$$\overline{S^*} \geq 0$$

The constant savings imply that the steady state capital accumulation function becomes:

$$K_t = K_{t-1} + \overline{S^*}$$

If I look closer into the capital market I can argue that the available capital in the steady state situation is either invested in production factors K_y or in excess goods that cannot be used for production K_E, because there is no excess labour available to work on it.

$$K_t = K_{Y_t} + K_{E_t}$$

In the steady state situation all available labour is assumed to be used in its most efficient way. K_{Y_t} therefore equals a constant optimal value $\overline{K_Y^*}$, which implies that K_t becomes:

$$K_t = \overline{K_Y^*} + K_{E_t}$$

Using the above formulas K_{E_t} can also be written as:

$$K_{E_t} = K_t - \overline{K_Y^*}$$
$$K_{E_t} = K_{t-1} + \overline{S^*} - \overline{K_Y^*}$$
$$K_{E_t} = K_{Y_{t-1}} + K_{E_{t-1}} + \overline{S^*} - \overline{K_Y^*}$$

Considering the fact that for each t > 0 the value of $K_{Y_{t-1}}$ equals $\overline{K_Y^*}$ it follows that:

$$K_{E_t} = K_{E_{t-1}} + \overline{S^*}$$

Let's now assume that all individual companies in the steady state situation have a joint profit that can be described as a fraction p of the global economic output (with 0 < p < 1). The total returns on capital for all the individual companies together can then be written as:

$ROK = \frac{p \bullet \overline{Y^*}}{\overline{K_Y^*}}$, with (0 < p < 1)

This implies that companies are still assumed to make a profit, though profits can be expected to be reduced due to enhanced competition that stems from the steady state knowledge base becoming gradually available to all commercial parties.

Let's now consider the effects on the overall capital market. If I assume that the available capital K_t is invested in stocks and bonds, that provide capital to the individual companies, the overall return on investment (ROI) for the entire investment market becomes:

$ROI_t = \frac{p \bullet \overline{Y^*}}{K_t} = \frac{p \bullet \overline{Y^*}}{\overline{K_Y^*} + K_{E_t}}$, with (0 < p < 1)

Let's now assume that there was no excess capital at t = 0. This implies that:

$ROI_t = \frac{p \bullet \overline{Y^*}}{\overline{K_Y^*} + \sum_0^t K_{E_t}} = \frac{p \bullet \overline{Y^*}}{\overline{K_Y^*} + t \bullet \overline{S^*}}$, With (0 < p < 1)

For any given steady state level of savings $\overline{S^*} > 0$, this implies that:

$\lim_{t \to \infty} ROI_t = 0$

In other words, the risk free returns on investment will eventually go down to zero (except for the special case in which $\overline{S^*} = 0$, in which saving no longer occurs).

This proves that, in absence of technological progress (i.e. growth of TFP), it will at a certain point in time no longer be possible to gain risk free returns on investment at the capital market – and if risk free returns on investment are eventually no longer possible, this also implies that the risk free discount rate is bound to go down to zero.

Therefore, from both the investment and social perspective, one can argue that the very long term discount rates should not only go to zero, because it is a plausible scenario, as would be the required criteria to apply such a low discount rate according to the proposition of Weitzman (1998), but also, because it is, from a post-neo-classical perspective, the only likely very long term scenario for the future development of the risk free discount rate.

Implications for discounting irreversible negative effects

Having discussed the reasons why I think the risk free discount rate should eventually go down to zero, I will now look at the effect on the hypothetical case of a nuclear power plant. If one applies a zero discount rate to the waste effects of a nuclear power plant this will change the outcome of the hypothetical SCBA completely. Instead of taking 18 to 200 years of waste preservation into account the policy maker now has to consider 250,000 years of waste preservation, as well as the far distant effects of possible future catastrophes that may occur during the period of waste preservation. This eventually brings the views of economists (that have advocated nuclear power to be cost effective) and environmentalists (that have advocated that such a burden may not be imposed on future generations) close together as both groups are now likely to arrive at a similar conclusion. I would like to conclude with the notion that any visionary policy maker will intuitively know it is no good to exchange a onetime benefit for ultra-long lasting disbenefits, but that this view will only be confirmed by the outcome of a SCBA if the future is discounted at a low enough discount rate.

C.5 Proposed Very Long Term Discount Scheme

On the basis of the discussion in this appendix I will now propose a new discount scheme that can, for instance, be applied as a sensitivity to the rates that are presently prescribed for official SCBAs. The suggested discount scheme is indicated in Table C-3.

Table C-3: Proposed Discount Scheme

Discounting period	Risk free base rate for investments	Project rate including 3.0% risk premium	Rate for irreversible negative effects
0-30 years	2.50%	5.50%	0.50%
31-75 years	1.78%	4.78%	0.36%
76 - 125 years	1.06%	4.06%	0.21%
126 - 200 years	0.49%	3.49%	0.10%
200 - 300 years	0.15%	3.15%	0.03%
300+ years	0.00%	3.00%	0.00%

***Note: The risk free investment rate is based on a value of 2.5% for the first 30 years which is similar to the value required by the Dutch Government and the assumption that 200 years from now 95% of the transition S-curve of labour productivity and economic growth will be completed.**

The proposed discount scheme consists of three elements, which are: (1) a risk free discount rate that reflects the risk free investment opportunities from the perspective of both the present and future generations; (2) a project specific discount rate that includes a risk and/or profit mark-up to justify the investment from the perspective of the present generation; and (3) a reduced social discount rate that deals with the irreversible negative very long term effects that are imposed onto future generations.

In line with the British standards the discount rates were defined for a number of time periods, being: 0-30 years, 31-75 years, 76-125 years, 126-200 years, 200-300 years, and thereafter. An alternative approach would have been to define a different rate for each individual year. This approach is more specific, but also less practical.

The risk free discount rate is obtained by assuming that: (1) there is a direct relation between the growth of economic output and the discount rate; (2) the economy is following a very long term transition S-curve that is now about halfway the transition process and will be completed for 95% some 200 years from now; and (3) the assumption that the risk free discount rate in the first 30 years equals the rate of 2.5% as prescribed by the Dutch government[181]. Of course

[181] The fraction of completion of the transition curve is described by the function 0.00736228305814892 * tanh(year from now) + 50%, in which the tanh() stands for the hyperbolic tangent function. On the basis of this function the overall output is defined for the target years (0, 30, 75, 125, 200, and 300). The obtained values are (50%, 61%, 75%, 86%, 95%, and 99%). The average annual growth factor of the economy over the representative period is defined by dividing the completion factors for the transition of the covering years and by taking the root over the number of years under consideration for the selected period. For example the value for the first 30 years is defined by (61%/50%)^(1/(30-0))=0,66%. During the next step the annual growth factors were all multiplied by a constant factor of 3.80095369526401 that corresponds with an obtained value of 2.5% for the first 30 years.

this is only a first attempt to derive discount rates that are in line with my post-neo-classical views on economic growth. I therefore regard it as a provisional discount scheme that can be used to put the current practice of future discounting in a different perspective.

In line with the present guidelines of the Dutch government the applicable project rate for the evaluation of normal effects (not being irreversible very long term negative external effects) consists of a risk free discount rate and a specific project related risk mark-up or premium. The proposed project rate was obtained by adding a similar standard risk premium of 3.0% (as presently prescribed by the official Dutch guidelines) to risk free discount rate.

According to Davidson (2004) the discount rate for irreversible negative effects can be related to loss of alternative investment opportunities (20%) and loss of consumption (80%). For loss of consumption he argues that it is not appropriate to apply discounting principles, as this would lead to inter-generational discrimination. In line with this argument I have applied a 0% discount rate to the consumptive fraction. For the loss of alternative investment opportunities I do not consider it appropriate to include a risk mark-up, because this would imply that we value the negative effects on future generations lower due to uncertainties regarding the profitability of the project for our own generation. I have therefore set the rate for irreversible negative effects at 20% of the risk free discount rate for investments.

The proposed discount scheme has the clear advantage that all effects are based on the same risk free discount rate, which is logic as the risk free discount rate has no preference for the interests of the present and future generations. When the proposed discount rates are applied to the hypothetical SCBA for a nuclear power plant, the outcome is likely to support the intuitive feeling that it is no good to exchange a onetime benefit for everlasting disbenefits. Due to the 0% discount rate from year 300 onwards, ultra long lasting irreversible negative effects will, eventually, turn out to become dominant in the decision making process.

It should finally be noted that the reason for applying a diminishing risk free base rate that gradually goes down to zero on the very long term is free of any ethical considerations, as it directly reflects the consequences of adopting the post-neo-classical paradigm on economic growth. This does of course not hold for the reason to apply even lower discount rates in case of irreversible negative external effects, that is entirely based on the ethical consideration not to judge the potential damage for the one exposed by a lower weight (or discount rate) due to the fact that he lives in the distant future. However, even if one disagrees with the ethical considerations, the neutral (no ethics involved) conclusion, that the risk free discount rate should gradually go down to zero on the very long term, will still have a major effect on the outcome of the SCBA. If the proposed discount rates are applied as a sensitivity to the present rates, the results are likely to point out clearly that more weight should be given to very long term effects.

Literature:

Blanchard, O. (2000) *Macroeconomics*, Second International Edition, Prentice-Hall Inc., Upper Saddle River, New Jersey.

Davidson, M.D. (2004) *Discontovoet voor klimaatschade behoeft politieke keuze,* Economisch Statistische Berichten (ESB), 89^e^ jaar, no. 4439, p. 290.

Feiveson, H., Z. Mian, M.V. Ramana, and F. von Hippel (eds.) (2011) *Spent Fuel from Nuclear Power Reactors, An Overview of a New Study*. International Panal on Fissile Materials (IFPM).

Gollier, C. (2002) *Discounting an uncertain future*, Journal of Public Economics, vol. 85, no.2, pp.149-166.

Goodin, R.E. (1987) *Uncertainty as an excuse for Cheating Our Children: The Case of Nuclear Wastes*, vol. 10, no. 1, pp.25-43.

Lind, R,C. (1982) *A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options.* In: R.C. Lind et al. (red) Discounting for Time and Risks in Energy Policy. Resources for the Future. Washington D.C.

Lowe, A.J. (2008) *Intergenerational wealth transfer and social discounting: Suplementary Green Book guidance*. HM Treasury, London, UK.

Ramsey, F.P. (1928) *A Mathematical Theory of Saving*, Economic Journal, vol. 38, pp. 543-559.

Schelling, T.C. (1995) *Intergenerational discounting*, Energy Policy, vol. 23., no.4, pp. 395-401.

Solow, R.M. (1956) *A Contribution to the Theory of Economic Growth*, The Quarterly Journal of Economics, vol. 70, no. 1, pp. 65-94.

Stern, N. (dir.) (2006) *The Stern Review Report: the Economics of Climate Change*, London, HM Treasury, October 30, 603 p.

Weitzman, M.L. (1998) *Why the Far-Distant Future Should Be Discounted at Its Lowest Possible Rate*, Journal of Environmental Economics and Management, vol. 36, no. 3, pp. 201-208.

Weitzman, M.L. (2007) *A review of the Stern Review on the Economics of Climate Change*, Journal of Economic Literature, vol. 45, pp. 703-724.

D Conversion of Base Year 2004 Data

In Chapter 11 it was discussed that the modelling of very long term IWT flows at the network level requires a completely different freight commodity classification system that complies with the characteristics of the transport system. I have therefore proposed a new classification system that consists of the following six commodity classes: non-containerised dry bulk, containerised dry bulk, deepsea containers, continental containers, parcel loads, and packages. To prove that it is possible to convert the available transport data into this new classification system I have converted the Dutch base year 2004 data files, that are used as input for the development of the BASGOED model, into this new commodity classification system. This appendix provides the basic principles and applied decision rules for the conversion of the base year 2004 data. The obtained results, that have also been used for the discussion in Chapter 12 and 14, are made available in four excel files that are listed in Appendix F.

D.1 General Approach

The 2004 base year data consists of a separate file for road-, rail- and IWT, which are named: *'BBGVV04_wegTOT.dat'*, *'BBGVV04_spoor.dat'*, and *'BBGVV04_bvrt.dat'*. Though the files are not public, they were made available for this PhD project by Rijkswaterstaat.

To handle the vast amount of data in these files I developed a specific conversion programme that was written in the computer language Delphi 7. The overall programme contains over 5,000 rows of programming language. The reason to use Delphi 7 instead of another programming language is that I was already familiar with this language. Despite the fact that Delphi 7 is no longer officially supported, it still turned out to function well.

The first challenge was to read the three text files that contain the data. These files are so large that I could not open them in notepad (at least not on my computer). The IWT file has a size of 170 MB, the Rail file is 189 MB, and the road file is 516 MB. To handle these large files I first implemented a routine that divided the files into a separate file for each NSTR1 commodity class. These smaller files could then be opened in notepad, which allowed me to understand the file and define how the data could be read by the programme.

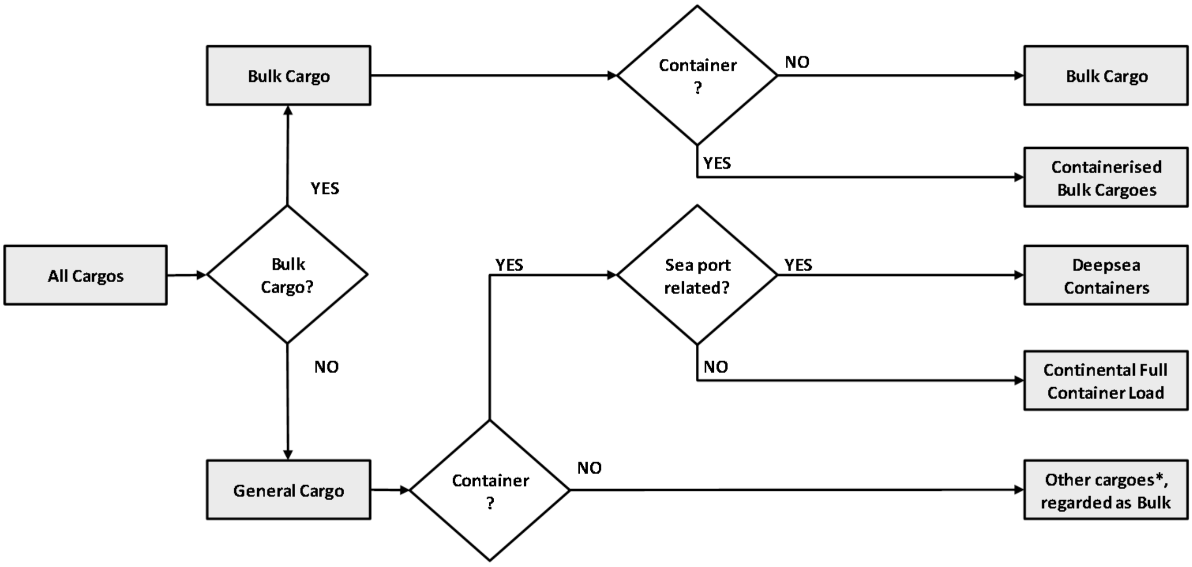
The remainder of this appendix provides the details on the various steps that were applied in the conversion of the transport data for inland waterway-, road-, and rail transport.

D.2 Conversion of the IWT Data Files

The first file that I was able to convert was the IWT data file. The basic principles for the conversion of this file are simple. The programme: (1) reads the data items of the transport flow that are reported on the first row of the data file; (2) defines the applicable new commodity class (i.e. non-containerised bulk, containerised bulk, deepsea containers, continental containers and full truck loads, parcel loads, and packages); (3) defines the relevant performance measures (i.e. gross tonnes, payload tonnes, and payload tonne kilometres); (4) adds the data to the output matrices; (5) clears its row memory; and (6) continues with the next row. However, in practice the conversion is complicated by the fact that quite some issues were encountered with the available data.

D.2.1 Defining the New Commodity Class

Figure D-1 presents the decision scheme that I applied to define the new commodity class for each individual row in the data file.



***Note: The other cargoes category relates to for instance vehicles, equipment, project cargoes or break bulks that have not been identified as a bulk commodity on the basis of their NSTR category.**

Figure D-1: Decision Scheme for defining New IWT Freight Categories

The first step in this decision scheme relates to the question whether the freight flow concerns a shipment of '*bulk products*' or '*general cargoes*'. To answer this question I initially looked at the data item *'versvorm'* (Dutch for appearance of cargo), that contains the following options [N/A, Liquid Bulk (LB), Dry Bulk (DB), and containers (CT)]. However, for IWT the bulk cargo properties were often not properly reported. The NSTR category 12 (beverages) for instance showed a large amount of cargoes that were reported as dry bulk cargoes. I only trusted the property *'containers'* to be correctly reported by the *'versvorm'* data item – and decided to determine whether or not it concerns a bulk product by looking at the NSTR2 classification number listed in the *'nstr2'* data item (that includes an additional -1 property to represent an empty trip).

The corresponding road and rail data files revealed a one to one relation between the reported NSTR2 categories and the reported types of cargo, that were labelled as Dry Bulk (DB), Liquid Bulk (LB), and General Cargoes & Break Bulk (GC & BB). I assumed that this relation, that must have been presumed for the construction of the base year 2004 data files, can also be applied to IWT. In addition I made a further distinction between General Cargoes (GC) and Break Bulk cargoes (BB), that was based on my personal judgement. The applied commodity conversion rules are indicated in Table D-1.

Table D-1: Applied Conversion Rules for NSTR Categories

Type	Numbers applied in data file *'nstr2'* property
Dry Bulk (DB)	1, 2, 6, 11, 17, 18, 21, 22, 23, 41, 45, 46, 61, 62, 63, 64, 65, 71, 72, 82, 84.
Liquid Bulk (LB)	31, 32, 33, 34, 81, 83.
Break Bulk (BB)	0, 5, 51, 52, 53, 54, 55, 56, 91, 92.
General Cargo (GC)	3, 4, 9, 12, 13, 14, 16, 69, 89, 93, 94, 95, 96, 97, 99.
Not Applicable (N/A)	-1 (empty), 98 (empty containers).

Note: Not all the NSTR2 commodities classes occurred in the applied road, rail, and IWT databases.
Source: Based on rules applied in road and rail data files to define (DB, LB, BB/GC) and my personal judgement (to distinguish between BB and GC).

The first decision point in the schedule of Figure D-1 asks if a certain commodity should be regarded as bulk cargo. To answer this question I applied the NSTR2 conversion rules listed in Table D-1. If the corresponding NSTR2 classification is of the category DB, LB or BB the commodity is classified as a bulk, if this is not the case it is classified as general cargo (GC).

The next step is to define if the commodity is shipped in containers (note that both bulk and non-bulk products can be shipped in containers). This aspect is assumed to be properly reported by the *'versvorm'* data item. On the basis of the *'bulk'* and *'containerised'* properties a first distinction was made between non-containerised bulk, containerised bulk, containerised general cargoes, and non-containerised general cargoes.

For container transport I aimed to make a distinction between deepsea and continental container flows[182]. These properties are however not listed in the data file. I therefore assumed that all port related container flows can be regarded as deepsea containers (though with the growing share of short sea shipping in continental 45 foot containers this assumption may no longer remain valid in the future)[183]. In order to define whether a container flow is port related or not, I looked if the reported origin and destination locations include the seaports of Amsterdam, Antwerp, Bremen, Bremerhafen, Calais, Delfzijl, Dordrecht, Dunkirk, Eems-mond, Flushing, Gent, Hamburg, Den Helder, Le-Havre, Moerdijk, Rotterdam, Terneuzen, Velsen, Vlaardingen, Wilhelmshafen, Zaanstad or Zeebrugge. The container flow is assumed to be port related if the origin or destination is similar to one of these locations.

The non-containerised general cargoes that are shipped by IWT are not expected to contain cargo of the following categories: *'continental containers and full truck loads'* (which would have presumably be shipped in containers); *'parcel loads'* (for which the share of IWT is still virtually nothing); and *'packages'* (which are expected to remain the exclusive domain of road transport). The non-containerised general cargoes are therefore expected to relate to other cargoes such as for instance vehicles, equipment, project cargoes or break bulks, that have not been identified as a bulk product on the basis of their NSTR category. I have categorised these flows as bulk cargo.

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[182] This is important because deepsea container flows are transported in standard ISO containers while continental container flows are transported in pallet wide, high cube, 45 foot containers. Given the current infrastructure dimensions the competitiveness of both container types is quite different.

[183] In this respect I would recommend to include the 45 foot containers as a new data item *'acont5'* in the file.

D.2.2 Defining the Transport Performance

The next step is to define the performance of the transport flows (i.e. in tonnes and tonne kilometres). For bulk cargoes the gross- and payload weights are similar and can be obtained from the data item *'vervgew'* (Dutch for transported weight). For container cargoes this issue is more complicated. The data item: *'vervgew'* is intended to reflect the gross weight of the container (i.e. the payload plus the weight of empty box), but in reality the container data is often not properly reported. There seems to be many issues with the data, such as:

- The data does not clearly indicate if the container is full or empty. In case the NSTR4 category is of type 9910 (used package material) I assumed the container to be empty. Otherwise the container is assumed to be full.
- The reported data on the number of shipped containers is incomplete. For a large number of container flows (*'versvorm'* = container) the number of containers is not stated. Where no container data is available I assumed the payload volume to be 85% of the gross load (based on my personal judgement).
- The data items on the number of containers (*'acont'*) and the number of TEU (*'antteu'*) were left empty in the data file, but the number of containers could still be calculated from the data items ('acont2' [20-29 foot]; 'acont3' [30-39 foot]; 'acont4' [40+ foot]; and 'acont9' [unknown size]). In case the number of containers was reported I deducted the tare weight from the gross weight to obtain the payload by applying a weight of respectively 2.3, 3.1, 3.8, and 3.1 tonnes per container.
- Full containers were sometimes reported at a gross weight of 1 tonne. This implies that the estimated payload becomes negative after deduction of the tare weight. In those cases I assumed the containers to be empty, though this may not be the case.
- In other cases the number of containers (or the gross load) was not reported properly and resulted in high gross loads of over 35 tonnes per box (which is very rare in practice). I then assumed the gross load to be correct (not the number of containers) and estimated the payload by applying the 85% of the gross load rule.

The above discussion shows that more attention needs to be given to the proper reporting of container data for IWT. In addition it would be appropriate to make a clear distinction between payload and gross load data in the data files.

To define the performance in payload tonne kilometres I had to know the corresponding distance. There were however also some issues with the data item on distance. I therefore defined the distance by dividing the gross load tkm data *('ladtkmto'*) by the gross load volume in tonnes *('vervgew'*). The performance in payload tkm was finally obtained by multiplying the payload with the calculated distance.

D.3 Conversion of the Road Data Files

The conversion of the road data files took place in a more or less similar way as for the IWT data files, but in some cases different data items were used.

D.3.1 Defining the New Commodity Class

Figure D-2 presents the decision scheme that was applied for road transport.

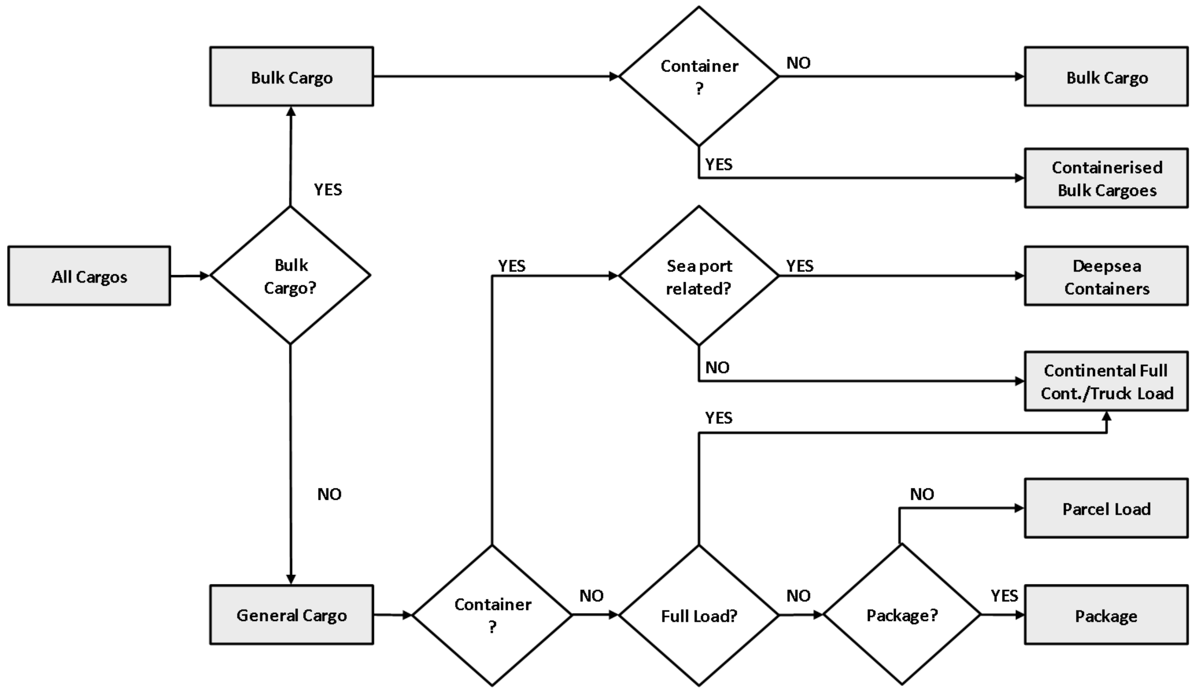


Figure D-2: Decision Scheme for defining New Road Freight Categories

To apply the scheme I had to determine whether: (1) the cargo type consists of bulk cargo; (2) the cargo is shipped in a container; (3) the origin of the cargo relates to a seaport; (4) the shipment consists of small packages; and (5) if the shipment consists of a full truck or container load. This information was obtained from the data items:

1. *'nstr_gr'* (NSTR2 category): By applying Table D-1 the NSTR2 category can be converted into the cargo types Dry Bulk (DB), Liquid Bulk (LB), General Cargo (GC), and Break Bulk (BB). If these types are of the DB, LB or BB categories the freight flow concerns a bulk shipment.
2. *'versvorm'* (appearance): This data item distinguishes between [Empty, Dry Bulk, Liquid Bulk, Container, or General Cargo/Break Bulk]. As for IWT I assumed it to properly report whether a freight flow is shipped in a container or not.
3. *'lken_lad'* and *'lken_los'* (characteristics of loading and unloading locations): This item indicates the type of loading and unloading location. If one of the locations has the property *'Seaport'* it indicates that the cargo is seaport related.
4. *'typevrtg'* (vehicle type): This property contains various types of vehicles including different truck sizes and a smal distribution van. It is assumed that a shipment consist of packages when it is transported in a distribution van.
5. *'rit_type'* (trip type): This property indicates whether a road trip contains a single or multiple shipments. In case a trip contains only one shipment it is assumed that it concerns a full load shipment.

D.3.2 Defining the Transport Performance

The data item *'otonkm'* refers to the gross load for containers and the payload for non-containerised cargo loads. To define the payload tonne kilometres for containerised cargoes I first calculated the distance by dividing the gross load performance in tonne kilometers (data item: *'otonkm'*) by the gross load in tonnes (data item: *'obcgew'*) and then multiplied the payload performance in tonnes (data item: *'obpgew'*) by the distance.

D.4 Conversion of the Rail Data Files

For several reasons the rail freight files were the most complicated to convert. The first complication relates to the fact that railway wagons also transport combi-trailers (truck trailer with load), for which the weight of the truck trailer is also included in the gross weight. This needs to be accounted for in the estimation of the payload. The second complication arises from the fact that container and combi-loads are all reported as NSTR2 class 98 and 99. This implies that for containerised bulk, deepsea containers, and continental loads no subdivision can be made according to the NSTR class.

D.4.1 Defining the New Commodity Class

The decision scheme for rail freight is similar to the scheme for IWT. To apply the scheme I had to identify if: (1) the cargo type consists of bulk cargo; (2) the cargo is shipped in a container or combi-trailer; and (3) if the origin of the cargo relates to a seaport. This information was obtained from the data items:

1. *'nstr'* (NSTR2 category): By applying Table B-1 the NSTR2 category can be converted into the cargo types Dry Bulk (DB), Liquid Bulk (LB), General Cargo (GC), and Break Bulk (BB). If these types are of the DB, LB or BB categories the freight flow concerns a bulk shipment.
2. *'versvorm'* (appearance): This property distinguishes between [Dry Bulk, Liquid Bulk, Container, General Cargo/Break Bulk, Combi-Trailer, and Service Traffic]. It directly indicates if the cargo is shipped in a container or a combi-trailer.

There is no single parameter that indicates if the cargo is port related, but different parameters could be combined to provide a reasonable indication. For Rotterdam the terminal of loading/unloading (*'aankstst'*/*'vertstst'*) was used. For other Dutch ports the arrival and departure regions are applied (*'aankverk'*/*'vertrverk'*). For foreign regions the area of the NUTS3 level provides the best indication (*'aannuts3'*/*'vertrnuts3'*).

Container cargoes were assumed to be port related if they depart from or arrive at the Maasvlakte, Botlek, Europoort, Pernis, and Waalhaven station in Rotterdam; the Dutch Delfzijl / Eemshaven, IJmond, Amsterdam, Flushing port areas; and the NUTS3 regions of Antwerp (BE211), Hamburg (DE600), Bremen (DE501 and DE502), Wilhelshafen (DE945), and Le-Havre (FR232).

For rail freight the non-containerised general cargoes cannot be expected to relate to the categories: *'continental containers and full truck loads'* (which would have presumably be shipped in containers); *'parcel loads'* (for which the share of rail transport is still virtually nothing); and *'packages'* (which are expected to remain the exclusive domain of road transport). The non-containerised general cargoes are therefore likely to relate to other cargoes such as for instance vehicles, equipment, project cargoes or break bulks, that have not been identified as a bulk product on the basis of their NSTR category. I have categorised these flows as bulk cargo.

D.4.2 Defining the Transport Performance

The gross load of the rail freight cargoes (bulk, container, and combi-trailers) is reported by the variable *'vervgew'* (transported weight). For containers the payload is reported by the variable *'gbcb'*. The payload of combi-trailers is reported by the variable *'gbocb'*. The gross load tonne kilometres are reported by the parameter *'tonkmtot'*. The distance was defined by dividing the gross load tonne kilometre by the gross load in tonnes. The payload tonne kilometre performance was obtained by multiplying the payload by the distance.

E List of Consulted Experts

For the execution of this PhD project I consulted a considerable number of experts. Table E-1 provides a list with most of the consulted experts.

Table E-1: List of Consulted Experts

Name	Function and Company	Contribution to this Thesis
Ayres, R.U.	Emeritus Professor in Policy, Technology and Economics Insead, France.	Discussion on very long term megatrends, Kondratieff waves and various paradigms on economic growth (Ch. 4).
Barto, A.	Director of Pro-Log (IWT Logistics).	Consulted on the characteristics and costs of container barge transport (Ch. 10).
Blaauw, H.	IWT Consultant at Henk Blaauw Consultancy B.V. Wageningen.	General discussion on PhD project, consulted on the options to develop climate adjusted shallow draft light weight barges (Ch. 9).
Bolt, E.	Senior Advissor Waterways and Shipping at Rijkswaterstaat.	Scope of this PhD project, regular discussions on progress and findings of the PhD project, detailed discussions on transport modelling (Ch. 11).
Bongers, H.	Senior Advisor on Economic Aspects, Ministry of Economic Affairs (EL&I).	Discussion on paradigm of economic growth and applied economic growth scenarios as well as on effects of decoupling of transport and economic growth (Ch. 3, 4, 7, and 14). Commented on background report for Delta Scenarios that feed into Chapter 13 and 14.
Brolsma, J.	IWT Specialist at Brolsma Advies, former employee of Rijkswaterstaat.	Consulted on historical development and future expansion of European waterways (Ch. 2 and 8).
Bruinsma, H.	Business Developer for the Inland Container Terminal Veghel.	Consulted on the development of continental container lines from Veghel to Rotterdam.
Bruggeman, W.	Senior Consultant at Deltares.	Commented on background report for Delta Scenarios that feed into Chapter 13 and 14.
Buitendijk, M.	Nautical Technical Advisor at Royal Schuttevaer	Consulted on regulations for sailing with 6 push barges on the river Rhine (in the BPR and RPR).
Dammers, E.	Scenario writer at the PBL Netherlands Environmental Assessment Agency	E-mail communication during development of the Shipping Scenarios for the Dutch Delta programme.
De Groot, H.L.F.	Professor Regional Economic Dynamics at VU University Amsterdam.	General discussion on PhD project and intended scope. Discussion on the presently applied economic growth assumptions (Ch. 3, 4, and Appendix B) as well as on population and economic growth assumptions that were applied in the very long term forecast presented in Chapter 7.

De Langen, P.W.	Professor Cargo Transport & Logistics at TU-Eindhoven (and former advisor Corporate Strategy at Port of Rotterdam Authority).	Consulted on availability of data concerning IWT in Port of Rotterdam (Ch. 2), discussion on implication of economic trends for development of transport networks and intermodal IWT (Ch. 4, 8), and discussion on very long term forecast of port throughput volumes (Ch. 7).
Den Haan, P.	Technical Expert at Mercurius Shipping Group.	Compared the outcome of the fuel consumption model that was developed in Chapter 10 with some known values for inland barges at deep water.
Den Heijer, F.	Senior Advisor at Deltares, former employee of Rijkswaterstaat.	Defining the scope of this PhD project, discussion on the background and broader aim of the project for Rijkswaterstaat (Ch. 1). Reviewed parts of Chapter 1, that were adopted in conference paper of Den Heijer et al. (2010).
De Vries, C.J.	Director Dutch IWT Promotion Bureau (BvB).	General discussion on the PhD project. Provided input for introduction chapter on IWT (Ch. 2).
Eisma, M.	Advisor Water Soil and Climate Adaptation, Port of Rotterdam Authority.	Commented on parts of the background report for Delta Scenarios that feed into Chapter 13 and 14, in particular with respect to effects of climate change for the port of Rotterdam.
Elzinga, T.	Senior Consultant at Royal HaskoningDHV.	Several discussions on the scope and findings during the initial stage of the PhD project.
Francke, J.	Senior Advisor at Knowledge Centre for Mobility (KiM).	Discussion on effects of high labour productivity assumptions on the GDP and transport scenarios applied in the WLO study (Ch. 3, Appendix B).
Geerlings, H.	Professor in Governance of Sustainable Mobility at Erasmus University Rotterdam.	Discussion on IWT in general (Ch. 2), economic trends and long term waves (Ch. 4), and transitions in transport infrastructure (Ch. 8). Commented on draft of Chapter 2, as well as on draft of Chapter 4, and parts of Chapter 8.
Havinga, H.	Sr. Hydraulic Engineer and River Specialist at Rijkswaterstaat.	Consulted on the effects of subsidence and erosion in combination with climate change, provided some guidance for hypothetical scenarios (Ch. 9). Commented on discussed in Chapter 9 of draft Summary Report.
Hekkenberg, R.	Assistant Professor Ship Design, Production & Operation at TU-Delft.	In particular discussions on IWT (Ch. 2), intermodal barge transport (Ch. 8), and estimating the weight and fuel consumption of barges (Ch. 10). Commented on outcome of the fuel consumption model developed in Chapter 10.
Helmer, J.	Transport Economist at Rijkswaterstaat.	Commented on draft Summary Report, with focus on economic growth and future discounting.
Hijdra, A.	Senior Advisor Waterways at Rijkswaterstaat.	Defining the scope of this PhD project, discussion on the background and broader aim of the project for Rijkswaterstaat (Ch. 1).
Kleijn, M.	Director Barge Operator MCT Lucassen.	Discussion on general development and costs of container barge transport (Ch. 2, 8, and 10).
Konings, R.	Senior Researcher at OTB, TU-Delft.	General discussion on PhD project, consulted on recent research related to IWT (Ch. 2).
Konings, V.	Trainee at Rijkswaterstaat.	Commented on draft Summary Report.
Kuub, N.	Logistics Student and son of Container Barge Owner.	Consulted on options to load four rows of 2.5 meter wide continental 45 foot containers next to each other in the hold of a standard Rhine barge (Ch. 2).
Kuipers, B.	Director Business Development Erasmus Smart Port Rotterdam.	General discussion on PhD project, uncertainty in transport, and Black Swans (Ch. 5).
Macharis, C.	Professor Transport and Logistics as Vrije Universiteit Brussel.	General discussion on PhD project, as well as a more specific discussion on the development of intermodal transport (Ch. 8).

Marchau, V.	Associate Professor on Transport Policy.	Discussion on first draft of Chapter 5.
Miete, O.	Modelling Expert at Rijkswaterstaat.	In particular discussions on modelling of very long term transport developments (Ch. 11).
Mouter, N.	Policy Researcher at the TU-Delft.	Discussions on the practice of cost benefit analysis and the various views that exist on discounting of very long term effects. Reviewed draft of Chapter 6 and Appendix C, with focus on SCBAs and very long term discounting.
Nägele, A.	Working for DG Move, European Commission.	E-mail communication on availability of European transport statistics (Appendix A).
Platz, T.E.	Professor Transport and Logistics, Baden-Wuerttemberg Cooperative State University Mannheim.	Discussions on recent research related to IWT (Ch. 2), as well as on development of intermodal continental container transport (Ch. 8).
Quist, P.	Head of Advisory Group Port Structures and Waterways at Witteveen+Bos.	Consulted on recent trends in IWT (Ch. 2).
Schmorak, N.	Modelling Expert at Rijkswaterstaat.	In particular discussions on modelling of very long term transport developments (Ch. 11).
Taneja, P.	Lecturer at TU Delft /UNESCO-IHE.	Commented on final draft of Chapter 5.
Tavasszy, L.A.	Professor of Freight Transport and Logistics at TU-Delft, Senior Consultant at TNO.	Various discussions throughout PhD project, that provided valuable insights in the very long term dynamics of the transport systems as well as in transport modelling (Ch. 3, 4, 8, 11, and 12).
Ten Broeke, I.	Rhine Shipping Commissioner, IWT Expert at Rijkswaterstaat.	General discussion on PhD Project, discussion on the importance of the CCRN for the IWT system, and expansion of inland waterways (Ch. 2 and 8).
Te Riele, H.	Transition Expert at Erasmus University Rotterdam.	Discussion on economic growth as a transition process, recommendation to distinguish between mainstream and undercurrent views (Ch. 4).
Turpijn, B.	Senior Advisor, Transport Economics Rijkswaterstaat.	Discussions on economic growth (Ch. 4), applied cost factors (Ch. 10), transport modelling (Ch. 11), and quantification of the Delta Scenarios (Scenario Report feeding into Ch. 13 and 14). Reviewed draft of Chapter 4 on very long term economic trends, as well as parts of Chapter 11 on transport modelling, and background report for Delta Scenarios that feed into Chapter 13 and 14.
Uijtewaal, E.	Transport Economist at Rijkswaterstaat.	Commented on draft Summary Report.
Van Arem, B.,	Professor of Transport Modelling at TU-Delft.	General discussion on PhD project.
Van Dalen, E.	Associate Professor in Policy Analysis at the TU-Delft.	Consulted on the use of system dynamics modelling (Ch. 5).
Van de Voorde, E.	Professor in Transport Economics at the University of Antwerp and the TU-Delft.	General discussion on PhD project. Review of paper with methodology for very long term forecast of port throughput volumes that feeds into Chapter 7.
Van Gelder, P.	Professor of Safety Science (Specialised in Probabilistic Methods) at TU-Delft.	Commented on draft of paper with methodology for very long term forecast of port throughput volumes that feeds into Chapter 7.
Van d. Bosch, J.	Traffic Manager and Spatial Planner at Rijkswaterstaat.	Commented on draft Summary Report.

Van der Staaij, A.	Advisor Corporate Strategy at the Port of Rotterdam Authority.	Commented parts of background report for Delta Scenarios that feed into Chapter 13 and 14, indicated that the scenario quantifications are reasonable and in line with his expectations.
Van der Wekken, T.	Senior Project Manager at Rijkswaterstaat.	Discussion on choices that had to be made for the development of the Shipping Scenarios for the Delta Programme (Ch. 13 and 14).
Van Duijn, J.	Emeritus professor in business economics.	Conversation on my new post neo-classical views on economic growth and future discounting (Ch. 4 and 6).
Veenstra, P.	Expert at Rijkswaterstaat for the region Zuid Holland	Involved in discussion on development of Dutch Delta Scenarios.
Verheij, H.	Sr. Hydraulic Engineer and Waterway Specialist at TU-Delft and Deltares.	Discussions on IWT in general and the effects of climate change in particular (Ch. 9). Reviewed initial and final draft of Chapter 9 on the effects of climate change for IWT.
Verspagen, B.	Professor in Economics of Knowledge and Innovation at the UNU-Merit University and Maastricht University.	Consulted by mail on mainstream neo-classical assumption that western countries move towards an ongoing steady-state exponential growth rate, for which most economists do not actually claim growth to go on forever, but simply ignore to take the ultimate limits into account (Ch. 3 and 4).
Volgers, M.	Senior Transport Economist at Royal HaskoningDHV.	Reflected on initial drafts of Chapter 3 and 4, as well as on paper concerning very long term port throughput forecast that feeds into Chapter 7.
Walker, W.	Professor of Policy Analysis at TU-Delft.	Several discussions on the available methods for dealing with high levels of uncertainty that come with a very long time horizon (Ch. 5). Reviewed the first and final draft of Chapter 5 as well as the draft Summary Report. On the basis of Walker's recommendations major changes to the initial draft of Chapter 5 were made.
Wiegmans, B.	Senior Researcher in Transport and Planning at TU-Delft.	General discussion on PhD project.
Witting, G.	Senior Transport Economist at Rijkswaterstaat.	Discussions on economic growth (Ch. 4), applied policy framework and cost benefit analysis (Ch. 6), as well as future discounting (Appendix C). Reviewed Chapter 6, Appendix C, and the draft Summary Report.
Zhang, M.	Transport Modelling Expert working at TNO and TU-Delft.	Discussions on transport modelling, the outline of the proposed very long term transport model, and the options to develop the proposed model from an existing transport model (Ch. 10, 11, and 12). Reviewed Chapter 10 and commented on parts of Chapter 11 and 12.
Zimmerman, R.J.	Director of Mercurius Shipping Group.	General discussion on results of PhD project and development of IWT.
Zimmerman, R.F.	Founder of Mercurius Shipping Group.	General discussion on results of PhD project and development of IWT. Reviewed Chapter 2 on the general characteristics of the IWT system. Discussion on lifetime of inland barges for which he indicated that one can calculate with a depreciation of 3% per year for new investment projects.
Zondag, B.	Managing Director at Significance.	General discussion on scope of PhD project and the modelling of IWT flows in particular.

F Data Files and Calculation Sheets

For the research in this thesis quite a number of data files and calculation sheets were prepared. I have made most of these files available on the internet and placed them under a single DOI (Data Object Identifier) number, that can be looked up at www.doi.org. The corresponding DOI number is **doi:10.4121/uuid:c9fc8faa-1516-44b2-bc5a-90d4765c580f**.

F.1 Available Data Files and Calculation Sheets

This section provides a list of the provided data files and calculation sheets that can be grouped around a number of topics. Each topic is presented in a separate sub section.

F.1.1 EU transport data

A file with the EU transport data discussed in Appendix A is available under the name:

- 1A Freight Transport in EU-27 (tkm).xls

F.1.2 Very long term transport projections

A number of data files related to the development of the very long term freight transport projections in Chapter 7 is made available. These include:

A file with the calculation of the Population and GDP estimate:

- 2A Population and GDP Assumptions.xls

A file with the ex-post forecast for Equations 7-1 to 7-3:

- 2B Ex-Post Forecast LHR.xls

A few files with the probabilistic projections for the port throughput volumes in the LHR:

- 2C Forecast LHR based on Levels Equation.xls
- 2D Forecast LHR based on Differences Equation.xls
- 2E Forecast LHR based on Combined Results.xls

A few files with the probabilistic projections for the inland transport volumes in the Region:

- 2F Forecast ITV based on Levels Equation.xls
- 2G Forecast ITV based on Differences Equation.xls
- 2H Forecast ITV based on Combined Results.xls

A few files with the probabilistic projections for short sea shipping volumes in the Region:

- 2I Forecast SSS based on Levels Equation.xls
- 2J Forecast SSS based on Differences Equation.xls

- 2K Forecast SSS based on Combined Results.xls

And a file with the combined forecast for the overall transport demand in the Region:

- 2L Combined Forecast for Overall Transport Demand.xls.

The proper reading of the files requires the add-on @Risk to be installed on the computer.

F.1.3 Climate Change

A file that contains the calculations regarding the Effects of Climate Change for IWT is made available under the name:

- 3A Calculation of the Effects of Climate Change on IWT.xls

F.1.4 Intermodal Transport Costs

A number of files that contain the models for the comparison of the intermodal transport costs (as well as the fuel consumption of inland barges) is made available in the files:

- 4A Barge Power Prediction Model.xls
- 4B Intermodal Cost Model for Continental Transport.xls
- 4C Calculations on Canal Seine - Nord Europe.xls

F.1.5 Converted Base Year 2004 Data Files

The converted base year 2004 data files are made available under the names:

- 5A Converted Year 2004 GL Data.xls
- 5B Converted Year 2004 PL Data.xls
- 5C Converted Year 2004 PLTKM Data.xls
- 5D Converted Year 2004 Road 300+ PL Data.xls

F.1.6 Quantification of Delta Scenarios

The file that contains the calculations for the quantification of the Delta Scenarios is made available under the following name:

- 6A Quantification of the Delta Scenarios.xls

F.2 Disclaimer

These file are made available to enable verification of the research work on the "Very Long Term development of the Dutch Inland Waterway Transport System". Though it may suit other needs it is not intended for other purposes. Where it concerns the use of the files presented in this appendix, it should be emphasised that, though I have compiled them with utmost care and diligence, nobody cannot be held directly or indirectly liable for the adequacy, completeness, and accuracy of the presented models, the presented data, the assumptions on which the models are based, and the results that are obtained from the models. All users of these files are advised to verify and control the applied assumptions, calculations, and results before a decision on the basis of this data is taken.

Summary

Infrastructures are essential to the well-functioning of modern economies, but once in place they are hard to change due to their high capital intensity and very long technical lifetime. Rijkswaterstaat, the agency within the Ministry of Infrastructure and Environment that is amongst others responsible for the construction, management, and maintenance of hydraulic structures on the main waterway system in the Netherlands, desires to prepare integrated very long term infrastructure development strategies that consider the necessary replacements of hydraulic structures as an opportunity to improve the infrastructure network at the systems level. Scientific methods for the evaluation of such strategies are however not yet available and still need to be developed.

This thesis provides the *'building blocks'* for a new policy evaluation method that enables the evaluation of such very long term strategies. The research examines how Rijkswaterstaat can develop a workable method for taking the very long term development of at least one subsystem of the Dutch waterway system into account, namely the inland waterway transport (IWT) system. In line with this objective the following Main Research Question was applied.

Main Research Question

- How can Rijkswaterstaat develop a workable method for taking the very long term development of the Dutch Inland Waterway Transport (IWT) system into account in the evaluation of integrated infrastructure development strategies with a very long term impact?

The development of this policy evaluation method does not only require a clear framework for the evaluation of policies with a very long term impact, but also: (1) insight in the external drivers that act on the Dutch IWT system; (2) methods and models to define the effects of external developments and proposed infrastructure policies on the very long term development of the Dutch IWT system; and (3) a plausible set of scenarios that envision the very long term development of the Dutch IWT system up to the year 2100.

In principle there is not much difference between the framework that can be applied for the evaluation of policies with a long term- and a very long term impact. In both cases one can apply the XPIROV policy framework, that defines the effects of proposed policies (P) and external developments (X) on the system domain (I&R) in order to evaluate the outcomes of interest (O) and value the effects (V). The only difference between the use of this policy framework for the evaluation of very long term instead of long term policy effects is that

different methods are required to define the external developments, model the system, and value the effects.

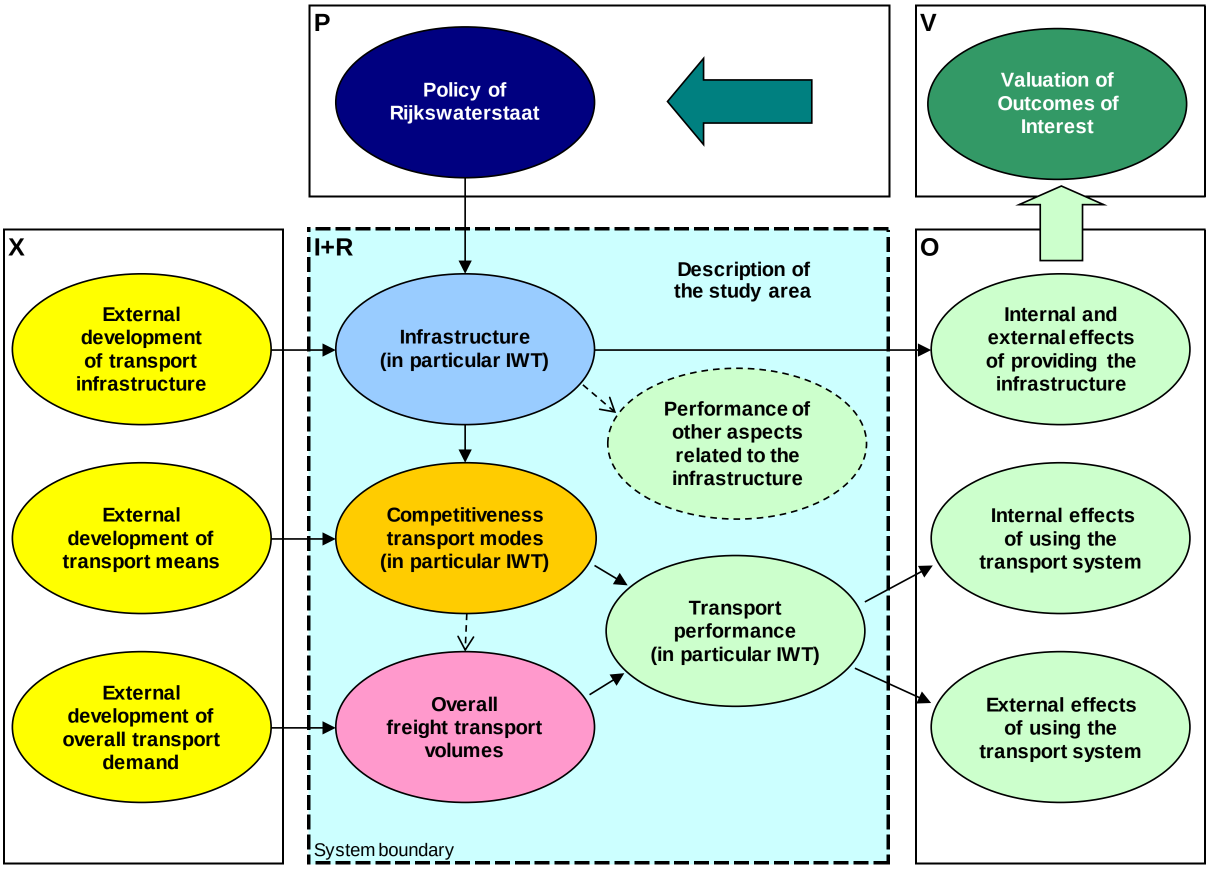


Figure S-1: Framework for Policies that affect the IWT System

Figure S-1 shows the proposed XPIROV framework for the evaluation of policies that affect the further development of the IWT system. The external developments (X) are related to the transport infrastructure, transport means, and transport demand. The development of new transport infrastructures is related to the pervasive drivers of the about 50 years lasting economic Kondratieff waves, that presently undergo a shift from the 'globalisation' driver towards the 'sustainability' driver. The quality and competitiveness of the more sustainable transport networks, such as the rail and IWT network as well as the intermodal transport network, are related to the societal aim to become sustainable. The more sustainable our society becomes, the more competitive these networks will be. Climate change affects the quality of the inland waterways. The effects of climate change can either be very small or very severe depending on the applied scenario. In the most adverse scenario the river Rhine will no longer remain all year round navigable in the second half of the century, unless far reaching mitigation measures are taken such as canalisation. The competitiveness of the IWT network is further affected by the development of the transport means as well as by their cost structure. The effects of major changes to the primary cost drivers (e.g. labour, energy, and capital) on the modal share of IWT are expected to be rather small for bulk cargoes, but can be all determining in case of intermodal barge transport, in particular when it concerns the potential development of intermodal continental container and pallet transport by barge. The overall transport demand is closely linked to the development of the economy. It is expected to keep growing throughout the first half of the century, after which it may either continue to grow, stabilise or decrease in the second half of the century.

The system domain (I&R) contains the modelling heart of the policy framework. The modelling of very long term transport flows at the network level requires a different approach than the approach that is currently applied in long term transport forecast models, because it is impossible to prepare sensible forecasts for detailed aspects up to the year 2100. This thesis proposes a new hybrid model structure in which the strengths of the aggregated foresight and detailed forecasting methods are combined by projecting aggregated very long term trends onto the intermediate results of a classical four stage transport model. The implementation of this very long term transport model is however complicated by a number of factors that still require a substantial amount of research and modelling efforts. For this reason the research on the proposed transport model concludes with a comprehensive research agenda.

The proposed very long term transport model would have been ideal for the quantification of a set of very long term IWT scenarios at the network level, but in absence of such a model a different approach had to be sought. It still turned out possible to prepare an aggregated set of very long term scenarios for the development of Dutch port throughput- and IWT volumes up to the year 2100. These scenarios were not only prepared for this thesis, but also contributed to the Dutch Delta Scenarios for which they provide the shipping section.

The Dutch guidelines for valuing (V) policy relevant outcomes of interest (O) prescribe a Social Cost Benefit Analysis (SCBA). When conducting a SCBA all relevant effects need to be expressed in monetary units (e.g. in Euros at constant price levels). Once the effects are defined in monetary units they ought to be discounted in order to take time preferences into account. There does however seem to be an issue with the current practice of discounting very long term effects, as the presently prescribed fixed discount rates imply that very long and ultra-long long term effects become virtually negligible. As a consequence almost no weight is given to sustainable policies that aim for very long term benefits.

The issue with the applied very long term discount rates turns out to be related to another issue that is extensively addressed throughout this thesis, namely the issue that there seems to be something wrong with the mainstream neo-classical paradigm on economic growth that assumes labour productivity and economic output to keep growing at an exponential rate without considering any physical limits to the development of new technologies. In the 1970s the growth of labour productivity was still considered to be related to an about 400 years lasting transition S-curve that started at the beginning of the Industrial Revolution some 200 years ago. However, in the 1980s economists developed the (first generation of) endogenous growth models, that assume constant returns to scale in the knowledge creation domain and no longer consider the growth of labour productivity and economic output to be constrained by physical limits. In line with these models the unfounded belief that the economies of advanced nations are slowly moving towards a fixed equilibrium growth rate on the very long term became the mainstream view. As a result virtually all official long- and very long term scenarios are now developed in line with the paradigm of ongoing exponential growth, but there are serious reasons to question this paradigm.

First of all, some economists that endorse the view that there are physical limits to the growth of labour productivity point out that the primary drivers of economic growth since the beginning of the industrial revolution are gradually losing their effect in the western world – and economists that belong to a relatively new conceptually distinct field of ecological economics make clear that the exceptional growth rates over the past century were a result of the ample availability of fossil fuels and other non-renewable resources for which the relatively easily exploitable mining areas are gradually becoming depleted. Even more important is the fact that economists in the field of endogenous growth modelling have already concluded some 20 years ago that the assumption of constant returns to scale in the knowledge creation function is not in line with empirical observations and needs to be replaced by a diminishing growth function. In response they have developed a second generation of endogenous growth models (that are known as the semi-endogenous growth models) for which the mathematical description complies with the physical view that the economy follows some kind of very long term transition S-curve. On top of that some economist have recently started to discuss the possibility that western economies are drawn into a Secular Stagnation. It is therefore remarkable that the mainstream view still takes exponential growth for granted.

This thesis provides ten arguments why the historical shift towards the exponential growth paradigm is considered a mistake that needs to be corrected to obtain realistic very long term economic (GDP) projections. In order to correct this mistake the use of a 'new' post-neo-classical (physical/semi-endogenous) economic growth paradigm is proposed that departs from the same neo-classical Solow model, but imposes one additional restriction namely that the state-of-the-art labour productivity in technological frontier countries is ultimately constrained by physical limits and therefore follows some kind of S-shaped transition curve that moves towards a still unknown (and unpredictable) horizontal asymptote on the very long term (say a few hundred to a thousand years from now). To show the relevance of this issue the difference between the two economic growth paradigms is indicated in Figure S-2.

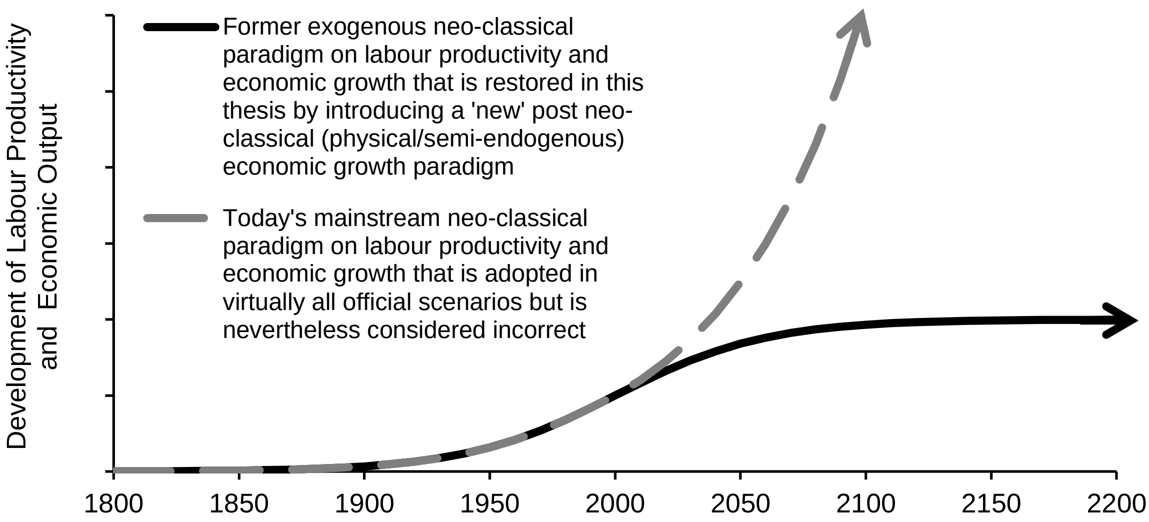


Figure S-2: Different views on Economic Growth

The transport projections and scenarios in this thesis are prepared in line with the post-neo-classical paradigm on economic growth. This choice had major consequences for the quantification of the transport scenarios, as the use of the mainstream neo-classical economic growth projections (such as those of the CPB) would have resulted in 25% to 50% higher projections for the year 2050 and in 2 to 3 times higher projections for the year 2100. However, the choice to adopt the post-neo-classical paradigm has no effect on the methodology that is developed in this thesis.

An equally important implication of using the post-neo-classical economic growth paradigm is that the risk free and social discount rates (as applied in future discounting) are bound to go down to zero on the ultra-long term. As a result one should apply much lower discount rates when discounting very- and ultra-long term effects, which is of particular importance when it concerns irreversible negative external effects. This thesis therefore suggests an alternative discount scheme that can for instance be used to address the sensitivity of a social cost benefit analysis to the applied discount rates.

On the basis of this thesis one can conclude that it should be possible to take the very long term effects of proposed policies and external developments on the Dutch IWT system into account in the policy making process of Rijkswaterstaat by implementing the so called XPIROV framework – but that still a considerable amount of research and modelling efforts will be required to obtain a workable very long term transport model. In addition it is argued that a different perspective on economic growth and future discounting is required to obtain realistic projections and develop sensible policies for issues with a very long term impact.

In line with this conclusion Rijkswaterstaat is recommended to continue the research on the development of a workable method for taking the very long term effects of proposed policies and external developments into account in the evaluation of policies with a very long term impact on the Dutch IWT system, for which the development of a very long term transport model has the highest priority. In addition economists, scenario developers, policy makers, and researchers doing policy relevant research are advised not to base their very long term GDP scenarios and future discount rates on the unfounded assumption of constant returns to scale in the knowledge creation domain (which is related to the assumption of ongoing exponential economic growth), as this assumption has already been rejected by the modern semi-endogenous economic growth theory some 20 years ago.

Samenvatting

Infrastructuur is essentieel voor het goed functioneren van moderne economieën, maar eenmaal geconstrueerd is het gezien de hoge investeringen en zeer lange levensduur moeilijk deze nog aan te passen. Rijkswaterstaat, de uitvoeringsinstantie van het Ministerie van Infrastructuur en Milieu die onder andere verantwoordelijk is voor het aanleggen, beheren en onderhouden van de natte infrastructuur op het Nederlandse Hoofdwatersysteem, beoogt daarom integrale zeer lange termijn ontwikkelstrategieën te ontwikkelen die de noodzakelijke vervanging van natte kunstwerken als een kans zien om het infrastructuurnetwerk op systeemniveau te verbeteren. Wetenschappelijke methoden voor de evaluatie van zulke strategieën zijn echter nog niet beschikbaar en moeten nog worden ontwikkeld.

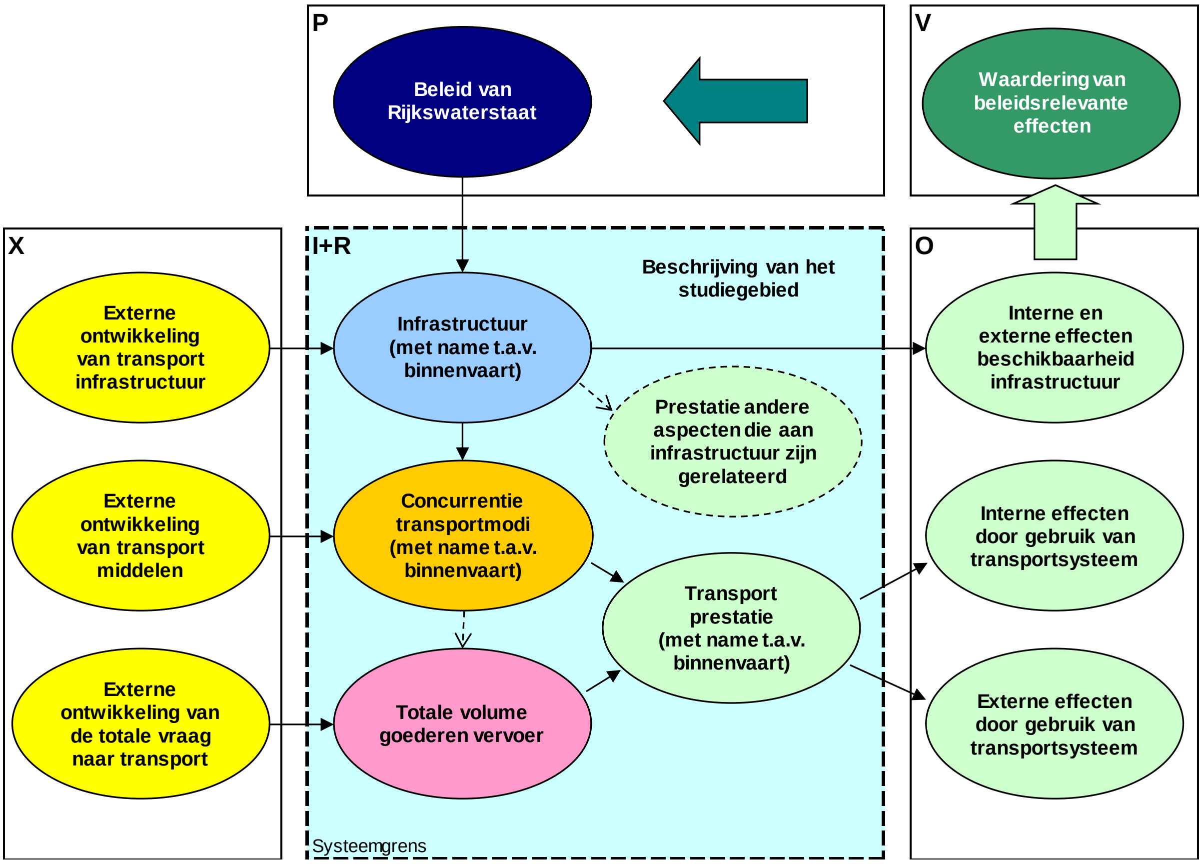
Dit proefschrift levert de *'bouwstenen'* voor een nieuwe beoordelingsmethode die de evaluatie van zeer lange termijn strategieën mogelijk maakt. Het onderzoek gaat na hoe Rijkswaterstaat een werkbare methode kan ontwikkelen om de zeer lange termijn ontwikkeling van tenminste één deelsysteem van het watersysteem te kunnen beoordelen, namelijk die van het binnenvaart transportsysteem. Hierbij is de volgende centrale onderzoeksvraag gehanteerd.

Centrale Onderzoeksvraag

- Hoe kan Rijkswaterstaat een werkbare methode ontwikkelen waarmee de zeer lange termijn ontwikkeling van het Nederlandse binnenvaart transportsysteem meegenomen kan worden in de beoordeling van integrale infrastructuur ontwikkel-strategieën met een zeer lange termijn impact?

De ontwikkeling van deze beleidsevaluatiemethode vereist niet alleen een helder raamwerk voor de beoordeling van beleidsopties met een zeer lange termijn impact, maar tevens: (1) inzicht in de externe drijfveren die invloed hebben op het binnenvaart transportsysteem; (2) methoden en modellen om de effecten van externe ontwikkelingen en mogelijke beleidsopties op de zeer lange termijn ontwikkeling van het binnenvaart transportsysteem te bepalen; en (3) een aantal plausibele scenario's die een beeld schetsen van de zeer lange termijn ontwikkeling van het binnenvaart transportsysteem tot in het jaar 2100.

In principe is er niet veel verschil tussen het raamwerk dat kan worden gehanteerd voor de evaluatie van beleid met een lange- en een zeer lange termijn impact. In beide gevallen kan het XPIROV raamwerk gebruikt worden, dat de effecten van voorgestelde beleidsopties (P) en externe ontwikkelingen (X) op het systeemdomein (I&R) inzichtelijk maakt ten einde de beleidsrelevante effecten (O) te kunnen waarderen (V). Het enige verschil tussen het gebruik van dit beleidsraamwerk voor de evaluatie van zeer lange termijn in plaats van lange termijn effecten is dat andere methoden vereist zijn om de externe ontwikkelingen te bepalen, het systeem te modelleren en een waarde toe te kennen aan de effecten.



Figuur S-1: Raamwerk voor beleid met invloed op het binnenvaart transportsysteem

Figuur S-1 toont het voorgestelde XPIROV raamwerk voor de beoordeling van beleid dat van invloed is op de verdere ontwikkeling van het binnenvaart transportsysteem. De externe ontwikkelingen (X) hebben betrekking op de transportinfrastructuur, de transportmiddelen, en de transportvraag. De ontwikkeling van nieuwe transportinfrastructuur is gerelateerd aan de diepgewortelde drijfveren van de ongeveer 50 jaar durende economische Kondratieff golven, die thans een verschuiving ondergaan van 'globalisatie' naar 'duurzaamheid'. De kwaliteit en het concurrentievermogen van de meer duurzame transportnetwerken, zoals die van het spoor- en het binnenvaart transportnetwerk alsmede die van het intermodale transportnetwerk, zijn gerelateerd aan de maatschappelijke drang tot verduurzaming. Hoe duurzamer onze maatschappij wordt, hoe concurrerender deze netwerken zullen zijn. Klimaatverandering beïnvloedt de kwaliteit van de waterwegen. De effecten van klimaatverandering kunnen afhankelijk van het scenario uiterst gering of uiterst fors uitpakken. In het minst gunstige scenario blijft de rivier de Rijn in de tweede helft van de eeuw niet langer het hele jaar door bevaarbaar, tenzij verstrekkende maatregelen worden genomen zoals kanalisatie. Het concurrerend vermogen van de binnenvaart wordt verder beïnvloed door de ontwikkeling van de transportmiddelen alsmede hun kostenstructuur. Het effect van grote veranderingen in de primaire kostenfactoren (zoals arbeid, energie en kapitaal) op het marktaandeel van de binnenvaart is naar verwachting tamelijk beperkt bij het vervoer van bulk goederen, maar kan allesbepalend zijn voor het intermodale binnenvaartvervoer, vooral wanneer het de mogelijke ontwikkeling van continentaal container en palletvervoer per schip betreft. De totale transportvraag is sterk gerelateerd aan de ontwikkeling van de economie. Naar verwachting zal de transportvraag in de eerste helft van de eeuw blijven groeien, waarna er in de tweede helft van de eeuw een verdere groei, stabilisatie, of daling optreedt.

Het systeemdomein (I&R) bevat het transportmodel waarop het beleidsraamwerk draait. Het op netwerkniveau modelleren van zeer lange termijn transportstromen vereist een andere aanpak dan de aanpak die thans in lange termijn transportmodellen wordt gehanteerd, omdat het onmogelijk is om betekenisvolle ramingen te maken voor gedetailleerde aspecten tot aan het jaar 2100. Dit proefschrift stelt een nieuwe hybride modelstructuur voor waarin de sterke kanten van de geaggregeerde 'foresight' en gedetailleerde 'forecasting' methoden worden gecombineerd door geaggregeerde zeer lange termijn trends te projecteren op de tussentijdse resultaten van een klassiek vier-stappen transportmodel. De implementatie van dit zeer lange termijn transportmodel wordt echter bemoeilijkt door een aantal factoren die nog steeds een zeer substantiële onderzoeks- en modelleeropgave vereisen. Daarom besluit de discussie ten aanzien van het beoogde transportmodel met een uitgebreide onderzoeksagenda.

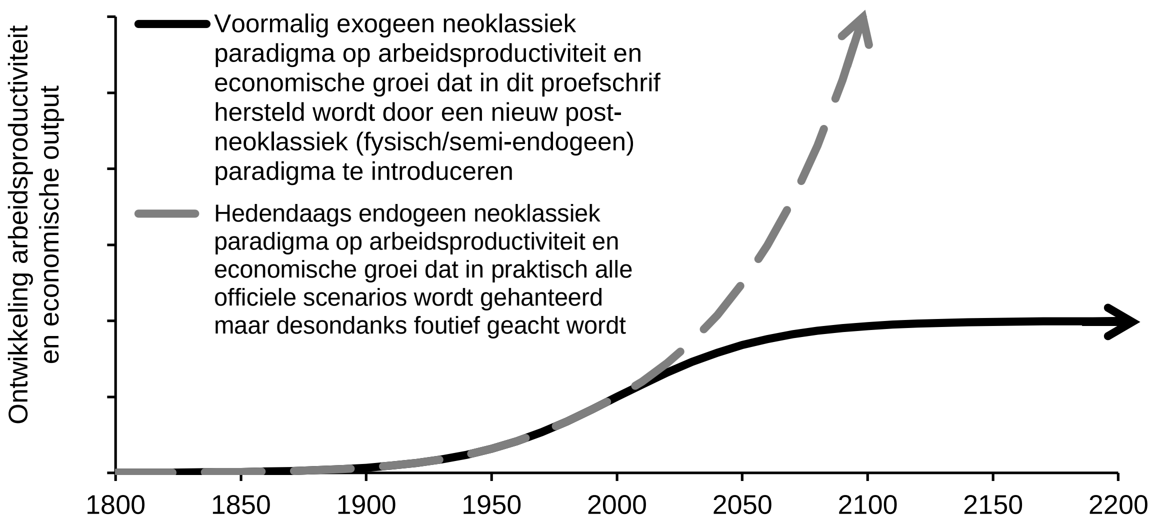
Het beoogde transportmodel zou ideaal geweest zijn voor het kwantificeren van enkele zeer lange termijn scenario's die het binnenvaarttransport op netwerkniveau beschrijven, maar in afwezigheid van een dergelijk model moest een alternatieve benadering worden gezocht. Het bleek nog steeds mogelijk om enkele geaggregeerde scenario's voor de zeer lange termijn ontwikkeling van de overslag in de Nederlandse zeehavens alsmede het transport op de Nederlandse binnenwateren tot aan het jaar 2100 op te stellen. Deze scenario's werden niet alleen in het kader van dit proefschrift opgesteld, maar hebben tevens ook bijgedragen aan de ontwikkeling van de Nederlandse Delta Scenario's waarvoor zij de scheepvaartsectie aanleveren.

De Nederlandse richtlijnen voor het beoordelen (V) van beleidsrelevante uitkomsten (O) schrijven een sociale kostenbaten analyse (SKBA) voor. Bij een SKBA dienen alle effecten in geldwaarden te worden uitgedrukt (b.v. in Euro's tegen constante prijzen). Eenmaal in geldwaarden uitgedrukt dienen ze te worden verdisconteerd om de waarde van tijd in de analyse mee te nemen. Er lijkt echter een probleem te zijn met de huidige wijze waarop zeer lange termijn effecten worden verdisconteerd, aangezien de thans voorgeschreven vaste discontovoeten impliceren dat alle zeer lange- en ultra-lange termijn effecten er vrijwel niet meer toe doen. Dit heeft tot gevolg dat er praktisch geen waarde wordt toegekend aan duurzame beleidsopties die streven naar voordelen op de zeer lange termijn.

Het probleem met de huidige zeer lange termijn discontovoeten blijkt gerelateerd te zijn aan een ander belangrijk probleem dat uitvoerig behandeld wordt in deze studie. Er lijkt namelijk iets mis te zijn met het thans gangbare neoklassieke economische groei paradigma dat een aanhoudende exponentiële groei van de arbeidsproductiviteit en de economische productie veronderstelt zonder daarbij rekening te houden met enige fysische beperkingen ten aanzien van de ontwikkeling van nieuwe technologieën. In de jaren 1970 werd de groei van arbeidsproductiviteit nog gerelateerd aan een ongeveer 400 jaar durende transitie S-curve die gelijktijdig met het begin van de Industriële Revolutie zo'n 200 jaar geleden aanving. Echter, in de jaren 1980 ontwikkelden economen de zogenaamde (eerste generatie) endogene groeimodellen, die uitgaan van constante meeropbrengsten in het domein van kennisontwikkeling en geen fysische beperkingen meer onderkennen ten aanzien van de groei van de arbeidsproductiviteit en de economische productie. In overeenstemming met deze modellen is de ongefundeerde opvatting dat economieën van ontwikkelde landen op de zeer lange termijn toegroeien naar een vaste evenwichtsgroeivoet gangbaar geworden. Dientengevolge zijn vrijwel alle officiële lange- en zeer lange termijn scenario's gebaseerd op het thans gangbare paradigma van aanhoudende exponentiële groei, maar er zijn zwaarwichtige redenen om te twijfelen aan de juistheid van dit paradigma.

Allereerst wijzen enkele economen die de grenzen aan de groei van arbeidsproductiviteit wel onderschrijven er op dat de voornaamste drijfveren voor de groei van de economie sinds het begin van de Industriële Revolutie gaandeweg hun effect verliezen in de westerse wereld – en daarnaast maken economen die behoren tot de relatief nieuwe wat alternatieve stroming van de ecologische economie duidelijk dat de exceptionele groeivoeten van de vorige eeuw volgden uit de ruime beschikbaarheid van fossiele brandstoffen en andere niet-hernieuwbare grondstoffen terwijl de relatief eenvoudig winbare bronnen nu geleidelijk aan uitgeput beginnen te raken. Nog belangrijker is echter het feit dat hedendaagse economen die zich bezig houden met het modelleren van endogene groei al zo'n 20 jaar geleden geconcludeerd hebben dat de aanname van constante meeropbrengsten in het domein van kennisontwikkeling niet overeenstemt met de empirische werkelijkheid en vervangen dient te worden door de aanname van afnemende meeropbrengsten. In navolging daarop is een tweede generatie endogene groeimodellen ontwikkeld die bekend staan als de semi-endogene groeimodellen. De mathematische beschrijving van deze modellen stemt overeen met de fysische opvatting dat de economie één of andere zeer lange termijn transitie S-curve doorloopt. Daarnaast is er onder sommige economen recentelijk een discussie uitgebroken over de vraag of westerse economieën al dan niet in een Seculaire Stagnatie terecht gekomen zijn. Het is daarom opmerkelijk dat de gangbare zienswijze nog steeds uit gaat van exponentiële groei.

Dit proefschrift verstrekt tien argumenten waarom de verschuiving naar het exponentiële groei paradigma een historische fout is die rechtgezet zal moeten worden teneinde realistische economische (BNP) ramingen te kunnen verkrijgen. Om deze historische fout te herstellen wordt voorgesteld een 'nieuw' post-neoklassiek (fysisch/semi-endogeen) economisch groei paradigma te hanteren dat gestoeld is op hetzelfde neoklassieke Solow model, maar de expliciete restrictie oplegt dat de 'state-of-the-art' arbeidsproductiviteit in technologisch ontwikkelde landen aan fysische grenzen gebonden is en derhalve een S-vormige transitiecurve doorloopt die op zeer lange termijn (zeg over een paar honderd tot duizend jaar) toe zal groeien naar een vooralsnog onbekende (en vooralsnog niet te ramen) horizontale asymptoot. Om de relevantie van dit probleem inzichtelijk te maken is het verschil tussen beide economische groeiparadigma's weergegeven in figuur S-2.



Figuur S-2: Verschillende opvattingen over economische groei

De in dit proefschrift opgestelde transportramingen en scenario's zijn in lijn met het post-neoklassieke economische groei-paradigma ontwikkeld. Deze keuze heeft grote gevolgen gehad voor de kwantificering van de transportscenario's, aangezien het gebruik van de gangbare neoklassieke economische groeiramingen (zoals die van het CPB) geresulteerd had in 25% tot 50% hogere transportramingen voor het jaar 2050 en in 2 tot 3 maal hogere transportramingen voor het jaar 2100. De keuze om het post-neoklassieke groeiparadigma te hanteren heeft echter geen effect gehad op de in dit proefschrift ontwikkelde methodologie.

Een evenzo belangrijke implicatie van het hanteren van het post-neoklassieke economische groei paradigma is dat de risicovrije en sociale discontovoeten (die gehanteerd worden bij het verdisconteren van tijd) op de ultra-lange termijn naar nul moeten gaan. Als gevolg hiervan zal men veel lagere discontovoeten moeten gaan hanteren voor het verdisconteren van zeer lange en ultra-lange termijn effecten, hetgeen vooral van belang is wanneer het onomkeerbare negatieve externe effecten betreft. Dit proefschrift stelt daarom een alternatief discontoschema voor dat onder andere gebruikt kan worden om de gevoeligheid van een sociale kosten baten analyse ten aanzien van de gehanteerde discontovoeten inzichtelijk te maken.

Op basis van dit proefschrift kan worden geconcludeerd dat het mogelijk moet zijn om de zeer lange termijn effecten van voorgestelde beleidsopties en externe ontwikkelingen ten aanzien van het Nederlandse binnenvaart transportsysteem in de beleidsprocessen van Rijkswaterstaat mee te nemen door het zogenaamde XPIROV raamwerk te implementeren – maar dat er nog steeds een aanzienlijke onderzoeks- en modelleerinspanning vereist is alvorens een werkbaar zeer lange termijn transportmodel kan worden verkregen. Daarnaast wordt er beargumenteerd dat een andere visie op economische groei en het verdisconteren van tijd vereist is om realistische ramingen te verkrijgen en zinvol beleid op te kunnen stellen voor zaken met een zeer lange termijn impact.

Als zodanig wordt Rijkswaterstaat aanbevolen om door te gaan met het onderzoek naar de ontwikkeling van een werkbare methode waarmee de zeer lange termijn effecten van voorgestelde beleidsopties en externe ontwikkelingen meegenomen kunnen worden in de beoordeling van beleidsopties met een zeer lange termijn impact op het binnenvaart transportsysteem. De ontwikkeling van een zeer lange termijn transportmodel heeft daarbij de hoogste prioriteit. Verder wordt economen, scenario ontwikkelaars, beleidsmakers en onderzoekers die zich bezig houden met beleidsrelevante vraagstukken aangeraden om zeer lange termijn scenario's en discontovoeten niet langer te baseren op de ongegronde veronderstelling van constante meeropbrengsten in het domein van kennisontwikkeling (die verwant is aan de veronderstelling van aanhoudende exponentiële economische groei), aangezien deze veronderstelling al zo'n 20 jaar geleden verworpen is in de moderne semi-endogene economische groeitheorie.

About the Author

Cornelis van Dorsser was born in Amersfoort, The Netherlands, on 8th October 1977. He studied at two universities simultaneously. In 2004 he graduated at the Erasmus University Rotterdam as an Economist specialised in the field of transport economy and logistics. In 2005 he graduated at the Technical University Delft as a Naval Architect specialised in the field of shipping. During his graduation period he worked for Vos Logistics (a trucking company) and the Mercurius Shipping Group (an inland shipping company). In 2005 he joined Royal Haskoning where he worked as a port consultant, transport economist, and inland waterway transport specialist on many interesting port development and IWT projects all over the world, such as in: Nigeria, Gambia, Guinea, Egypt, Israel, Jordan, Trinidad, and Costa-Rica. In these projects he was mainly responsible for parts of the forecasting, master planning, as well as the financial- and economic evaluation stage.

In 2009 he started this part time PhD project at the Technical University of Delft on the Very Long Term Development of the Dutch Inland Waterway Transport System up to the year 2100, while at the same time he remained working at Royal Haskoning for two days a week. In 2011 he left Royal Haskoning and re-joined the Mercurius Shipping Group where he now works two days per week as a research and business developer and strategic adviser to the management. In this new function he is amongst others responsible for: expanding the services of two innovative inland container crane barges, as well as other services provided by the in-house barge operator MCT Lucassen; keeping up with new developments in the IWT sector; and providing input to the overall strategy of the group.

In the course of his PhD project he amongst others wrote a paper on *"A Very Long Term Forecast of the Port Throughput in the Le Havre – Hamburg Range up to 2100"*, as well as the background report on which the shipping section of the Dutch Delta Scenarios is based.

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Summary

This thesis addresses how a new method for the evaluation of policies with a very long term impact on the Dutch Inland Waterway Transport (IWT) system can be developed. It proposes an outline for a very long term transport model, prepares a number of very long term scenarios, and indicates that a different perspective on economic growth and future discounting is required to obtain realistic projections and develop sensible policies for issues with a very long term impact.

About the Author

Cornelis van Dorsser studied Economics at the Erasmus University Rotterdam and Maritime Technology at the Delft University of Technology. He graduated on two highly innovative IWT projects and gained substantial working experience as a Port Consultant, Transport Economist, and IWT Specialist.

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