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

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Extended Summary Report

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Acknowledgements

Content

Executive Summary

This report contains an extended summary of my PhD thesis on the Very Long Term development of the Dutch Inland Waterway Transport (IWT) System up to the year 2100. It explores the options to create a consistent very long term view on the development of the IWT system, in order to improve the evaluation of infrastructure policies with a very long term impact on the IWT system.

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 study 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 shows the proposed XPIROV framework for the evaluation of policies that affect the further development of the IWT system.
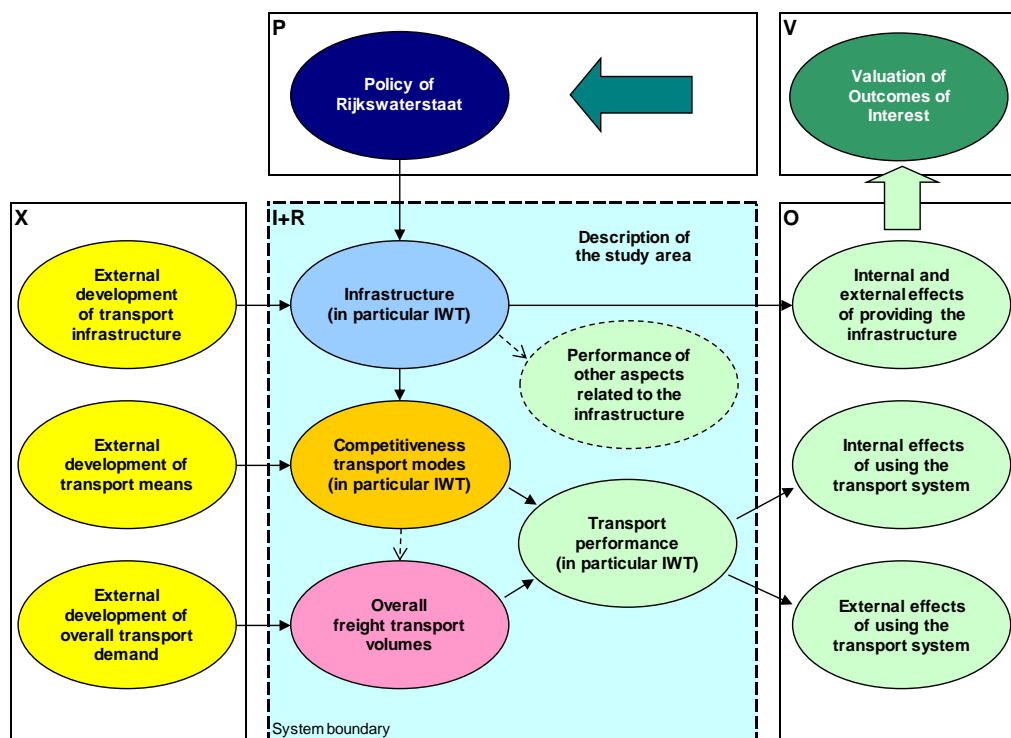
Figure S-1: Framework for Policies that affect the IWT System

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 study 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 PhD study, 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 study, 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 study 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.
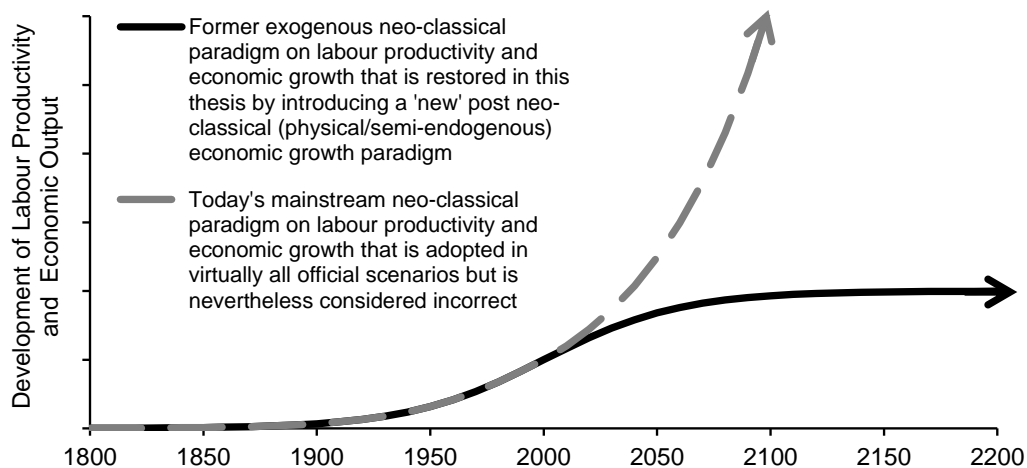
Figure S-2: Different views on Economic Growth

The transport projections and scenarios in this study 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 study.

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 study 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.

Main Conclusions and Recommendations

On the basis of this study 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 (that 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.

Management Samenvatting

Dit rapport bevat een uitgebreide samenvatting van mijn proefschrift over de zeer lange termijn ontwikkeling van het Nederlandse binnenvaart transportsysteem tot in het jaar 2100. Het verkent de mogelijkheden om een consistente zeer lange termijn visie ten aanzien van de ontwikkeling van het binnenvaart transportsysteem te ontwikkelen, ten einde de evaluatie van infrastructuur beleid met een zeer lange termijn impact op het binnenvaart transportsysteem te verbeteren.

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 onderzoek 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 ontwikkelstrategieën 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

toont het voorgestelde XPIROV raamwerk voor de beoordeling van beleid dat van invloed is op de verdere ontwikkeling van het binnenvaart transportsysteem.
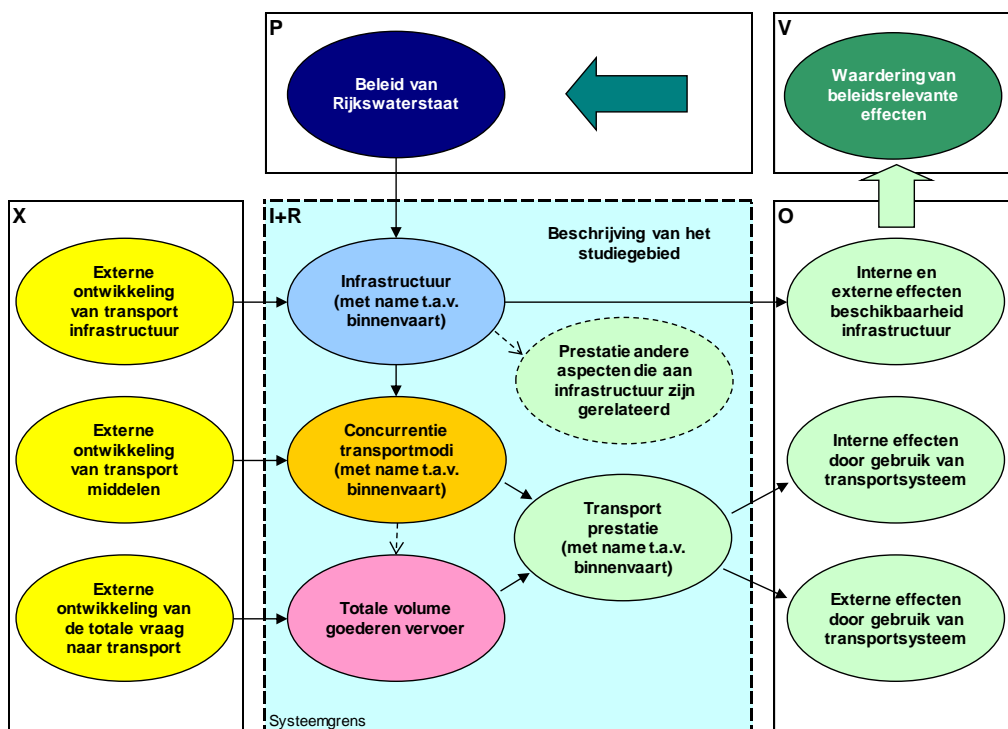
Figuur S-1: Beleidsraamwerk voor het binnenvaart transportsysteem

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 onderzoek 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 onderzoek 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 de 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.

Deze studie geeft 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.

De in deze studie 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 deze studie ontwikkelde methodologie.
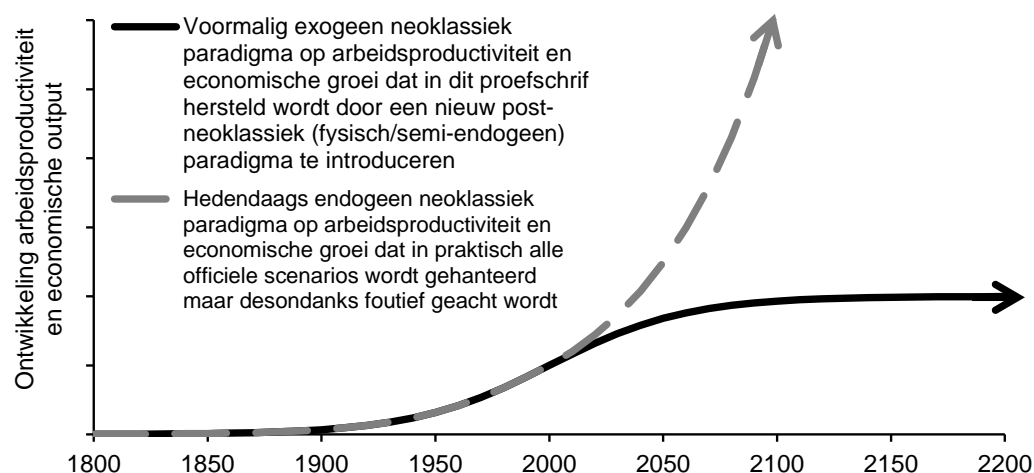
Figuur S-2: Verschillende opvattingen over economische groei

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. Deze studie 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.

Voornaamste conclusies en aanbevelingen

Op basis van deze studie 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.

1   Introduction

This report provides an extended summary of my PhD study on the very long term development of the Dutch inland waterway transport (IWT) system up to the year 2100. Unlike the title suggests, I do not possess the knowledge of what will be happening at such a rather long time horizon. There is no such thing as a *'crystal ball'* and pure knowledge of the future cannot be obtained, but the development of well thought infrastructure policies with a very long term impact on the system does require a very long term view. This study explores the options to create a consistent very long term view on the possible development of the IWT system. The obtained results are intended to improve the evaluation of infrastructure policies with a very long term impact.

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. 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 waterway system. This study 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. It aims to investigate how Rijkswaterstaat can 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 development strategies with a very long term impact[1]. In line with this objective the following research question was defined.

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[1] The choice for this sub-system does not imply that other sub-systems are irrelevant, but the scope of the study had to be reduced to keep it manageable.

> **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?

1.1 Preliminary Research

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 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 study therefore starts to address four general sub questions that contribute to the development of these 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?

GSQ1 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. 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. 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. GSQ 4 finally 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.

1.2 Main Research

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 research project. This study therefore concludes with a provisional answer to the Main Research Question on the basis of the joint answers to the six Methodological Sub Questions.

The four general sub questions are discussed in Chapter 2 to 5. Chapter 6 to 14 continue with a discussion of the six methodological sub-questions. Chapter 15 concludes with the answer to the mean research question. The recommendations to Rijkswaterstaat and others are made in Chapter 16.

1.3 Secondary Objectives

The primary objective of this study 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 study 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 study, 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, for which I prepared six scenarios (see Van Dorsser, 2012), of which four of them are now fully adopted in the official Delta Scenario report of Bruggeman et al. (2013).

The first additional research objective is addressed in the reflection sections of Chapter 3, 4, 6, and 14; the probabilistic GDP projection of Chapter 7; and the conclusion section on this subject in Chapter 15. The second additional research objective, concerning the development of the Shipping Scenarios for the Dutch Delta Programme, is discussed in Chapter 13 and 14.

2 The Inland Waterway Transport System

This chapter addresses the first general sub-question (GSQ 1) *"Concerning the Dutch and West European IWT System"*, that consists of four sub-questions. Each of these four sub-questions is discussed in a separate section.

2.1 Importance of IWT in the overall freight transport system

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?".*

In response to sub-question 1a it can be concluded 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 19th 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 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.

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.

2.2 Historical development and present characteristics of the IWT system

Sub-question 1b: *"How has the historical development of the IWT infrastructure and barge fleet affected the present characteristics of the IWT system?"*.

In response to sub-question 1b it can be concluded 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.

2.3 Effects of present IWT policies on the development of the IWT system

Sub-question 1c: *"What are the present IWT policies and how can they be expected to effect the future development of the IWT system?"*.

In response to sub-question 1c it can be concluded 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 the future of IWT. Example 1: *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*. Example 2: *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*.

2.4 Interaction of the IWT with other user functions of the water system

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?"*.

In response to sub-question 1d it can be concluded 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.

2.5 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.

3 Learning From Long Term Transport Studies

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 input data.

3.1 Answer to the general sub question

In response to GSQ 2 it can be concluded 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.

3.2   **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 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 3-1).

Source: Various EU Publications (2000, 2001, 2003, 2010), ITC/OECD Database (2010), UNECE Database (2010); TRANS-TOOLS Estimates: Petersen et al. (2009).
Figure 3-1: Comparison of Historical Data and TRANS-TOOLS Estimate

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.

3.3 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.

4 The Very Long Term Economic Perspective

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.

4.1 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. The Kondratieff waves can be clearly observed from the S&P 500 stock index (see Figure 4-1).
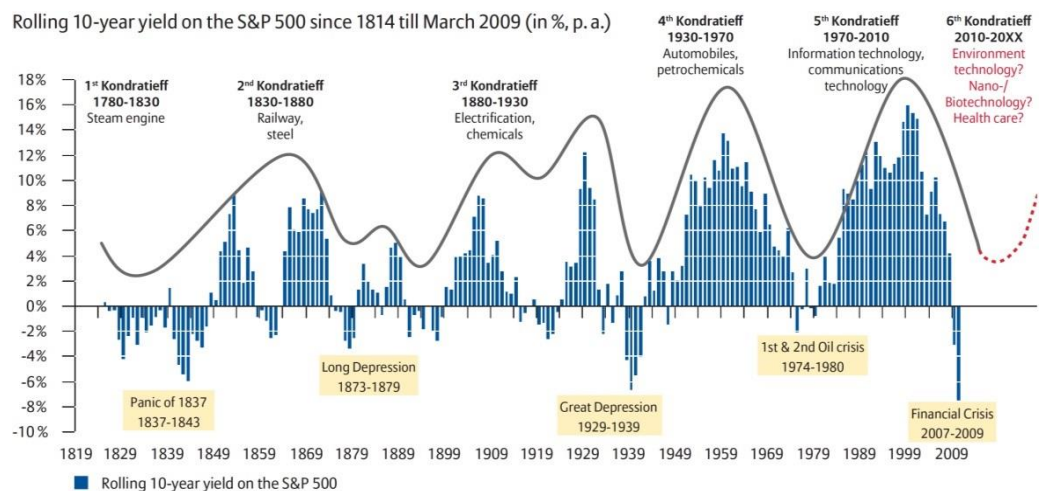
Source: Allianz Global Investors, Analysis & Trends (January, 2010).
Figure 4-1: Kondratieff Waves and S&P 500 Stock Index

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.

4.2 Reflection on the 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 are presented in this study 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.

4.3 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 study 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.

5 Dealing with Very Long Term Policy Issues

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 the obtained insights I proposed a clear policy guideline for selecting the most appropriate methods for looking ahead and dealing with uncertainty.

5.1 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).
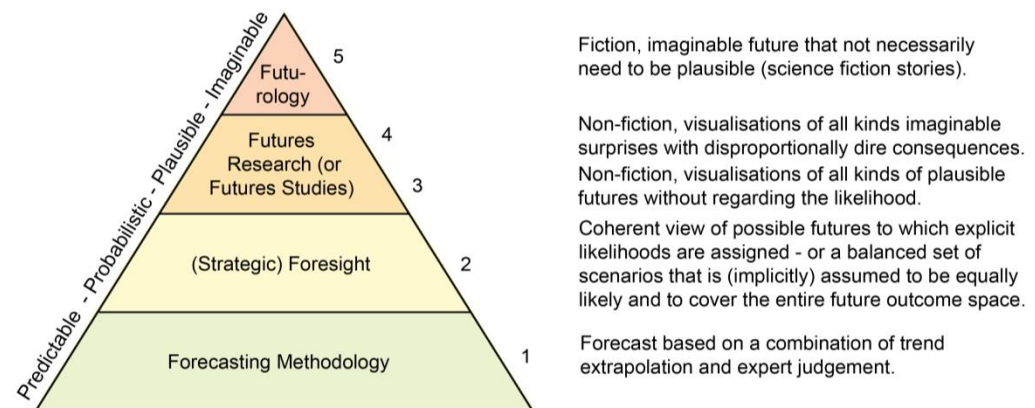
Figure 5-1: Futures Research Pyramid

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 study. 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, 2013) 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.

5.2   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 5-1.

Table 5-1: 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, 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 above, combined with an adaptive decision making structure.

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 study, 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.

5.3   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.

6 The Proposed Policy Framework

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.

6.1 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 dealt with 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).
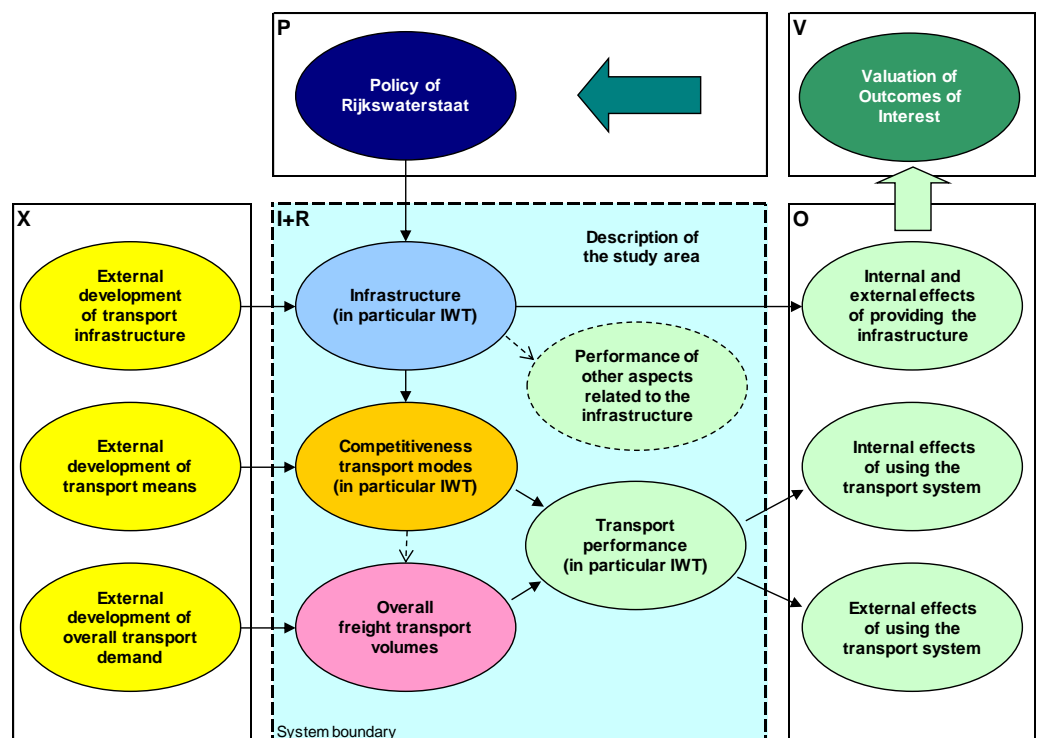

Figure 6-1: Proposed Policy Framework for IWT Infrastructures

I made the XPIROV framework specific for the management of IWT infrastructures (see Figure 6-1). 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 have not 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.

6.2 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).

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.

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.

6.3   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.

7   Development of Freight Transport Demand

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.

7.1   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.

7.2   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 (see for instance Figure 7-1).
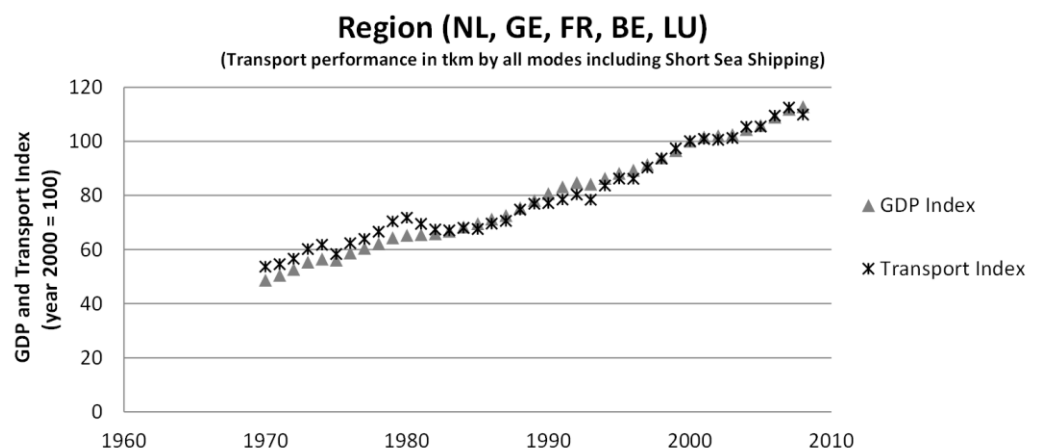
Source: Various EU Publications (2000, 2001, 2003, 2010), ITC/OECD Database (2010), UNECE Database (2010).
Figure 7-1: Economic Output and Freight Transport Index for the Region

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 (see Figure 7-2).
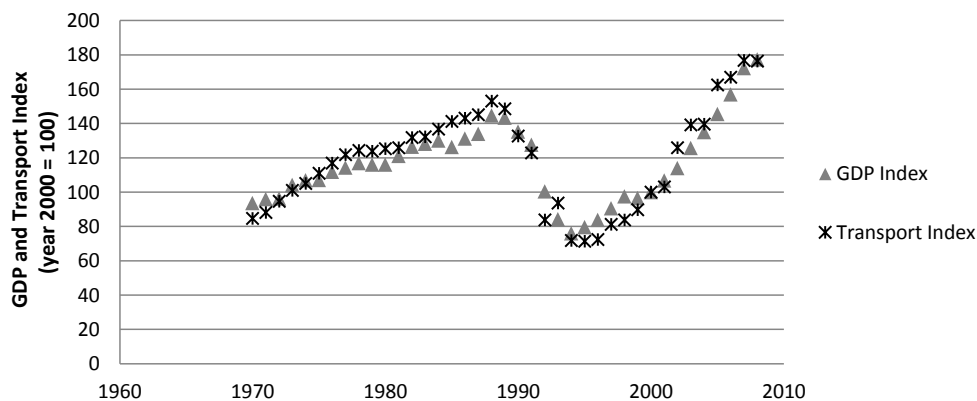
Source: Various EU Publications (2000, 2001, 2003, 2010), ITC/OECD Database (2010), UNECE Database (2010).
Figure 7-2: Economic output and Freight Transport Index for Lithuania

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 (see also Figure 3-1). 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 7-3 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.
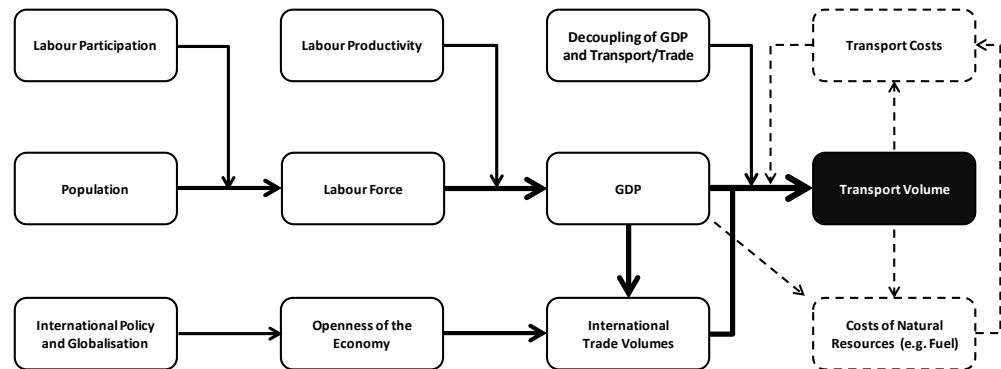
Figure 7-3: Causal Structure for defining Overall Transport Volumes

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.

7.3 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 7-4.
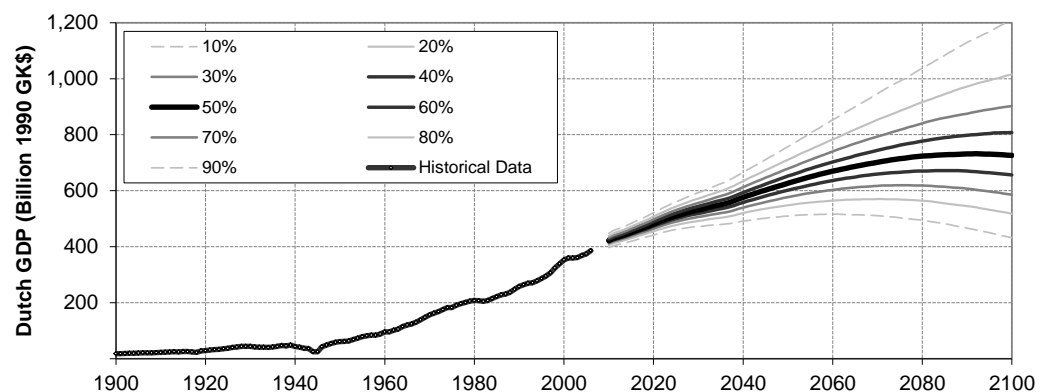
Source: Historical data obtained from Maddison (2010).
Figure 7-4: Probabilistic Projection for development of Dutch GDP

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 7-5.
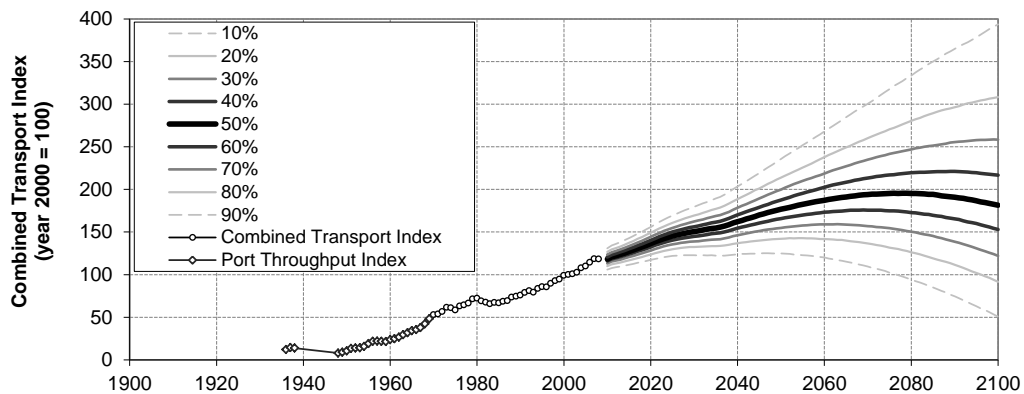
Source: Port throughput index based on data from Port Authority of Antwerp and Rotterdam; combined transport index based on own calculations from various sources.
Figure 7-5: Probabilistic Projection for development of Overall Transport Demand

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.

7.5   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.

8   Development of Transport Infrastructure

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.

8.1   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 1st, 2nd, and 3rd Kondratieff waves gave birth to the development of the canal-, rail-, and road networks which became mature during the 2nd, 3rd, and 4th 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 4th, 5th, 6th, and 7th Kondratieff wave. This updated view is indicated in Table 8-1.

Table 8-1: Clusters of Pervasive Technologies

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 expanded with my personal views.

Literature revealed that the 5th and 6th Kondratieff wave are likely to be driven by the broad concepts of 'Globalisation' and 'Sustainability'. I would argue that the 4th 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 5th and 6th 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 6th and 7th Kondratieff wave in a period that is presumed to last from about 2020 to 2120. The presumed overall development of the transport infrastructure networks is indicated in Figure 8-1.
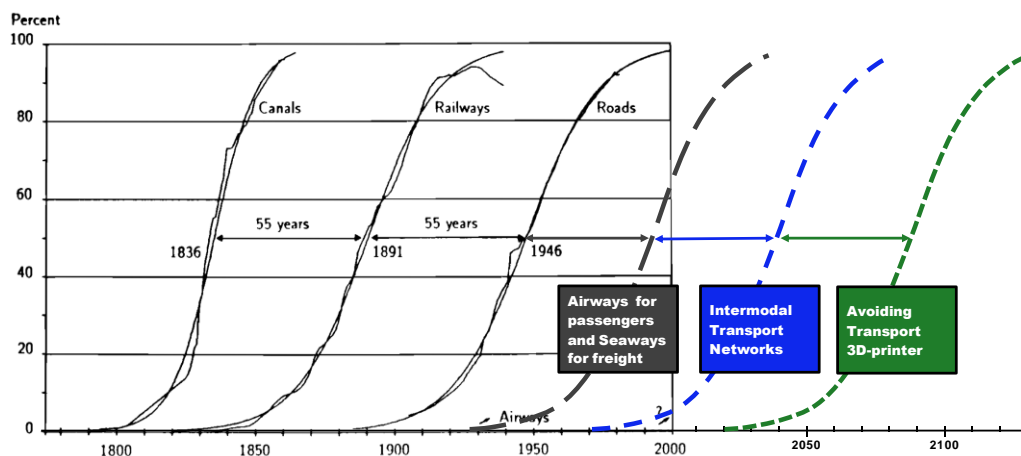
Source: Grübler (1990, p.187), updated with my personal views.
Figure 8-1: Development of Transport Infrastructure Networks

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 should be considered a dominant technology of the next 6th 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.

8.2 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.

8.3 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.

8.4 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.

8.5   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.

9   Effect of Climate Change on IWT

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?"*. 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.

9.1   The effect of climate change 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.
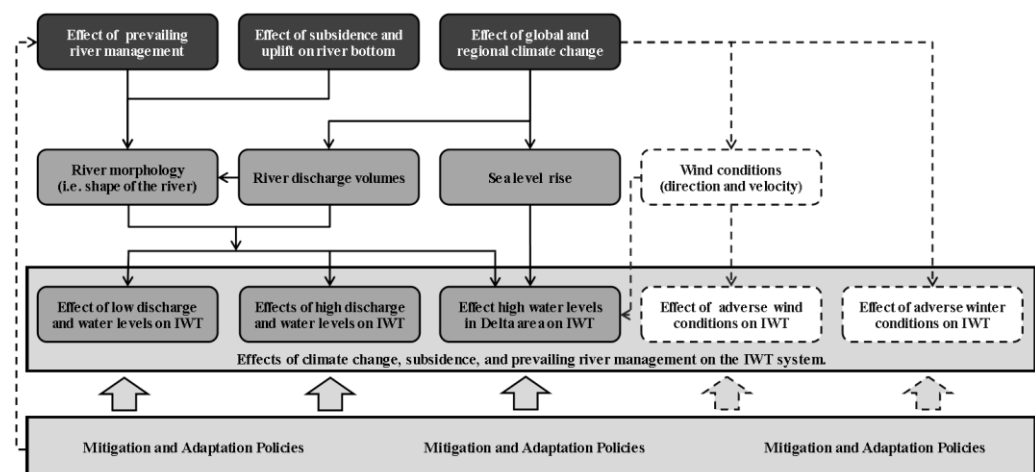
Figure 9-1: Adverse effects of Climate Change and Morphological Changes

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. Figure 9-2 and 9-3 indicate the maximum barge loading draft towards Ruhrort and Basel for the year 2050 and 2100.
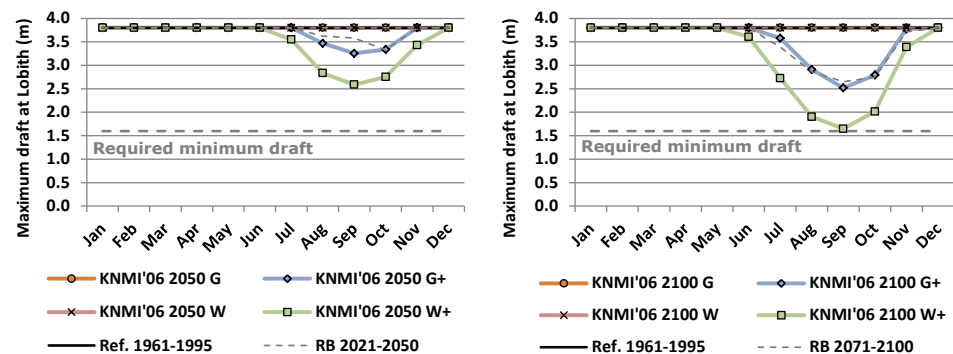
Figure 9-2: Maximum Draft of Barges on Route via Lobith to Ruhrort
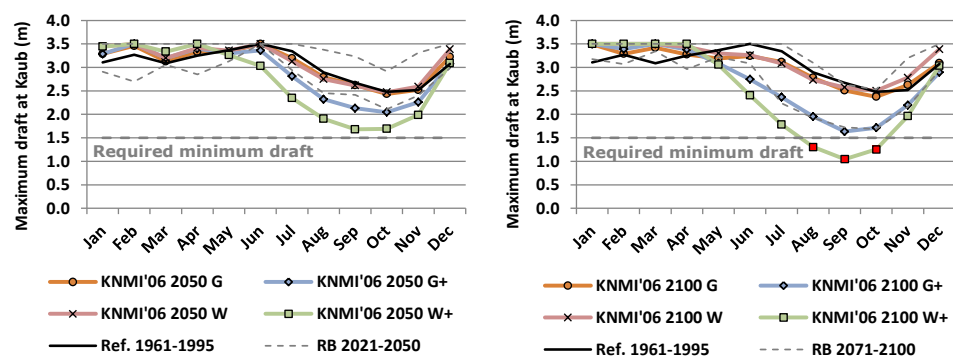
Figure 9-3: Maximum Draft of Barges on Route via Kaub to Basel

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.

9.2   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.

9.3 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 study 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.

9.4 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.

10 Major Shifts in the Mode of Transport

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, labour, energy, materials, and capital) as well as the effects of a number of other important drivers (being: the possible shift of companies to waterfront business areas; 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.

10.1 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 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 6th 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.

10.2 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.

10.3   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.

10.4   **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.

11 Proposed Structure for Transport Model

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.

11.1   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 11-1.

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.

Apply an existing transport model to
obtain a long term transport projection
for the corresponding scenario

Production / attraction matrices
for future base year projection
(e.g. for future base year 2040).

Apply expert judgement to account for changes
in relative share of freight commodities.

Apply expert judgement to include effect of
changes in industrial, spatial, and trans-
portation activities (for period 2040 - 2100).

Normalize production and attraction matrices in
such a way that the total transport volume equals
one tonne.

Stage 1

Define the aggregated very
long term trend of the overall
transport demand (volume in
tonnes).

Apply very
long term
transport
scenario

Apply expert judgement to
account for effect of trend
breaches caused by major
transitions in the industry.

Stage 2

Production / attraction matrices for the
very long term projection of the overall

Run distribution module (stage 2 of classical
transport model) to prepare future OD matrix.

OD - matrices for the very long term
projection of the overall transport
flows (period 2040 to 2100).

Stage 3

Apply expert judgement to
define a plausible scenario
for the development of the
relative performance of the
inland transport modes.

Apply very
long term
modal split
scenario

Take into account the
availability and service
levels of future transport
infrastructure networks
(including the effect of
climate change on IWT).

OD - matrices for very long term
projection of transport flows by mode

Stage 4

Prepare plausible scenario for development of
very long term IWT fleet composition.

Allocate transport flows to the (IWT) network by
taking future infrastructure developments (and
service levels) into account.

Very long term projection of the
transport flows at the (IWT)

Figure 11-1: Hybrid Model for quantifying Very Long Term Scenarios

## 11.2   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.
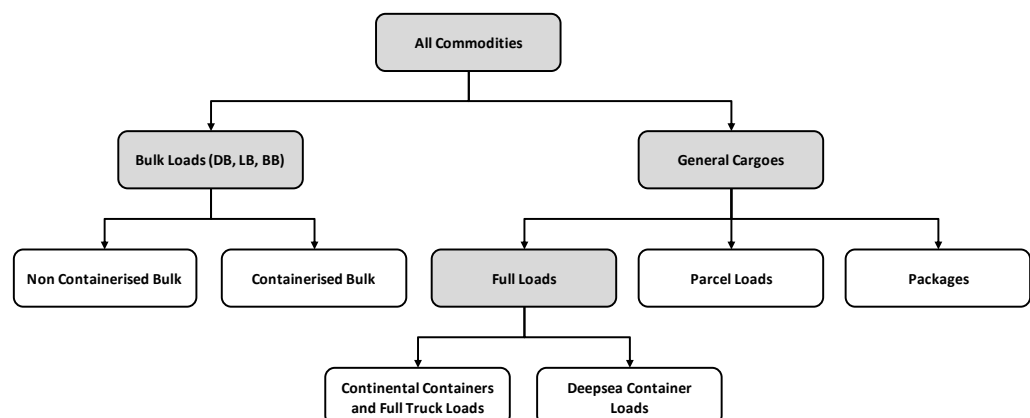
Figure 11-2: Restructuring Commodities into New Categories

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. The structure of the proposed classification system is indicated in Figure 11-2.

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.

11.3 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.

12 Towards implementation of Transport Model

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.

12.1 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. A single OD-matrix was obtained for each commodity class and for each mode of transport (i.e. road, rail, and IWT). The OD-matrices were prepared for gross load, payload, and payload tonne kilometres. The aggregated results of the converted payload data are indicated in Figure 12-1.
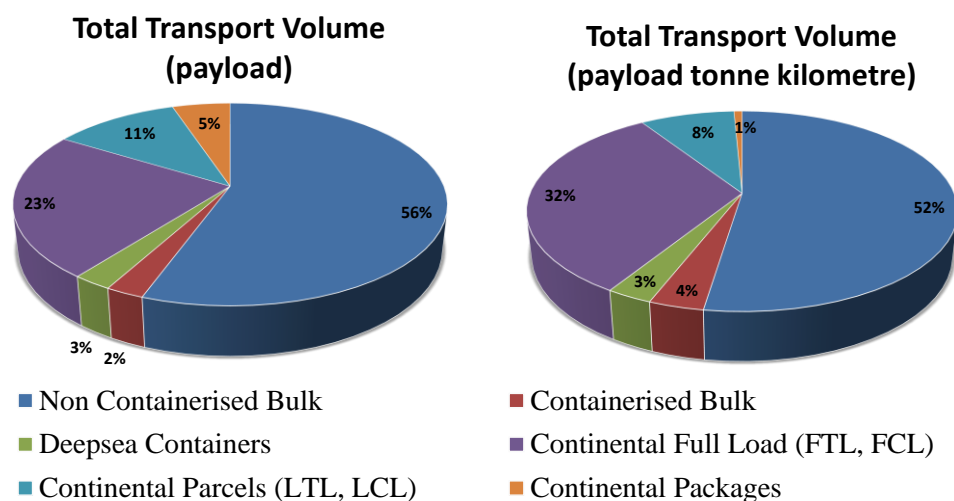
Figure 12-1: Aggregated results of Converted Payload Data

During the second step I nevertheless 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 project. I therefore conclude this chapter with a research agenda for the further development of the desired very long term transport model.

12.2 Research agenda for the development of the desired model approach

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 proposed a comprehensive research agenda for the 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.

12.3 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 project.

13   Shipping Scenarios for Delta Programme

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 in the framework of this study, 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 (see Van Dorsser, 2012; and Bruggeman et al., 2013).

13.1   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 is indicated in Figure 13-1. 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.
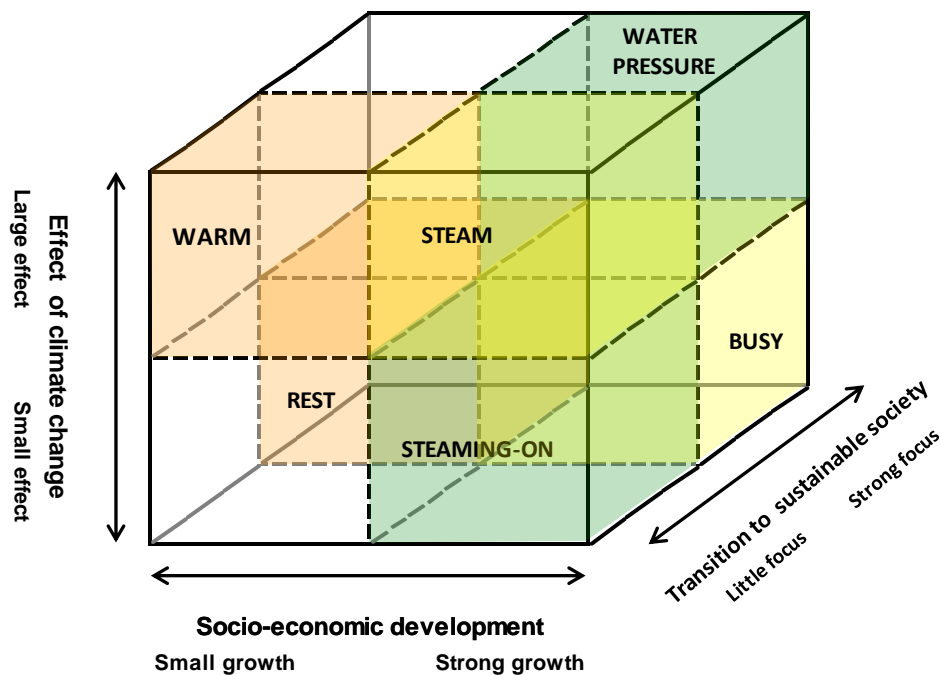
Figure 13-1: The four official and two additional Delta Scenarios

Basic Outline of the shipping scenarios

An outline of the four official and two additional shipping scenarios follows below:

- *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.

13.2   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.

13.3   Answer to Methodological Sub Question 5

In answer to MSQ 5, I prepared six deductive storyline scenarios that explore the outer corners of plausible future developments. The scenarios were not only prepared in the framework of this study, 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.

14 Quantification of the Shipping Scenarios

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 study. Apart from some minor corrections and a few new insights the text is fully in line with the earlier report of Van Dorsser (2012), that provided the background for the shipping section in the official Delta Scenario report of Bruggeman et al. (2013).

14.1 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.

14.2 The obtained scenario quantifications

The obtained scenario quantifications for the development of the overall port throughput- and IWT volumes are summarized in Figure 14-1 and Figure 14-2. It can be observed from Figure 14-1 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 14-2 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 14-3 and Figure 14-4. 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

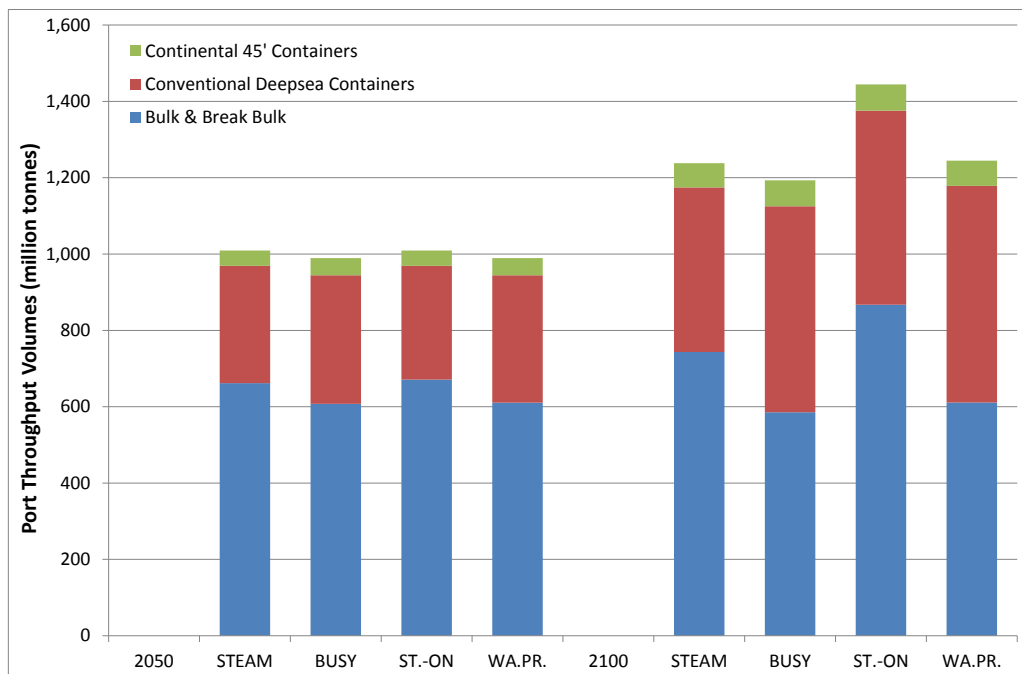the WATER-PRESSURE scenario will have major implications for the provided IWT infrastructure, as it amongst others presumes the river Rhine to be fully canalised.
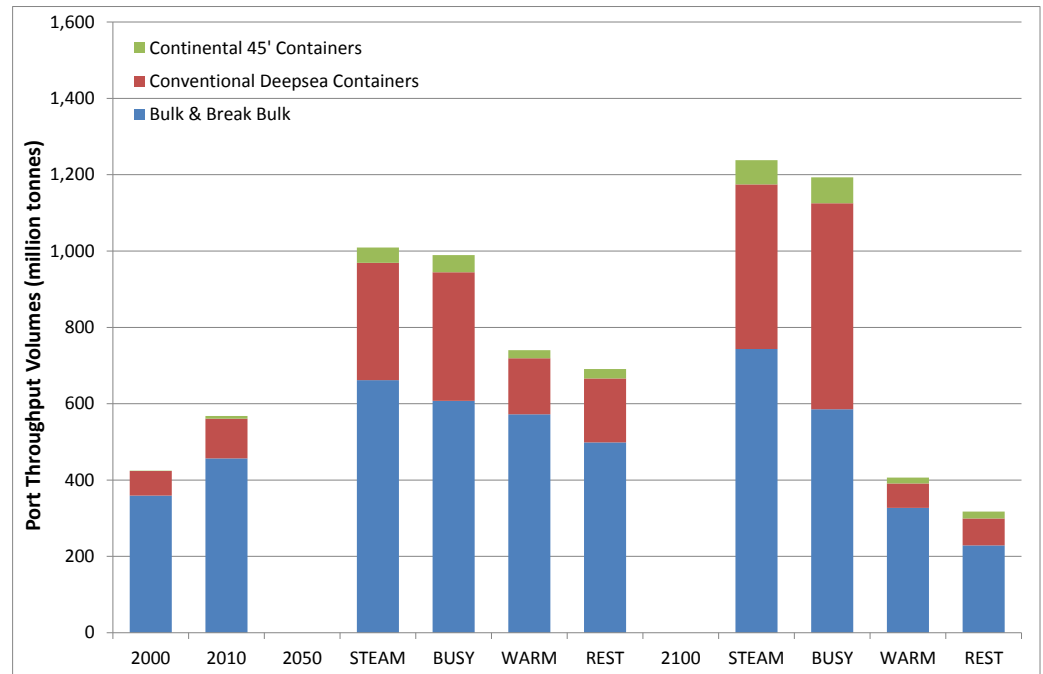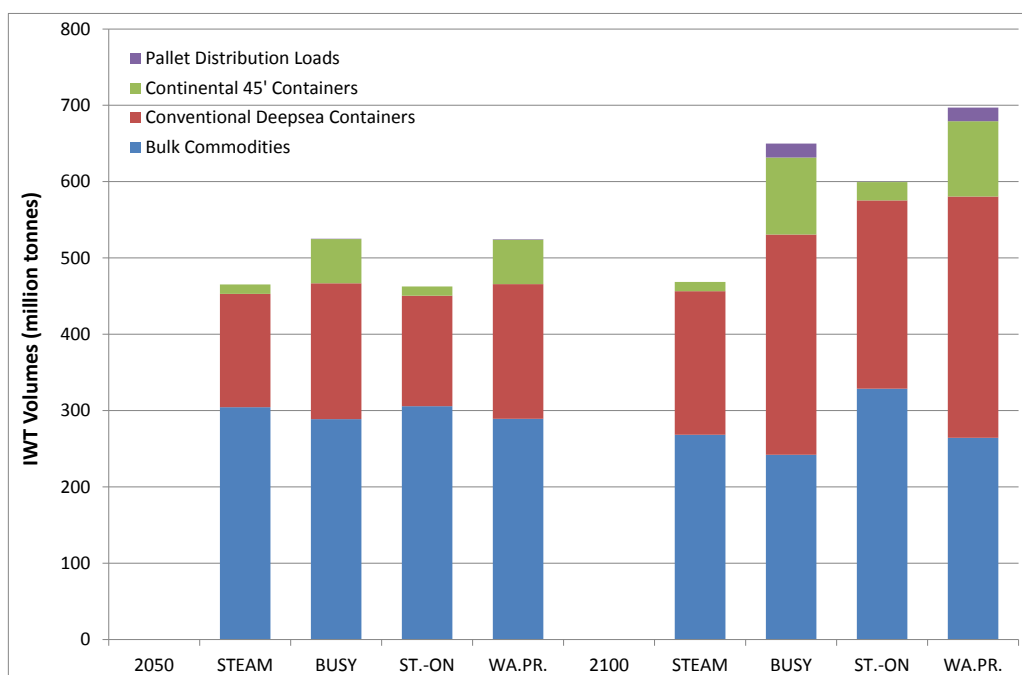

Figure 14-1: Port Throughput Volumes in official Delta Scenarios
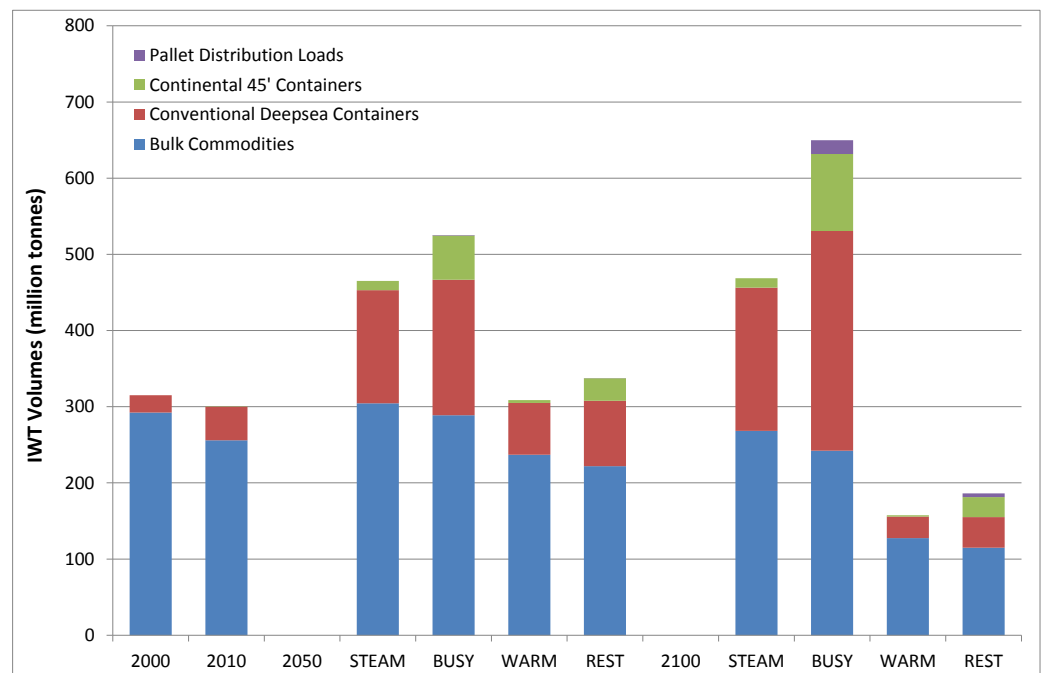
Figure 14-2: IWT Volumes in official Delta Scenarios

Figure 14-3: Sensitivity Analysis on Port Throughput Volumes

Figure 14-4: Sensitivity Analysis on IWT Volumes

14.3   **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 scenario quantifications with a few experts of Deltares, the Dutch Government, 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 study, as such a discussion would have endangered the completion of this study too much. However, with the publication of the study results 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.

14.4   **Answer to Methodological Sub Question 6**

> In answer to MSQ 6, I conclude that this study 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.

15 Conclusions

This chapter provides an overarching view that answers the main research question and elaborates on the findings with respect to the two additional research objectives that have been added in the course of this study. The answers to the four general- and six methodological sub-questions have already been discussed in Chapter 2 to 14 and will therefore not be repeated.

15.1 Introduction

The primary aim of this study 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. In line with this objective the following main research question was defined (see Chapter 1).

> **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?

In order to answer this question the study 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.

The scope of this study has nevertheless not been limited to addressing the main research objective. In the course of this study two additional research objectives were added. 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). This 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.

15.2   Findings from the preliminary research section

The primary research section addresses the main findings from the preliminary research part of this study 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.

<u>The historical development and present state of the IWT system</u>

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.

<u>The present way of dealing with freight transport in long term scenarios</u>

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 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.

The very long term economic perspective

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 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 study.

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 the thesis, but it has no effect on the methodology that I propose for the evaluation of policies with a very long term impact. The proposed methodology is therefore also valid in case the mainstream endogenous neo-classical view on economic growth is applied.

<u>The options to deal with the uncertainty levels in policy making</u>
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 (see Table 5-1 on page 37).

For issues dealing with high or even deep levels of uncertainty 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 in Chapter 14.

15.3 Answer to the Main Research Question

In order to answer the main research question six methodological sub questions were defined that have been addressed in the main research part of this study. 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 next section addresses the findings with respect to the development of the scenarios.

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. Figure 6-1 (on page 41) shows how the XPIROV framework can be made specific for the management of IWT infrastructures.

The various items in the proposed policy framework

All items of the proposed policy framework were studied. The text 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 discussed the findings of this case study, 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. This study contains an in depth enquiry 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.

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 a new hybrid model structure was proposed 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 however 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.

Table 15-1: 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.

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 study 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.

Value 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 has been presented in Table 6-1 (on page 43). The reason for applying a diminishing risk free base rate that gradually goes down to zero on the very long term is free of 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, that 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.

<u>Towards implementation of the proposed policy framework</u>
The scope of this study 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 study therefore justify a further continuation of the research work.

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 to apply much lower diminishing discount rates for the valuation of very long term and ultra-long term effects.

15.4 Conclusions with respect to 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 (see Van Dorsser, 2012). 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.

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. I therefore argue that the outer corners of plausible future developments would have been better explored if two different corner points 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) and two additional scenarios (STEAMING-ON and WATER PRESSURE) has been indicated in Figure 13-1.

The obtained storylines and scenario quantifications
The storylines of the shipping scenarios are 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 six storylines that have been addressed in Chapter 13.

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 study. 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 have been addressed in Chapter 14.

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 the 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 the 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.

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 the thesis concludes 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 as follows:

- **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[2].

- **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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[2] 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   Main Conclusions

On the basis of this study 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.

16   Recommendations

In line with the findings of this study the following recommendations are made to Rijkswaterstaat as well as to a number of other institutions and communities.

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.

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 stake-holders. It may be worth considering a joint European research project on each of these topics.

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.

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.

Recommendation 5: reconsider the applied economic growth paradigm
I recommend economists, scenario developers, and politicians 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.

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).

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