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The analysis and adoption of environmental innovations in inland waterway transport

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by

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Preface

Dear reader,

It has taken a great deal of my dedication and hard work to complete this research. I must point out, however, that this thesis is not the product of my merit alone. It would not have been possible to write this thesis without the input of so many other people, and I want to take this opportunity to thank them.

First of all I want to thank those who guided me in the process of writing this Master's thesis. I want to thank professor Eddy Van de Voorde and my teacher Koos Frouws for their constructive feedback and advice. I thank my supervisor at TNO, Jorrit Harmsen, for his patience, his suggestions and his support. It are the critical questions of these three gentlemen which enabled me to improve the quality of my thesis research. I also want to thank Henk de Koning Gans and Hans Veeke for joining my exam committee and taking the time to review my thesis research.

I also want to thank everyone I interviewed for sharing their thoughts with me so openly. So here is a big thank-you to all the gentlemen I interviewed: Maurits Prinssen from the Port of Rotterdam, Gernot Pauli from the CCNR, Roelof Weekhout from the Ministry of Infrastructure and Environment, Hans Swarts from Alcotrans, Cok Vinke from Contargo, Bart Post from Kuehne + Nagel, Eduard de Bock and Bart Vermeire from de Hoop, Ben Maelissa from Danser, Martin Seine from PTC, Gerard Pols from ABN AMRO, Machiel Bode and Dirk Jan van Swaay from ING, Bram Kruyt from Wärtsilä, Wout Van Valkenburg from Van Valkenburg Shipping, Wim Middelkoop from the Harmonie, Willem de Bruijn from the Decibel, and all the others who answered my questions but who explicitly preferred to remain anonymous.

Apart from these people who had a direct influence on my thesis research, there are also people who had an indirect effect on it.

I want to thank my STL colleagues at TNO for accepting my rather odd work habits, and for providing me with some much needed distractions. Their sharp minds and bright personalities created the ideal context for me to work on this research. They made this experience into one of the most enjoyable chapters of my life so far. I also want to thank our manager, Nico Zornig, for allowing me to do this Master's thesis at the department of Sustainable Transport and Logistics, and for (not so) patiently reminding me of my priorities every now and then.

Another thank-you goes out to my fellow board members of Jong TNO. They never

questioned why I was juggling so many balls at once and they happily provided me with projects to distract me from my thesis. My favourite procrastination project was without a doubt the organisation of our Lustrum party on a boat. Cruising through the port of Rotterdam with 80 fellow researchers who were glowing in the dark: it was vaguely related to my thesis subject and therefore ‘extra unforgettable’.

Lastly, I want to thank my parents, my sisters and my friends. These extraordinary people have given me the motivation, inspiration and support that I needed to complete this thesis successfully. They are the ones who shaped me into an ambitious idealist who does not just think about sustainable development, but who actually wants to help make it happen. It are my friends and family who keep on challenging me to raise the bar, and they are also the ones who provide me with a cushion to land on when I fall.

To all of you: thank you.

Sara Consuegra
Den Haag & Delft & Leuven, the Netherlands & Belgium

Contents

List of Abbreviations

AVV Adviesdienst Verkeer en Vervoer

BLN Binnenvaart Logistiek Nederland

BVB Bureau Voorlichting Binnenvaart

C Celcius

CBRB Centraal bureau voor Rijn- en Binnenvaart

CBS Centraal Bureau voor de Statistiek

CCNR Central Commission for the Navigation of the Rhine

CEMT Conférence Européenne des Ministres de Transport

CEN Comitée Européen de Normalisation

CFD Computational Fluid Dynamics

CH4 Methane

CO2 Carbon Dioxide

COVADEM Coöperatieve Vaardieptemetingen (research program)

DG Directorat General

DNV Det Norske Veritas (classification society)

EEDI Energy Efficiendy Design Index

EGR Echaust Gas Recirculation

EICB Expertise en Innovatiecentrum Binnenvaart

EUR Euro(s)

EVO Ondernemersorganisatie voor logistiek en transport

GHG Greenhouse gas

GL Germanischer Lloyd (classification society)

gr gram(s)

HC Hydrocarbon(s)

IDVV Impuls Dynamisch Verkeersmanagement Vaarwegen (research program)

ILO International Labour Organisation

IMO International Maritime Organisation

IT Information Technology

ITF International Transport Forum

IWT Inland Waterway Transport

km Kilometre(s)

kW Kilowatt

kWh Kilowatt-hour(s)

LASH Lighter Aboard Ship

LPG Liquified Petrol Gas

m metre(s)

MGO Marine Gasoil

mm Million

N2O Nitrous Oxides

NGO Non-governmental Organisation

NOx Nitrogen Oxides

OBM On-Board Monitoring

OBO Oil Bulk and Ore

ODS Ozone Depleting Substance(s)

OECD Organisation for Economic Co-operation and Development

PM Particulate Matter

PROMINENT Promoting Innovation in the Inland Waterways Transport (research program)

PTC Particuliere Transport Cooperatie

SEEMP Ship Energy Efficiency Management Plan

SGS Société Générale de Surveillance (emission testing company)

SOx Sulpherous Oxides

STL Sustainable Transport and Logistics

TNO Toegepast Natuurwetenschappelijk Onderzoek

tonkm tonkilometer(s)

TU Delft University of Technology Delft

UN United Nations

VOC Volatile Organic Compound(s)

VOS Vignet Olie Scheepvaart

List of Figures

Note that all the figures are compositions from the author, unless stated otherwise in the caption of the figure. “Image from” reveals that the figure has been copied without any changes and “adapted from” means that (a part of) the image was altered: the labels may have been changed from Dutch to English, additional labels may have been added, and colours may have been changed. In some cases, the caption explicitly states that the image is an “own composition” from the author. This is done to stress the originality of the figure.

List of Tables

Note that all the tables are compositions from the author. In case the information in a table is derived from other publications, this is stated in the caption. In some cases the caption explicitly states that the table is an "own composition" from the author. This is done to stress the originality of the table.

Summary

The attention for sustainable development in inland waterway transport is mainly about the reduction of exhaust gas emissions. Greenhouse gases and air pollutants have a negative effect on the environment and on public health, which explains why stakeholders want to lower these emissions. However, the inland shipping industry is struggling to improve its environmental performance. Its historically better performance than road transport in NOx and particles, for example, has diminished to that extent that road transport has surpassed inland waterway transport on this level. This research aims to present knowledge and provide insights which can help the inland shipping industry in its efforts to improve its environmental performance. It does so by identifying the environmental innovations which are most promising for a fast, cost and effort effective adoption in the inland shipping industry.

To find the innovations which are most promising, and to find what is needed to ensure their successful adoption in the inland shipping industry, this research answers the following research questions:

- What does the inland shipping network look like?
- What is the current status of the environmental performance of the inland waterway transport industry?
- Who are the stakeholders in the Dutch inland waterway transport network?
- Which are the environmental innovations relevant to Dutch inland waterway transport?
- How is the market adoption of environmental innovations?
- Which measures are most promising for implementation by the industry?
- What is needed (from the stakeholders) to improve the market adoption?

To understand what the inland shipping network looks like, a literature research is performed. It reveals that the inland shipping network transports mainly liquid bulk, dry bulk and containers. Many of these cargoes are carried through the Rhine corridor and the North-South corridor by approximately 8500 ships and another 3000 coupled units. The size of these inland vessels varies from 'spitsen' of less than 40 m long, to coupled units with 9 barges measuring up to 285 m in length. Inland vessels are mainly

operated by captain-owners who operate on the spot market, and the vessels are old. Small vessels for example are on average 70 years old.

Next, the environmental performance of inland waterway transport is looked into. Literature research shows that inland vessels have a good fuel economy per tonkm when compared to other transport modalities but the engines are only replaced about once every 35 years. Emission requirements for new IWT engines have not evolved at the same pace as those for engines in the automotive industry. The PM emissions and NOx emissions of inland vessels are nowadays worse than the emissions of the automotive industry.

Through the creation of a network model (see Figure 1), the stakeholders of inland waterway transport are identified. Stakeholder analyses of these actors are performed based on the Business Model Canvas method. The information which is used as input for these stakeholder analyses, is gathered through stakeholder interviews and additional literature reviews. The analyses reveal that the stakeholders have different attitudes and considerations about environmental innovations, which can be explained by the different characteristics of their core businesses.

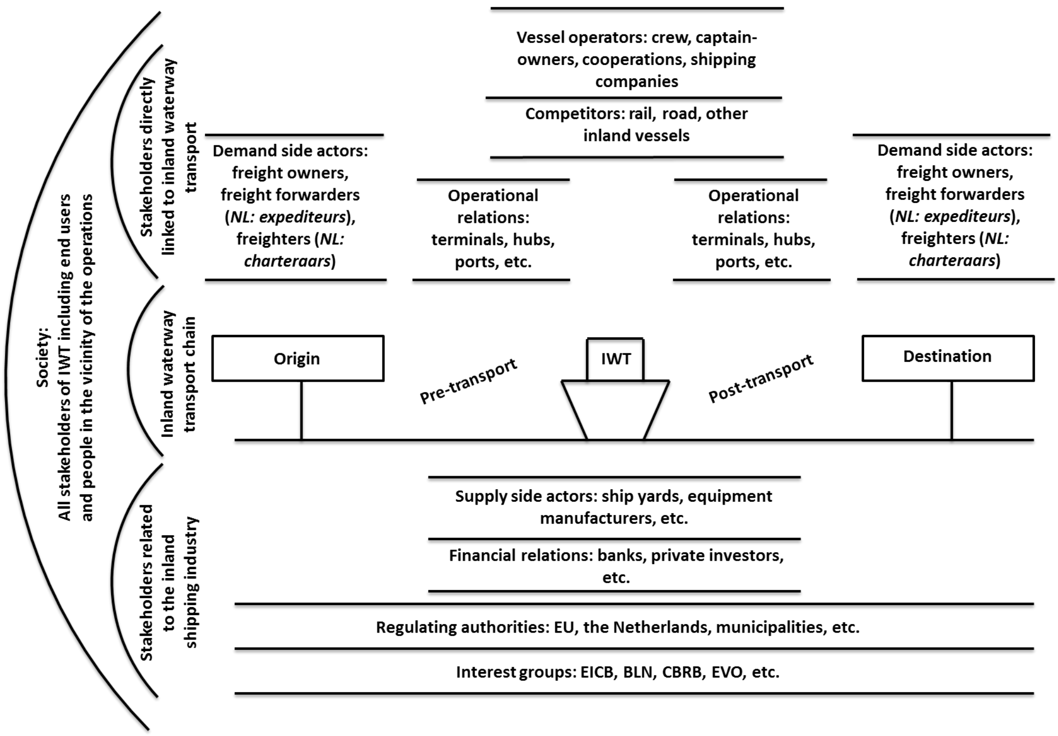

Figure 1: The stakeholders in the inland waterway transport network. Own composition.

The stakeholder interviews and literature review are also used to identify and analyse the market adoption of the environmental innovations which are relevant to inland waterway transport. This research identifies 4 categories of technical innovations: changes in the energy source, changes in the power generation system, changes in the energy demand and changes in the exhaust gases. Apart from technical innovations, there are also operational innovations and logistical innovations. In total, 29 relevant innovations are identified and a structured analysis shows the great variety of environmental innovations:

- Some have high investment costs, others have low investment costs
- Some have a well-to-tank effect, others have a tank-to-propeller effect
- Some have a fuel-saving effect, others do not
- Some require cooperation with other stakeholders, others do not
- Some have a high emission reduction potential, others have a low potential
- Some are suitable as retrofit option, others are only suitable for newbuilds
- Some are in the first stages of market adoption, others are further

The widely accepted theory of [Rogers, 1962] is used to describe an innovation's level of market adoption in this research, and the analyses show that some innovations are in the earliest stages of development while other have reached the mainstream market but may still have some potential left.

To find which measures are most promising for implementation by the industry, case studies are carried out. This is because of the great diversity within inland waterway transport: it cannot be evaluated for the entire market, because the differences between market segments are so large. There are no 'one size fits all' solutions for the segments of inland waterway transport, as mentioned by [Posthumus et al., 2012], [Verbeek et al., 2015b], and [Kadijk et al., 2015]. This thesis research therefore looks into two case studies which represent an important part of the inland shipping industry: the container market and the sand, stone and gravel market.

Within each case study the criteria for innovations which can be implemented in a fast, cost- and effort effective way are identified. This is done by analysing the previously gathered data through summarising the case-specific information. This summarizing methodology is common in narrative literature reviews (e.g. [Green et al., 2006], [Elsevier, nd] and [Rother, 2007]). The summarized data are then catergorised (or 'coded'). The categories which are used in this classification process are the essential functions for market adoption which are identified by [Suurs, 2009]. Suurs' modern theory on the adoption of innovations is chosen because it is the only theory found to go into the 'necessary ingredients' for the successful implementation of innovations. Most traditional marketing-inspired theories, like that of [Rogers, 1962], merely describe the market-uptake process.

After classifying the information in these categories, the conclusive criteria for market adoption are identified. Table 1 shows the conclusive criteria for market adoption for both case studies.

Table 1: The criteria for market adoption

Essential function [Suurs, 2009]	**criteria: sand, stone, and gravel market**	**criteria: container market**
Entrepreneurial activities	Innovations must not still require entrepreneurial activities to be developed	Innovations which have already developed entrepreneurial activities are more promising, but this aspect is not experienced as an essential function
	Innovations must be able to implemented individually (with input from ship yards and suppliers of the technology)	Innovations must improve the throughput, punctuality, customer services or freight tariffs (e.g. by reducing fuel consumption)
Knowledge development	Innovations must not still require R& D	Innovations with high levels of knowledge development are more promising, but this aspect is not experienced as an essential function
Knowledge diffusion	Innovations must have a well-established knowledge diffusion	Knowledge diffusion is helpful but this aspect is not experienced as an essential function
Support from advocacy groups	Support from advocacy groups is helpful, but not experienced as an essential function for the adoption of innovations	Innovations with high levels of support from advocacy groups are more promising, but this aspect is not experienced to be essential
Guidance of the search	Innovations must not require exemptions from regulations	idem
	Standardisation is helpful, but not experienced as an essential function for the adoption of innovations	idem
Market formation	Market formation can be helpful but is not experienced as an essential function for the adoption of innovations	idem
Mobilising resources	Innovations must have low investment costs	Innovations with low investment costs are more promising, but this aspect is not experienced to be essential
	Innovations must have low pay back periods (and thus save fuel)	Innovations must have low pay back periods (read: innovations must reduce fuel costs)

The research then evaluates which innovations meet these criteria. This is done by a multi criteria analysis: only the innovations which meet all the criteria are 'the most promising innovations'. For the market segment of sand, stone and gravel the most promising innovations are LED lighting, and the operational innovations (advanced route planning, cold ironing, fuel- efficient sailing techniques and on-board monitoring). For the container segment the innovations which meet all the criteria are the logistical innovations (hubs & spokes, hops, fairway infrastructure information sharing, chain-partner planning integration and various types of network cooperation) and some operational innovations (advanced route planning, fuel-efficient sailing techniques and on-board monitoring).

Finally, this research looks into what is needed (from the stakeholders) to improve the market adoption of the most promising innovations. These conclusions are based on the previously gathered data about the case study's context, the stakeholders, the environmental innovations, and the theories about market adoption of innovations. Table 2 summarises what is needed for the successful adoption of the innovations which are 'most promising'

Table 2: What is needed in to ensure the successful implementation of the most promising innovations

Innovation	**What is needed**
LED lighting	Raising awareness of the cost-effectiveness of LED lighting
Advanced route planning	Incorporation of modern insights into planning software and encouraging captains to carry out the planning mindfully
Fuel-efficient sailing techniques and OBM	Showing and convincing captains that they can still improve their -already good- navigation techniques
Cold ironing	Agreements on the standardisation of the cold ironing procedures and technique
Hubs & Spokes and hops	Creating communication between the stakeholders and setting up digital platforms
Fairway infrastructure information sharing	Creating a digital information stream
Chain partner planning integration	Creating communication between the stakeholders and setting up digital platforms
Various types of network cooperation	Creating communication between the stakeholders

Generally speaking, it comes down to making sure the essential functions for market adoption are all present, as first described by [Suurs, 2009]. This thesis research shows that all the stakeholders of inland waterway transport have a role to play in at least one of these functions. This is shown from a theoretical perspective: when the essential functions for market adoption are linked to stakeholders it appears that all the identified stakeholders of inland waterway transport have a role to play. This is also shown from a practical perspective: the stakeholder interviews reveal that the stakeholders themselves indicate that they need each other to improve environmental performance of inland waterway transport.

Chapter 1

Introduction

The introductory chapter shows that this thesis research can be placed in a broad context of sustainability in the transport industry. It then clarifies the objectives, research questions, methodology and the scope of this research.

1.1 The broad context of sustainability in the transport industry

The attention for sustainable development has continuously grown over the last decades in several industries, including the industry of transportation and logistics. Even though this research focuses on inland waterway transport (IWT), it is useful to relate it to developments in other markets.

One of the competitors of inland waterway transport is automotive transport (e.g. [Quispel, 2011]). This market has rapidly improved its environmental performance over the past years. There are, for example, the European emission norms for vehicles which have driven the industry to perform better. These so called Euro I to Euro VI norms have resulted in a significant decrease of emissions caused by European road transport. In addition to these European requirements, national authorities have developed their own policies concerning sustainability in the automotive industry. The Dutch government for instance stimulates the market adoption of clean trucks and cars. Fiscal policy measures and several subsidy programs support its market adoption. On a more regional scale, some other instruments (like Milieu Zones) are being used in this progression towards sustainability. [van Mensch et al., 2013].

This progression towards sustainability is also happening in the maritime industry. But what is sustainability, to start with?

> *Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs. [UN, 1987]*

This definition of sustainable development is certainly not the only one , but the UN Brundtland-definition is still popular and contemporary today [Drexhage and Murphy, 2010]. [1]

The ‘bigger sisters’ of the inland waterway transport market are the deep sea and short sea shipping market, and these industries are also working on sustainable development. A guiding and leading role in this evolution can be attributed to the International Maritime Organisation (IMO). Its most relevant convention is the MARPOL convention about prevention of maritime pollution [IMO, 2015a]. Since MARPOL Annex VI entered into force in 2013, the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) have become a requirement [IMO, 2011]. Because these requirements are applicable to over 95 % of the world’s merchant tonnage [IMO, 2015b], these conventions have a vast effect in forcing ship owners to consider new methods to improve their vessels’ environmental performance.

The IMO’s regulations are not the only agent stimulating the industry’s sustainability efforts. Just as in the automotive industry, there are different levels of regulating

[1] The Brundtland-definition of sustainable development is the subject to many debates. Several authors in the field, including [Dalal-Clayton, ND] and [Cervantes, 2013], comment on its shortcomings and suggest alternative definitions. Even though the Brundtland definition may not receive general support, it is the best known definition and can be seen as the basis for modern concepts of sustainable development.

authorities which have their own environmental policies. This multi-level aspect to policy also characterises the maritime transport market (Stopford, 1999). Some of the maritime regulating authorities which have rules related to sustainability are:

- International organisations: IMO, International Labour Organisation (ILO), European Union (EU), ...
- National authorities: the Dutch government, the Belgian government, flag states, ...
- Regional authorities: Central Commission for the Navigation on the Rhine (CCNR), Province South Holland, ...
- local authorities: Port of Rotterdam, Port of Antwerp, ...

Most of these regulating authorities tend to focus on the environmental aspect of sustainability. It must be stressed that there is more to sustainability than that. The triple bottom line definition of sustainability, also called the people-planet-profit concept, is particularly popular because it emphasises the different aspects of sustainability:

> *Sustainability is the principle of ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations. [Elkington, 1998]*

Even so, the efforts of the maritime industry mostly target environmental issues. Some measures in this effort are the use of optimised hull shapes, waste heat recovery systems, contra rotating propellers, wind kites, and the use of advanced route planning and weather routing. Countless publications have looked into these options. Some often referred to publications are the second and third IMO Greenhouse Gas (GHG) study ([Buhaug et al., 2009] and [Smith et al., 2014]). Another popular publication focussing on the reduction of GHGes and emissions is a discussion paper from the OECD and the International Transport Forum [Christ, 2009]. DNV's 'Pathways to low carbon shipping' focuses on the marginal abatement cost of different GHG reduction measures [Alvik et al., 2010] and is also regularly cited. Considering the number of publications on the subject, it is clear that the transport industry is actively working on the sustainability.

This is also the case for the inland waterway transport industry (e.g. [Green Award, 2015] and [Nelissen and Faber, 2014]). In this industry the sustainability debate boils down to how the negative impact on public health and the environment can be decreased (e.g. [Gemeente Rotterdam, 2010] and [Provincie Noord-Holland, 2015]).

The inland waterway transport industry makes efforts to improve the air quality by reducing its polluting emissions. Some examples of regulations which are relevant to the Dutch inland shipping industry are the European rules about sulphur levels of fuel [EU, 2012] and the treaty about waste produced during navigation on the Rhine [CCNR, 2014a]. Perhaps the best known policy measures in inland waterway transport aimed at improving the air quality, are the CCNR's engine requirements [EU, 1997].

The exhaust gas emissions from inland vessels which are powered with a conventional diesel engine are: carbon dioxide (CO2), greenhouse gases (GHG), nitrogen oxides (NOx), sulphurous oxides (SOx), particulate matter (PM) and hydrocarbons (HC's) (e.g. [Stapersma and Klein Woud, 2008] and [Kristensen, 2012]). These exhaust gas emissions are getting most attention from the industry (e.g [BLN, 2015], [Platform Schone Scheepvaart, 2015] and [EICB, 2015a]) so a brief description of these emissions is provided in Table 1.1.

Table 1.1: The exhaust gas emissions from inland vessels

Emission	**Description**
CO2	Carbon dioxide is a greenhouse gas that is directly related to the combustion of fossil fuels. (e.g. [ICS, 2014]). It contributes to global warming like all other greenhouse gases. (e.g. [EU, 1997]).
GHG'es	Other greenhouse gases include methane (CH4) and nitrous oxide (N2O) (e.g. [Environmental Protection Agency, 2015]). These greenhouse gases also contribute to global warming.
NOx	Nitrogen oxides are also a greenhouse gas, but they also cause acidification (e.g. [Bureau Voorlichting Binnenvaart, 2015]). Acidification is harmful to ecosystems, can cause damage to buildings and can cause health problems (e.g. [EU, 2015a]). Health issues may include respiratory problems and damage to lung tissue (e.g. [GAPF, 2012]).
SOx	The amount of sulphurous oxides in the exhaust gas depends on the sulphur content of the fuel (e.g. [Debiastre, 2009]). SOx has a similar effect as NOx (e.g. [EU, 2015a]).
PM	Particulate matter (or soot) is the collection of extremely small particles which are produced during the combustion of fuel. These particles have a negative effect on public health. (e.g. [Green Ship, 2015b])
HC's	Hydrocarbons include fragments of the fuel which are not completely burned by the engine. These are called unburned HC's. Another type of HC's are volatile organic compounds (VOC's) which can be, for example, released when tankers open their pressure relief valves (e.g. [Green Ship, 2015a]). All of these HC's can be harmful to public health and may contain ozone depleting substances (ODS) (e.g. [Maritime Coastguard Agency, 2012]).

In the effort to lower these emissions, several types of methods may be effective. One can identify policy measures, technical methods, operational methods and logistical methods[2]. Policy measures that are being used are differentiated port tariffs and subsidy

[2] Policy measures are all kinds of laws, rules, regulations and guidelines. Technical methods are tangible additions or changes to the vessel or any of its components. Operational methods are changes in the operation of vessels which can be performed by the shipper and/or crew. Logistical methods are changes in the operation of vessels that require the effort of several actors in the transport chain.

programs (e.g. [Verbeek et al., 2015b] and [Van Essen et al., 2012]). Technical measures to improve the environmental performance of inland waterway transport include the use of particle filters, exhaust gas recirculation (EGR), engines that run on liquefied natural gas (LNG) and the use flexible propeller tunnels [Hekkenberg, 2013b]. Some operational measures are slow steaming and advanced route planning. Logistical measures include network integration and the further development of hubs [van Meijeren et al., 2013].

1.2 The objectives and research questions of this research

The previous section already introduces some measures to improve the environmental performance of the inland waterway transport. However, not all the environmental innovations are adopted by the market. The reasons why some innovations are implemented successfully and others are not, are complex (e.g. [Mohr et al., 2010] and [Suurs, 2009]). Understanding these complexities will allow the different stakeholders of the inland shipping industry to improve their strategy, which will ultimately help to reduce the industry's negative effect on the climate and on public health.

The goal of this research is to identify the environmental innovations which are most suitable for implementation by the Dutch inland waterway transport industry. Note that the 'most suitable' is a broader concept than only 'the most effective in reducing emissions'. The most suitable measures are those measures which are effective in reducing the emissions and which can be implemented in short term and in a cost- and effort effective way. This concept of 'suitable' thus relates to market adoption and non-environmental considerations the stakeholders may have.

To reach this goal, knowledge must first be developed on the complexities of the market adoption process in the inland shipping industry. This thesis also aims to provide stakeholders with insights in the (cost-) effectiveness of different environmental innovations. The thesis will also provide information on the steps that need to be taken to ensure the innovations' successful implementation.

The research questions that must be answered to reach these objectives are:

- What does the inland shipping network look like?
- What is the current status of the environmental performance of the inland waterway transport industry?
- Who are the stakeholders in the Dutch inland waterway transport network?
- Which are the environmental innovations relevant to Dutch inland waterway transport?
- How is the market adoption of environmental innovations?
- Which measures are most promising for implementation by the industry?
- What is needed (from the stakeholders) to improve the market adoption process?

1.3 The scope of this research

Figure 1.1 visualises the structure of the research.

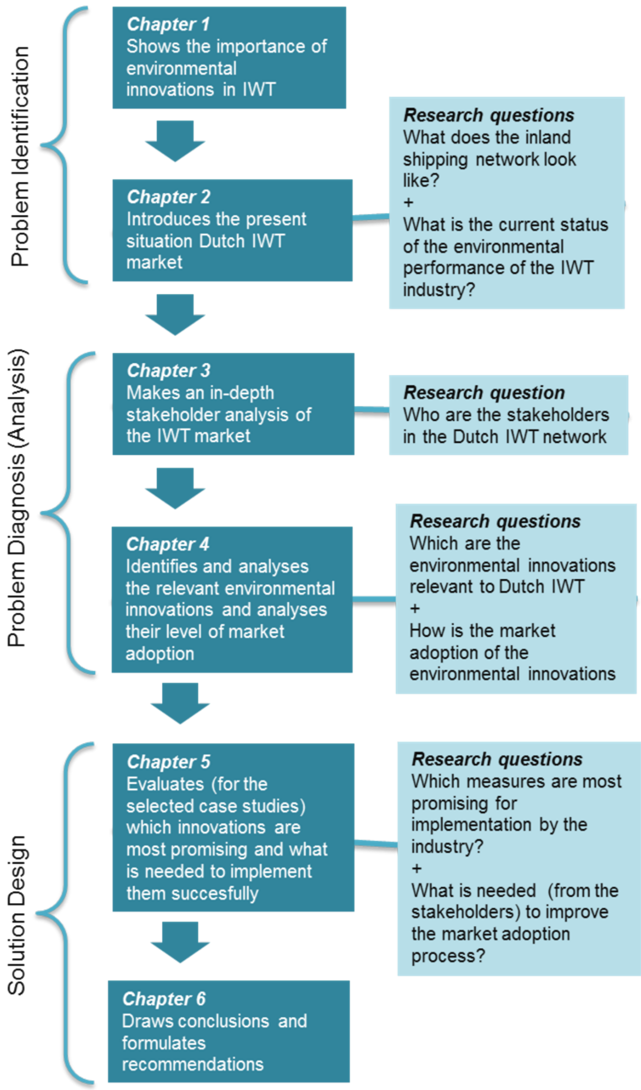

Figure 1.1: The structure of this research in a flow chart

To answer the research questions a practice-oriented research is proposed. Even though there is not one fixed methodology to this kind of pragmatic research (e.g. [Bleijenbergh et al., 2010] and [Butter, 2014]) the handbook on research methods by [Christiaans et al., 2004] identifies five general steps: 1) problem identification, 2) problem diagnosis, 3) solution design, 4) change and 5) evaluation. This thesis research is limited to the first three steps of a practice-oriented research. The last two steps in which changes are implemented and evaluated are out of the scope of this thesis research.

The first two chapters of this thesis correspond to the first step of practice-oriented research: the problem identification. The previous sections of this first chapter -the introduction- show that the in inland shipping industry is working on environmental issues. It has also been established that the research focuses on exhaust gas emissions from conventional inland vessels: CO2, GHG'es, NOx, SOx, PM, VOC's and ODS's. To answer the first research question (what does the inland shipping network look like) the second chapter goes into the Dutch inland waterway transport market and takes a look at the characteristics of this industry.

The next chapters are about diagnosing the issues in the implementation of environmental innovations. Innovations, in this research, are defined as all the new techniques which are aimed to improve existing products or practices. Chapter 3 answers the research question 'who are the stakeholders in the Dutch inland waterway transport industry'. An in-depth stakeholder analysis reveals which considerations the stakeholders have with respect to the adoption of innovations. The fourth chapter then goes into a wide variety of innovations. The scope of this research is limited to the innovations which are directly related to inland vessels and their operations. Apart from providing an explanation of their concept, the chapter also analyses what their level of market adoption is and what the stakeholders' attitudes are towards these innovations. The research questions which are answered in the fourth chapter are 'which are the environmental innovations relevant to Dutch inland waterway transport' and 'how is the market adoption of environmental innovations'.

In the last part of the research, the problems in the adoption process are diagnosed. The barriers which are holding back the market adoption are analysed and the necessary steps to resolve these barriers are discussed. This reveals which innovations are the most promising for implementation by the inland waterway transport industry.

Note that the scope of this research is limited to the current situation of the industry, the innovations and the policy. No other scenarios with variations or changes in this state of the art is considered in this research.

1.4 The process and methodology of this research

To answer the research questions suitable research methodologies are used. Figure 1.2 shows which methodologies are used.

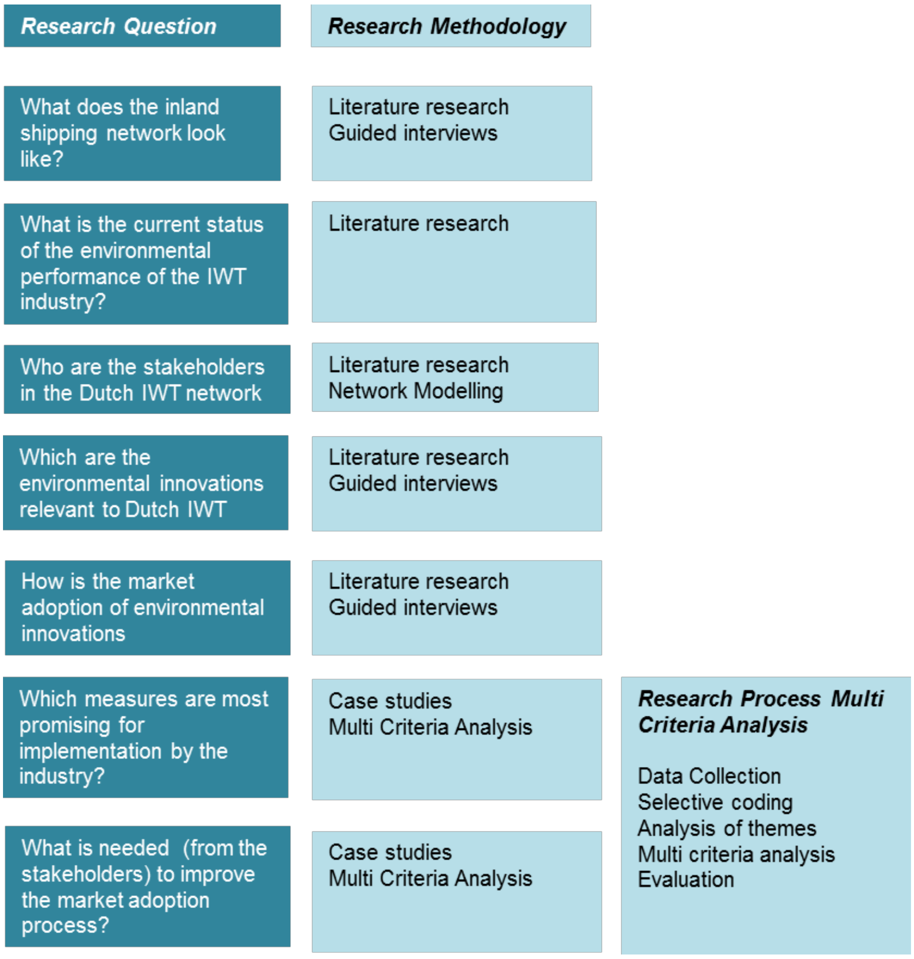

Figure 1.2: The research methodologies used in this research

1.4.1 Literature reviews

A literature review is conducted to gather the necessary information for this research. Relevant literature on inland waterway transport includes the reports of research programs, periodic market outlooks, Master's and PhD theses on the subject, and numerical data from statistical databases. The most recent available publications and data are used. References to the literature and citations are provided throughout this thesis, when appropriate. The bibliography provides a complete list of literature references.

1.4.2 Stakeholder interviews

Eighteen stakeholder interviews with a guided approach are conducted with actors in the Dutch inland shipping industry[3]. The respondents were selected to cover a wide variety of stakeholders of the IWT industry (see Chapter 3). The following criteria were used to select them:

- The group of respondents should be large enough to cover the different types of stakeholders (see Table 3.1).
- The group of respondents should be small enough to keep the number of interviews down to a manageable number for the researcher. This is due to time constraints inextricably related to a Master's thesis research.
- The respondents should be relevant to the selected case studies discussed in Chapter 5.
- The respondents should be willing to participate with the research without the need of any persuasion.

Rather than using standardised open-ended or fixed-response questions, this research uses general interviews with a guided approach. This type of interview gives the researcher more flexibility to go deeper into the stakeholder-relevant topics, which is necessary because of the considerable differences between the selected respondents: the respondents' experiences with environmental innovations are diverse, as are their opinions about (the adoption of) environmental innovations in the inland shipping industry.

A flowchart of the interview questions is given in Appendix A. When useful, an additional handout with an overview of the environmental innovations relevant to the inland shipping industry was provided to the respondents. This handout is also provided in the appendix.

1.4.3 Network modelling

Network modelling is used in this research to aid in the identification of the stakeholders of the inland waterway transport industry. Modelling has been documented to be an effective research methodology in various applications (e.g. [Jordaan and Lategan, 2006]). Comprehensive network models show the steps in the transport chains of the case studies, and show which stakeholders relate to these processes.

1.4.4 Case studies

Case studies are used because the inland shipping industry is so diverse and there seem to be no 'one size fits all' solutions. This thesis looks into two case studies to evaluate

[3]The interviews were conducted face-to-face in a confidential setting at the preferred location of each of the respondents. Two interviews were performed over the phone, but also took about an hour like all the other face-to face interviews. The interviews were conducted in Dutch or in English and recordings of the interviews were made. However, due to the confidential nature of the information which was shared with the researcher these recordings will not be transcribed or made public in any way.

the implementation of environmental innovations. The selection of these case studies is based on both quantitative and qualitative considerations.

The main considerations in the selection of the case studies are: 1) to choose case studies which are representative and very common in the inland waterway transport industry, and 2) to choose case studies with considerable differences to show the effect of the variations on the result of the analysis. The following arguments show why the case study of the sand, stone and gravel market, and the case study of the container market were selected.

1) Representativeness

- The chosen case studies represent the second and third largest market segments, as shown in Figure 2.3
- The selected case studies are with dry cargo vessels. The majority of inland vessels is a dry cargo ship, as shown in Table 2.3
- CEMT III and CEMT IVa are the selected sizes of the case studies' vessels. These are the first and third most common ship sizes, as presented in Table 2.2
- 40% of all the inland waterway transports in the Netherlands originates from, or is destined to the Port of Rotterdam. This makes it the first port of the industry and a 'must' to include.

2) Diversity

- CEMT III vessels are classified as a medium sized ships and CEMT IV as large ones.
- One exporting-importing route and one inland route adds diversity to the case studies.
- One case study is dominated by captain-owners operating in the spot market, and the other case study by shipping companies working with long-term contracts.
- The outlook of the growth in the selected segments is different. For the sand market the economic outlook seems to be decreasing, while it augments in the case of container transport. This is introduced in Chapter 2.2.4.

An additional argument for the selection of the case studies is that the composition of coupled units can change each journey. Therefore ships are chosen for the case studies. This excludes any ambiguities about the configuration of the vessel.

Within each case study, this research uses the next process to find the most promising innovations.

Table 1.2: The research process within each case study

Process step	Description
Data collection	By summarizing the case-specific information, the case study is presented. No new information is presented, this step is merely a case-specific analysis of the previous chapters which are based on both literature research and stakeholder interviews.
Selective coding	The data are coded and classified into categories. The categories which are used, are the essential functions for the market adoption of innovations as identified by [Suurs, 2009].
Analysis of themes	The conclusive criteria for adoption are identified. This is done by analysing the case studies' key issues with respect to each essential function for market adoption.
Multi criteria analysis	The innovations that meet the conclusive criteria are identified through a multi criteria analysis. Each innovation which meets all the conclusive criteria is one of the 'most promising innovations' for a fast, cost- and effort effective implementation
Evaluation	A discussion describes what is needed from the stakeholders to ensure the successful market adoption of the most promising innovations

This process is based on guidelines of [Creswell, 2007] on how to perform case studies in qualitative research. While Creswell states that '*there is no agreed upon structure for how to design a qualitative study*', he does go into the steps of case studies. Chapter 5.1 elaborates on the research methodology.

The theoretical framework used to assess which innovations are suitable for a fast, cost and effort effective adoption, is Suurs' theory on the essential functions for the adoption of innovations. This theory is used because it is the only one found to offer clear 'ingredients' for the successful implementation of innovations. Traditional marketing-inspired theories, like the theory of [Rogers, 1962], do not analyse the underlying reasons for market uptake but only describe the process. These theories are also used in this research, but merely to show the current level of market uptake of environmental innovations. Because Suurs' theory goes into what is needed to realise this market uptake, this theory is better suited to evaluate which innovations are most promising and what is needed fto ensure their successful implementation.

Chapter 2

The current situation of the Dutch inland shipping market

This chapter answers two research questions: ‘what does the inland shipping network look like’ and ‘what is the current status of the environmental performance of the inland waterway transport industry’. Therefore several characteristics of the industry are introduced, like the financial structures, the flow of goods and the types of vessels. The final section of this chapter gives conclusions to the two research questions.

Note that the most recent available data are used in this chapter. These dates may not match the publication year of this research (2016).

2.1 The flow of goods

The core business of the inland shipping industry is transporting cargoes from one site to another. This section elaborates on the quantity and types of goods which are transported by inland waterway transport in the Netherlands. The section finally gives an overview of the geographic area of these flows of goods.

2.1.1 The modal split and overall transport volumes

The total amount of transported goods for an entire transport modality, is expressed in terms of tonkilometers (tonkm). This dimension allows to easily compare the transport volumes of different modalities. Inland waterway transport, for example, is often compared to road and rail transport. The relative size of these three modalities is also called the 'modal split'.

Of all the cargo transported in the Netherlands in 2013, about 56 % was transported by road, 5% was transported by rail and 39% was transported by inland waterways. This is 48,641 million tonkm [Eurostat, 2015]. This significant share of inland waterway transport in the Dutch modal split can be attributed to the dense waterway network and the presence of much waterway infrastructure (e.g. [Hekkenberg, 2013a]), but it is also linked to the commodities which are transported (e.g. density of the cargoes). These characteristics also explain why the modal split is unique for every country. Figure 2.1 shows the modal split of each Rhine country. [1]This figure does not show the total amount of transport since this value varies over time, which is also the case for the modal split. The recent evolution of the modal split in the Netherlands is therefore shown in Figure 2.2.

This latter figure shows that, even with the competition from rail and road transport, the total volume of cargoes which are transported by inland waterway transport continues to rise. The data show a slow but steady rise of this volume with only one distinct drop in 2008. This break in the rising trend can be attributed to the economic crisis which caused the transport volumes to drop in 2009.

The rising trend of European inland waterway transport is expected to continue. The Central Commission for Navigation on the Rhine believes that the transport volume may rise by 52 % or 3.8 billion tonkm by 2030 [CCNR, 2010]. [CE Delft, 2011] comes to a similar conclusion. It finds that the tonkm of European inland waterway transport may rise from 128 billion in 2011 to up to 260 billion tonkm by 2040. A similar growth level is also expected for container transport in the Port of Rotterdam. This may be attributed to the containerisation of cargo. Containerisation has made intermodal transport more easy to realise and has made inland terminals more common (e.g. [TNO et al., 2012]).

Another reason to expect growth in the inland shipping market is that the EU sees it as an important part of the solution for overloaded roads. The situation on European roads, in particular the frequency and length of traffic jams, has become a threat to

[1]Switzerland has been omitted from these charts even though it is a Rhine country. This is because Eurostat does not provide any data on the size of the Swiss inland waterway transport volumes.

mobility. The [EU, 2011] stresses the importance of inland shipping as a part of the solution in its White Paper on Transport.

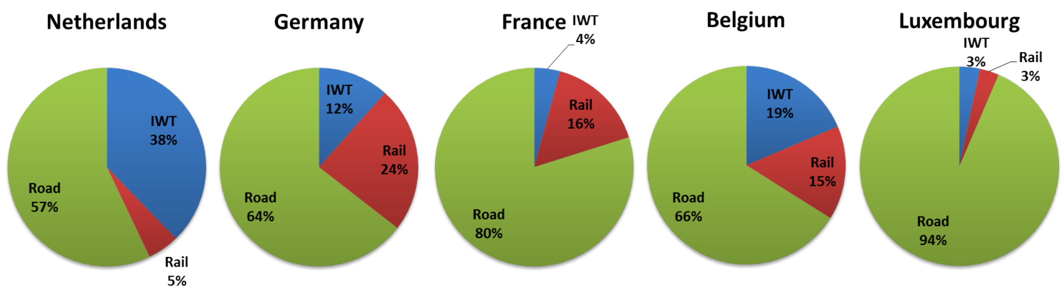

Figure 2.1: The modal split of the Rhine countries for 2011 in tonkm. Data from [Eurostat, 2015]

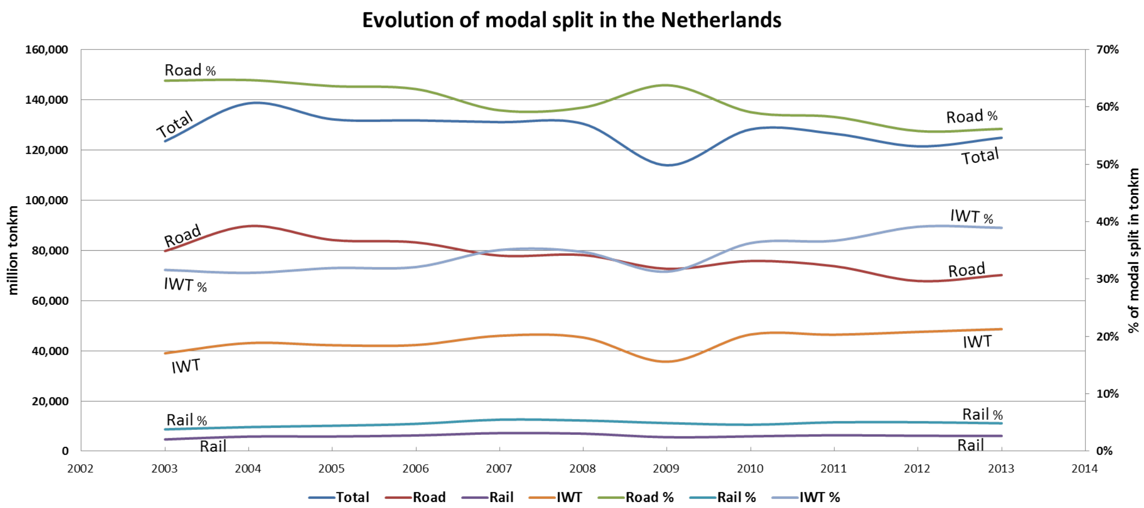

Figure 2.2: The recent evolution of the Dutch modal split for road, rail and inland waterway transport. Data from [Eurostat, 2015]

2.1.2 The different types of cargo

The last figure in the previous section shows the total amount of transported goods for the three transport modalities of the modal split. However, this overall transport volume does not show that the type of cargo which is transported by these modalities is quite different.

[Hekkenberg, 2013a] explains that, in general, non-bulk and non-continental cargoes are being transported mainly over road, while low-value bulk goods are transported by water. To understand why some goods are transported by water and some are not, one should know that the choice of transport modality depends on the size of the cargo, the cost of transport and the speed of transport. With this in mind, it is easy to see why inland waterway transport is the preferred transport modality for moving bulk goods (*because vessels can carry large volumes at once*), and that this is not the case for most perishable consumer goods (*because vessels are slow compared to the other modalities*).

Some of the cargoes which are transported by inland vessels are: metal ores, petroleum products, grain, gravel, sand, coal, chemicals and containers. An overview of the products that were transported in the Netherlands in 2013 is given in Figure 2.3. This image shows the transported goods based on the transported tonkm.

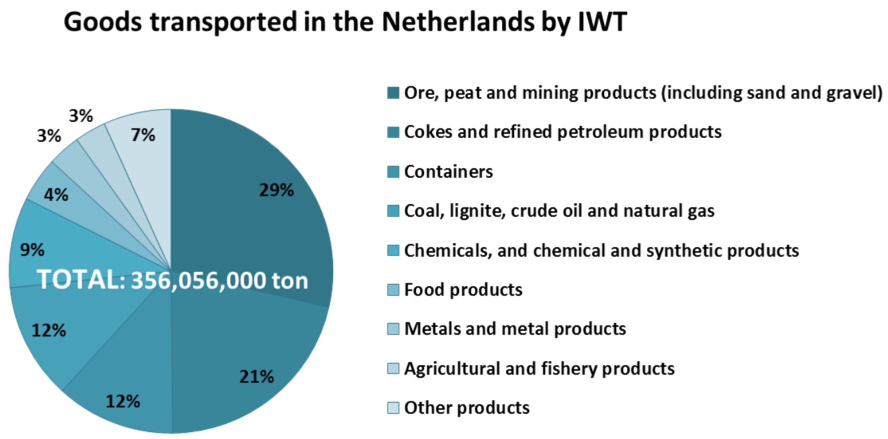

Figure 2.3: The breakdown of goods which are transported in the Netherlands by inland waterway transport in 2012. Data from [CBS, 2013]

2.1.3 The geographical area of operations

The goods mentionned in Chapter 2.1.2 are transported over Dutch waterways. The total length of Dutch navigable waterways in 2014 amounted to 6251 km [CBS, 2014]. Figure 2.4 shows the variety of Dutch waterways based on their character. In other words: it shows the different kinds of waterway contexts in which vessels can operate. Appendix C provides detailed descriptions of the categories in this figure and also provides a an overview of the Dutch waterways based on their size. It is needless to say that the navigable waterways are quite diverse in their size: the depth, width and curvature of the waterways are only some of the restricting factors.

Figure 2.6 shows how these inland waterways are distributed over the country. The largest ports for inland shipping, in terms of transhipments of tons of goods, are: Rotterdam, Amsterdam, Terneuzen, Vlissingen, Velsen, Moerdijk, Cuijk, Delftzijl, Utrecht and Oss [Bückmann et al., 2010]. Note that most of these are sea ports which also facilitate inland vessels.

By analysing metadata from the [CBS, 2013] on Dutch inland waterway transport, several important trends are revealed. Appendix B elaborates on how this quantitative analysis is performed.

- Of the total transport volume in tonkm, 38 % corresponds to exported cargoes, 25% of the volume corresponds to domestic transports, 19% is caused by imported cargoes and another 18% of the overall volume was caused by transit cargoes.
- 65% of the transport volume in tonkm comes from or goes to one of these four ports: Rotterdam (40%), Amsterdam (18%), Vlissingen (4%) and Terneuzen (4%).
- Cargoes which originate in Rotterdam and are exported to other countries are responsible for 23% of the entire transport volume in tonkm. International cargoes destined to Rotterdam represent another 6% of the overall transport volume in tonkm. Domestic transports which either originate from or are destined to the Port of Rotterdam, represent 11% of the overall transport volume in tonkm of Dutch inland waterway transport.

Another important trend that must be mentioned, is that the Dutch inland waterways are a vital part of two main transport corridors: the North-South axis and the Rhine corridor (e.g. [Hilferink, 1999]and [Beelen, 2011]). The North-South axis connects France, Belgium and the Netherlands. The Rhine corridor on the other hand, links the Eastern part of France with Luxembourg, the Netherland, Western Germany and Switzerland.The quantitatie analysis of metadata form the [CBS, 2013] shows that:

- 21% of all the overall transport volume can be attributed to import and export through the North-South corridor.
- 29% of the total transport volume can be attributed to import and export through the Rhine corridor.
- these corridors combined are responsible for 50% of all the tonkm of transported cargo by Dutch inland waterways.

The importance of the Dutch inland waterways is shown in Figure 2.5.

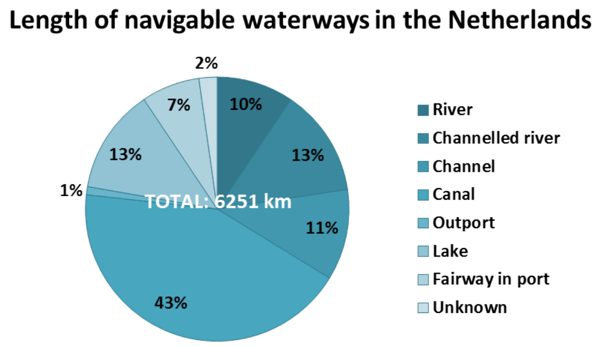

Figure 2.4: The length of waterways in the Netherlands in 2014 in kilometres. Data from [CBS, 2014]

Figure 2.5: The amount of transport on European inland waterways in mm tons. Image adapted from [CCNR, 2014b]

Figure 2.6: The transshipment points and container terminals in the Netherlands. Image adapted from [CBS, 2002]

2.2 The vessels in the inland shipping fleet

The flow of goods has been introduced in the previous subchapters. This section elaborates on the vessels that sail on these inland waterways and transport these goods. The common dimensions of inland vessels are presented and so are the typical types of vessels and their share in the European and Dutch inland fleet. Finally, the age of the fleet is examined and its overall capacity is discussed.

2.2.1 The dimensions of inland vessels

The maximum dimensions of vessels on certain waterways depend on "*the smallest locks located on that waterway (length and width) or by the depth of the waterway (draft). The air draught is limited by the height of the bridges crossing the water*" [van Hassel, 2011].

Since the dimensions of vessels are usually taken 'as large as possible', the main dimensions of inland vessels traditionally correspond to the dimensions of the waterways they sail on. The CEMT categories of the waterways indicate how large vessels can be on to sail on a certain waterway. These categories were introduced in 1992 by the [CEMT, 1992], which is the European predecessor of the OECD's international Transport Forum (ITF) (e.g. [International Transport Forum, 2015]). Table 2.1 shows that the categories distinguish between ships and coupled units. Coupled units exist of at least one ship (a pushing ship or a regular ship) and a number of barges. This means their configuration is not fixed. Usually all the vessels up to CEMT class II are considered to be small vessels, class III and IV ships are seen as medium ships, and all Va ships and coupled units are considered to be large (e.g. [van Hassel, 2011]).

Table 2.1: The CEMT classification of inland vessels. Based on [CEMT, 1992]

Class	Length (m)	Width (m)	Draft (m)	Air Draft (m)	Payload (ton)	Common Name
0	-	-	-	-	-	Pleasure boat
I	38,50	5,05	1,8-2,2	4.0	250-400	Spits/ Péniche
II	50-55	6,6	2,5	4 to 5	400-650	Kempenaar
III	67-80	8,2	2,5	5 to 5	650-1,000	Dortmund-Ems canal ship
IV	80-85	9,5	2,5	5,25-7	1,000-1,500	Rhine-Herne Canal/ Europa-ship
Va	95-110	11,4	2,5-4,5	5,25-7	1,500-3,000	Large Rhine ship
Vb	172-185	11,4	2,5-4,5	9,1	3,200 (1 x 2 barge coupled unit)	2 barge long combination
VIa	95-110	22,8	2,5-4,5	7-9,1	3,200-,6000 (2 x 1 barge coupled unit)	2 barge wide combination
VIb	185-195	22,8	2,5-4,5	7-9,1	6,400-12,000 (2 x 2 barge coupled unit)	4 barge combination
VIc	193-200	34,2	2,5-4,5	9,1	9,600-18,000 (2 x 3 barge coupled unit)	6 barge combination
VIIb	195/285	34,2	2,5-4,5	9,1	14,500-27,000 (3 x 3 barge coupled unit)	9 barge combination

2.2.2 The composition of the fleet

Information from the [EICB, 2015c] shows that the European inland fleet has approximately 18,000 cargo vessels. About 13,000 of these vessels sail in western Europe's Rhine region. When looking at the overall fleet capacity, it must be noted that there is currently some overcapacity. This overcapacity appeared after the economic crisis of 2008 and is still present today (e.g. [ABN AMRO, 2013], [Beelen, 2011] and [van Hassel, 2015]).

Table 2.2 gives the composition of the European fleet based on the size of the vessels. This table only distinguishes between two categories of vessels: ships and coupled units. An overview of the vessels that operate in the Rhine and North-South region, based on the different categories of vessels instead of the size of them, is provided in Table 2.3.

One may notice that these two tables have a different overall number of vessels.

Table 2.2: The active inland fleet of freight vessels in the Rhine countries, based on the size of the Vessels. Data from 2012 from [Buck Consultants International et al., 2014]

SHIPS Country	**I**	**II**	**III**	**IV**	**Va**	**Vb**	**Total**
Netherlands	223	825	1,467	940	906	159	4,519
Germany	29	85	687	443	193	2	1,439
France	620	155	191	35	7	0	1,008
Belgium	312	215	454	198	117	15	1,311
Switzerland	2	2	4	24	33	0	65
Luxembourg	3	2	6	14	3	3	30
TotalFleet	1,051	1,168	3,025	1,779	1,202	146	8,372
COUPLED UNITS	**IV**	**Va**	**Vb+**	**Total**			
Netherlands	335	846	33	1,214			
Germany	278	552	0	830			
France	137	394	17	548			
Belgium	51	196	20	267			
Switzerland	6	0	0	6			
Luxembourg	2	0	0	2			
Total Fleet	811	1,975	81	2,867	**OVERALL**		**11,239**

Table 2.3: The active inland fleet of freight vessels in the Rhine countries. Data from [EICB, 2015c]

Rhine Country	**Dry cargo Ships**	**Tankers**	**Push Boats**	**Dry Cargo Barges**	**Tank Barges**	**Tugs**	**Total**
Netherlands	3,993	1,240	649	1,135	51	479	7,547
Germany	916	419	285	789	44	140	2,593
France	860	44	93	383	47	0	1,427
Belgium	806	216	94	230	8	10	1,364
Switzerland	17	55	0	4	3	2	81
Luxemburg	8	16	11	0	2	0	37
Total	6,600	1,990	1,132	2,541	155	631	13,049

Apart from the more common vessel types which are listed in Table 2.3, some more specific types of vessels can be identified. Table 2.4 gives an overview of the different types of inland vessels. Concise descriptions of these vessel categories are provided in Appendix D.

Table 2.4: The various types of vessels in inland waterway transport. Categories mentioned by [Beelen, 2011], [Rijkswaterstaat, 2009] and [IVR, 2013]

Dry cargo ship and barge	Pushboat	Tug
Normal tanker (N type)	Chemical tanker (C type)	Gas tanker (G type)
Container ships and barges	Roro ship	Push barge for heavy goods
Car carrier	Powder tanker	Well barges and ships
Lighter vessel	Lighter aboard ship (LASH)	LNG-carrier
LPG-carrier	Oil-Bulk-Ore carrier (OBO)	Fishing vessel

2.2.3 The age of the inland fleet

The previous section shows the fleet composition, but this composition is in reality dynamic. This means that it changes over time. Another time-related aspect of inland shipping is the age of vessels. Several authors, including [Beelen, 2011], show that the majority of the inland vessels is considerably old. The age of a fleet depends on the number of scrapped vessels and on the number of newbuilds. It also depends on the number of imported and exported second hand vessels. The shipbuilding market, the scrapping market and the second hand market are constantly fluctuating, resulting in a complex evolution of the fleet composition. [van Hassel, 2014], for example, categorises vessels according to their width and shows how many of these vessels were built over the years. This can be seen in Figure 2.7, which clearly shows large fluctuations in the newbuild market.

[van Hassel, 2014] also shows the composition of the Western-European dry cargo fleet and shows how there is a significant age difference between the larger and smaller vessels. The medium and small sized inland vessels are considerably older than the large vessels. [van Hassel, 2011] reveals that the average age of small inland vessels (CEMT I and II) is 70 years, that of medium vessels (CEMT III and IV) is 59 years and that of large vessels (CEMT V and larger) is 26 years. These differences can be explained by the evolution of the fleet composition. Figure 2.8 and Figure 2.9 show the cargo capacity of the vessels and the number of inland vessels over the years. In an even more recent publication [van Hassel, 2015] looks into the evolution of inland tankers. The results from this study strongly resemble the results of the bulk-segment, which are shown in the next figures.

However, it must be noted that these figures show the age of the hull of the inland vessels and some may argue that this representation is irrelevant since most vessels have been modernised. When looking at the age of the engines for example, a similar conclusion can be made: the engines of inland vessels are quite old. This is because, in general, a diesel engine of an inland vessel is changed when it reaches about 35 years [Verbeek et al., 2015a]. More specifically, the interviews reveal that an engine gets some maintenance about every 10,000 running hours, a major revision is scheduled after about 40,000 running hours, and when it reaches 70,000 running hours is usually time to replace it. Figure 2.10 shows the age of the engines of the active Dutch inland fleet.

The categories which are used in this figure are the AVV categories for ships, which are similar to the CEMT classes. Appendix sE shows the relation between these different classifications of vessels.

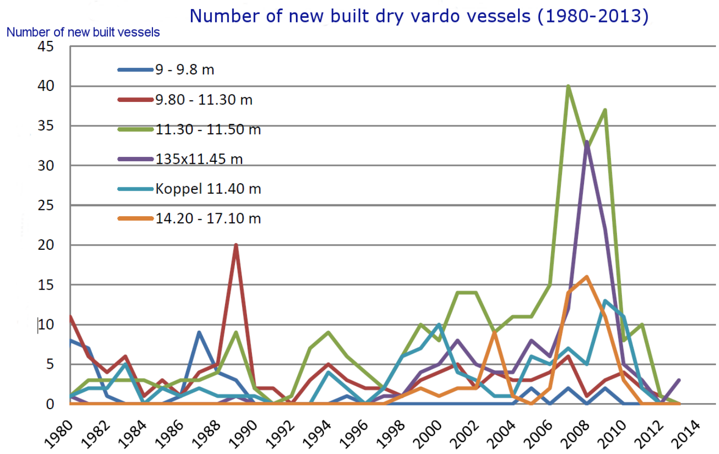

Figure 2.7: The evolution of newbuilds of dry cargo vessels, differentiated by their width. Image adapted from [van Hassel, 2014]

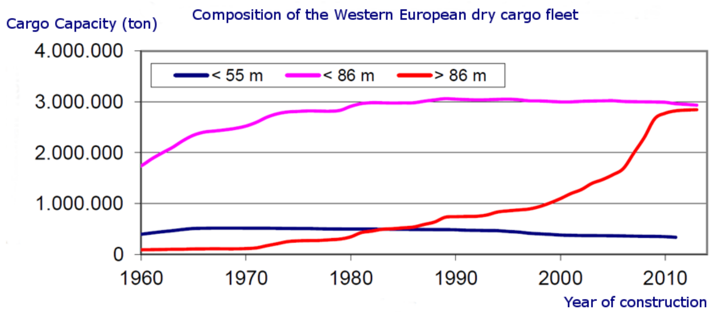

Figure 2.8: The evolution of the Western-European dry cargo fleet by cargo capacity. Image adapted from [van Hassel, 2014]

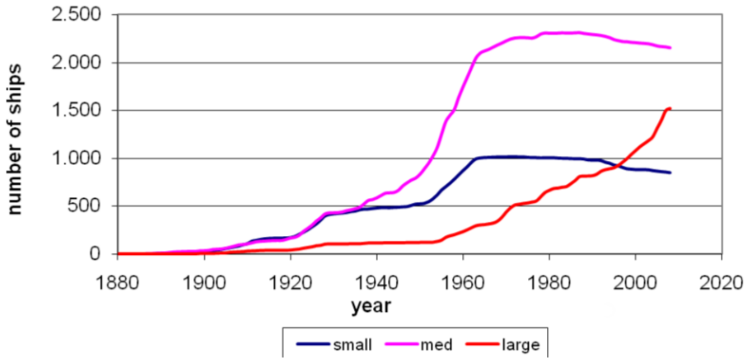

Figure 2.9: The evolution of the Western-European dry cargo fleet by number of vessels. Image adapted from [van Hassel, 2011]

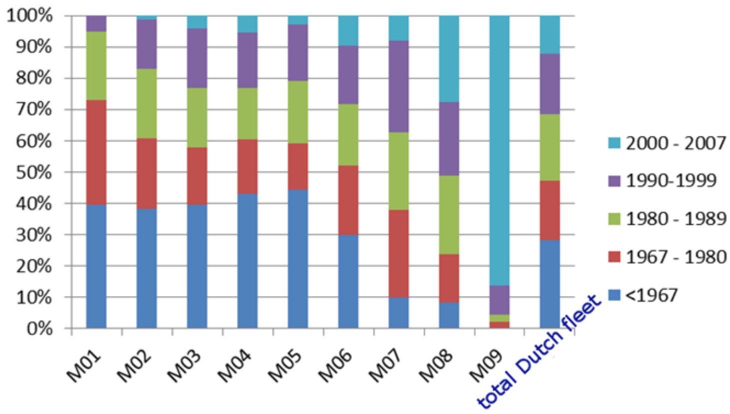

Figure 2.10: The age of diesel engines in the active Dutch inland fleet. Image adapted from [Verbeek et al., 2015a]

2.2.4 The capacity of the inland fleet

The capacity of the inland fleet is the combined cargo capacity of all the vessels, which is dynamic as shown by Figure 2.8. This capacity is is the supply side of the market and its relation to the demand of transport results in fluctuations of freight tariffs.

The over- or undercapacity in the inland shipping industry is the result of complex developments within the market. However, the importance of market segments must not be underestimated in this discussion. Some of the cargo capacity of the fleet is exclusive to some types of cargo. The capacity of tankers is for example only suitable for liquid bulk. This exclusivity means that these segments form distinct submarkets with their own supply and demand evolutions. Other market segments on the other hand, are interrelated. Dry cargo vessels can carry salt, grain and containers for example.

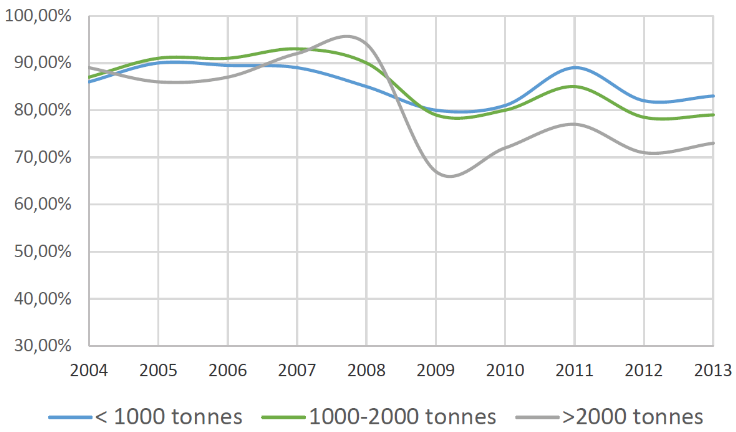

Figure 2.11: The evolution of the capacity utilisation rate of the inland fleet. Image from [CCNR, 2014c]

While the demand side of these commodities is not directly related to each other, their supply side is. Similar complex market relations exists between vessels of a different size. Small vessels may compete with large vessels for transports on large waterways, but large vessels do not compete with small vessels for cargoes on small waterways.

This discussion of interrelated markets can be elaborated to include the supply-side competition with rail and road transport. Another element in this discussion is the possibility of vessels to be retrofitted and switched from one market to another. The overcapacity within certain markets is also related to market fluctuations in the demand side and newbuilds and scrappings in the supply side.

In general, there is currently overcapacity in the inland shipping market. 2.11 shows that the capacity utilisation rate before the economic crisis of 2008 was around 90 % for small, medium and large vessels. After a steep drop in 2008 these rates have not yet recovered. The capacity utilisation rate of small vessels is in the low 80 % range, medium size vessels are just short of 80% and large vessels are the worst off, being at a capacity utilisation rate in the low 70% region.

This structural overcapacity has lead to low freight tariffs. While the demand-side actors are able to transport their cargoes for low freight tariffs, the supply-side actors are struggling to cover their expenses. The interviews reveal that all of the stakeholders are aware of this problem and are attentively following the evolution of freight prices and the cargo capacity in the inland waterway industry.

2.3 A typology of the financial structures

the previous sections look into the flow of goods and into the vessels that transport these goods. This section continues with the financial structures of the industry. First of all the ownership of vessels is introduced and the financing of vessels is described.

The expenses related to inland waterway transport are presented and finally, the freight contracts are looked into.

2.3.1 The ownership of inland vessels

The largest group of inland vessels is owned by a captain-owner. Captain-owners are those operators who are the captain of a vessel they own. These vessels are often also these people's homes and these businesses are often run without any land-based supporting staff. Data from [CBS, 2002] show that about 78% of all the inland vessels was owned by a captain-owner in 2002. As [Beelen, 2011] explains, operators with less than 5 vessels are all considered to be captain-owners. This way, owners who operate a pushboat and a some barges are also included. When considering the number of companies (instead of the number of vessels), about 95% of the inland shipping companies is operated by a captain-owner. Figure 2.12 shows the size of inland shipping companies in the Netherlands. It clearly shows that the share of larger shipping companies is significantly smaller than the number of captain-owners.

[Hubens, 2004] goes deeper into the situation of captain-owners and reveals that about half of the inland shipping captain-owners operate a dry bulk vessel in the Rhine corridor. Close to 20% of the captain-owners operate dry bulk vessels within the Netherlands or over the North-South axis. Another fifth of these enterprises transport sand and gravel in this region. This leaves about 10% of the captain-owners of which the majority operates container vessels or tankers.

Even though these data are from 2002 and 2004 it seems that the vast majority of inland shipping companies is still run by captain-owners. There are no indications that this situation would have changed in the past decade[2].

Vessels which are not owned by captain-owners are owned by shipping companies, commercial cooperations and own-account operators (e.g. [Beelen, 2011]). Cooperations are an example of horizontal cooperation in the inland shipping market: actors with the same role cooperate with each other. The shipping companies usually operate with a fleet of own vessels and chartered vessels. Even though shipping companies can be found in many inland shipping segments, the largest shipping companies operate in the liquid bulk market. The own-account operators are often large industrial companies that have some vessels to transport their own goods. Own-account operators can be found in the sand and gravel industry, but also in the oil, steel and energy industry. This is an example of vertical integration of the inland shipping market. Interviews with stakeholders reveal that this type of ownership is declining, which also seems to be the case for the number of large shipping companies.

[2] Just as with the fleet composition mentioned in Chapter 2.2.2, there is some ambiguity when it comes to how many of the vessels are owned by captain-owners. The figures mentioned by [Schrijvershof et al., 2015] do not show how many of the vessels are owned by captain-owners but the publication does state that over 70% of the inland shipping companies owns less than 6 vessels. Overall, these authors indicate that the amount of captain-owners is lower, but still very high.

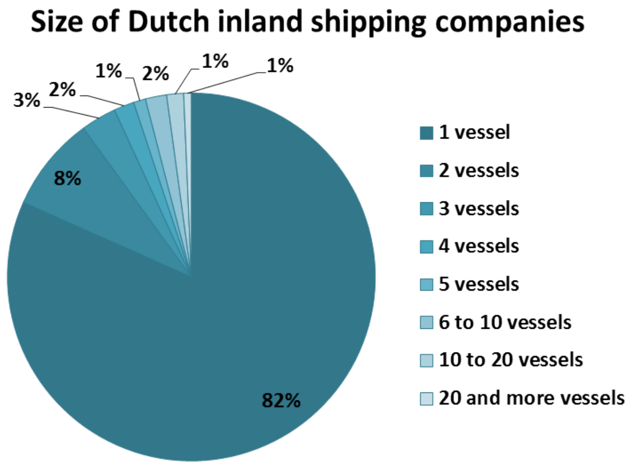

Figure 2.12: The size of Dutch inland shipping companies. Data from [CBS, 2002]

2.3.2 The financing of inland vessels

It is common in the inland shipping market for vessels to be financed by a mix of own capital and a mortgage credit from a bank. Rabobank is the largest bank which is active in the Dutch inland waterway transport market with about 60% of the market (e.g. [Duursma, 2014] and [Henne, 2013]). ABN Amro and ING have a smaller interest in the market of each about 20% (e.g. [d'Hont, 2013] and [Henne, 2013]). The percentage of own capital which is required to get a bank loan for a vessel usually ranges from 10 to 30% and these mortgage loans are often repaid over a period of 15 years [Beelen, 2011]. Just as with the deep sea shipping market, these figures change rapidly because they are closely linked to other economic indicators (e.g. [Stopford, 2009][3] and [CCNR, 2014c]).

Vessel owners who do not have enough own capital to obtain a loan from financial institutions, often resort to their family members. It also occurs that they find alternative ways of financing their ship through their relations in the industry. This may be arrangements with vessel brokers, in other situations the vessel owner appeals for help from the seller of the vessel, or even from their freighter if they have a good relationship. In 2015 another alternative method of financing a vessel was re-introduced in the Netherlands. The Kredietunie has been set up (again). This is a cooperation of inland shipping entrepreneurs that allows other (captain-) owners to obtain a loan to finance their vessel [Kredietunie, 2016]. Less common ways to procure an inland vessel are through limited partnerships, franchising and leasing a vessel. [Beelen, 2011]

[3] Stopford's handbook on maritime economics is an established publication about the economic structures of the deep sea shipping industry. The handbook explains the intricate effect of external economic fluctuations on the market of maritime transport. The same principles apply to inland waterway transport, albeit at a different scale.

2.3.3 The freight contracts in inland shipping

To pay for these vessels, shipping companies do their best to negotiate profitable freight contracts. There are three common options when it comes to freight contracts: shipping companies can operate on the spot market, arrange long-term contracts, or can opt for commercial cooperations with other shipping companies. [Beelen, 2011] meticulously explains how these types of contracting work for the inland shipping market.

When vessels operate on the spot market this usually means that freight contracts are arranged with the intermediary services of a freighter. These charterers link freight owners to owner-operators of vessels, often captain-owners. The freighters receive a commission for this work, which is usually a certain percentage of the freight tariff, in the range of 2.5% of the freight tariff. The freight tariff is often a price per ton cargo, which is very common for bulk cargoes. For other types of cargo a lump sum tariff can be set. This is often the case for project cargoes. A third way in which prices are set, is by agreeing on a tariff per day. Above these freight prices, some surcharges are common in the inland shipping market. These include fuel surcharges and demurrage.

The next type of freight contacts are long-term contracts. Most captain-owners who choose to sign long-term contract, opt for a long-term contract with a cargo owner, a shipping company or a charterer. The tariff is often fixed for the entire contract period with some additional surcharges, like in the spot market. There are several types of long-term contracts however: bareboat charters, time charters, single voyage charters and multiple voyage charters. The differences between these types of charters are about the accountability for certain expenses. The next subchapter, Chapter 2.3.4, goes deeper into this.

The third type of freight contracts in the inland waterway transport market, are the commercial cooperations between several vessel owners. These cooperations are organised in many ways. Some require exclusivity from their members while others do not. While some cooperations focus on the spot market, others specialise in long-term arrangements. A complete overview of the cooperations in the Western European inland fleet is given by [Schrijvershof et al., 2015]. The publication shows that about 20% of the shipping companies is a part of of a cooperation.

Image 2.13 shows how often the different types of freight contracts are used in different market segments of inland waterway transport.

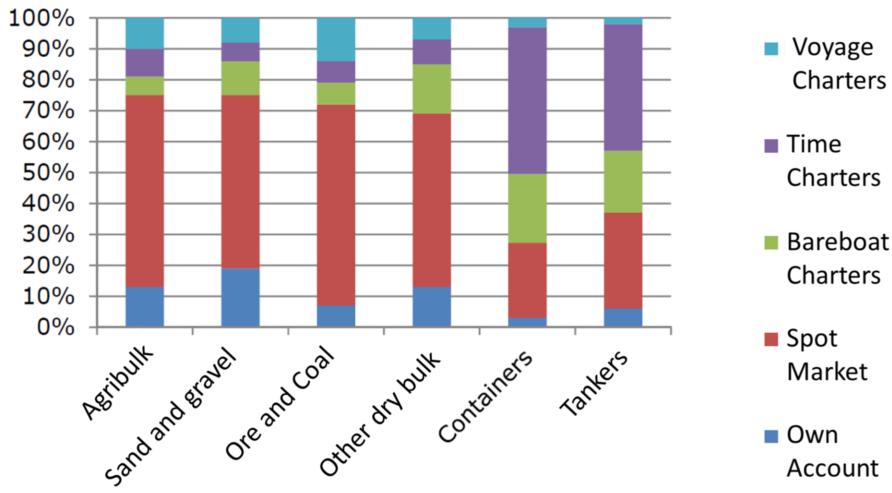

Figure 2.13: The freight contracts in different segments of inland waterway transport. Image adapted from [Schrijvershof et al., 2015]

2.3.4 The costs and expenses in inland shipping

The freight tariffs should cover the costs and expenses of the vessel operators to allow them to maintain a financially healthy business. An overview of the expenses which are related to inland navigation, is given in Table 2.5. It must be noted that when vessels operate with long-term contracts, these costs and expenses can be accounted for by different parties. In some cases the owner of the vessel covers the expenses, in other cases the one who is paying the owner takes on these costs. This is explained by several authors, including [Stopford, 2009] and [Pruyn et al., 2014].

Table 2.5: The costs and expenses related to inland navigation, and who pays for them in case of long-term freight contracts

Category	**Description**	**Voyage Contract**	**Time Contract**	**Bareboat Contract**
Voyage Expenses	fuel costs, consumables, port fees, cargo handling	Owner	Freighter	Freighter
Operational Expenses	Crew salaries, maintenance and repairs, insurance	Owner	Owner	Freighter
Capital costs	interests, depreciation, amortisation	Owner	Owner	Owner
Administrative costs	Legal costs, brokering, acquisition of new components and systems	Owner	Owner	Owner

Several publications look into the costs and expenses of owner-operators. [van der Meulen et al., 2009] is particularly clear in giving a detailed overview of the costs and expenses for several types of vessels and voyages.

2.4 The environmental performance of inland vessels

The previous section indicates that the depreciation of an inland vessel (and its components) is one of the costs vessel-owners have. This helps to explain why the engines of inland ships are quite old, as mentioned in Chapter 2.2.3. This has an effect on the environmental performance of the inland shipping industry. Even though the inland shipping industry is profiled a an environmentally friendly transportation mode (e.g. [Blue Road, 2014]), there are some growing concerns when it comes to its performance when compared to trucks.

The fuel economy and emission of CO2 per tonkm is quite low, as Figure 2.14 shows. When analysing data of [CBS, 2015] on the overall emission of CO2, it appears that inland waterway transport produces about 7% of the CO2 emissions of the road transport in the Netherlands. Because the share of other mobile sources in the emission of CO2 is limited, the inland shipping industry emits about 5% of the total amount of CO2 which is caused by mobile sources. The image also differentiates between two types of emissions: well-to-tank and tank-to-propeller emissions. The difference between both concepts is where the system boundaries are drawn. In the case of tank-to-propeller emissions the system boundaries are laid around the vessel (or the fleet), and the exhaust gas emissions which are produced by the vessel(s) are considered. In the case of well-to-tank emissions, the system boundaries are not around the vessel, but they are taken from the production process until the delivery on board. To the people in the vicinity of waterways, the tank-to-propeller emissions are more relevant since they are focussed on the local emissions of vessels. When analysing the problems in a broader view, with global warming in mind for example, the overall well-to-propeller emissions of CO2 are more relevant.

However, CO2 is only one element of the exhaust gas emissions which are relevant to the inland waterway transport industry (see Table 1.1). Figure 2.15 shows the performance of inland waterway transport based on the emission of NOx and PM. The image allows to compare the industry's performance to that of road transport, and it shows the evolution over the years. The image reveals that road transport is currently preforming better than inland waterway transport on this level. The image clearly shows the influence of legislation on the environmental performance of these transport modalities. The large 'jumps' in the emission levels correspond to new rules going into effect.

While there is a clear driver for vessel operators to reduce their CO2 emission (this means they reduce their fuel consumption and save on their voyage expenses), reducing other emissions does not have the same driver. It are mostly ports and other regulating authorities which are acting in the best interest of the general population to reduce these other emissions (e.g. [Weekhout, 2015]).

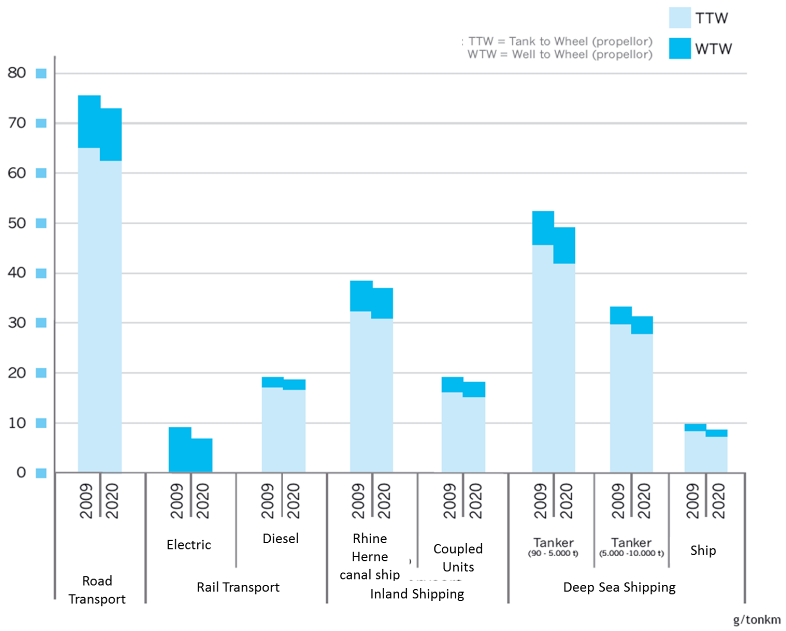

Figure 2.14: The emission of CO2 in gr/tonkm of inland waterway transport, compared to other modalities. Image from [Blue Road, 2014]

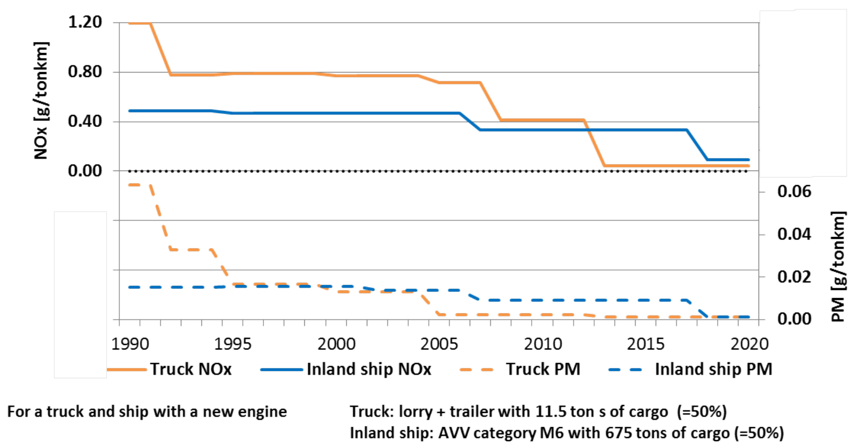

Figure 2.15: The emission of NOx and PM of inland waterway transport compared to that of heavy duty vehicles in gr/tonkm. Image from [Verbeek et al., 2015b]

2.5 Chapter conclusion

This chapter conclusion answers to the two research questions of this chapter: 'What does the inland shipping network look like' and 'what is the current status of the environmental performance of the inland waterway transport industry'. For this, the previous sections describe the flow of goods over inland waterways, the vessels in the industry, the financial structures in the market and the environmental performance of inland waterway transport.

2.5.1 What does the inland shipping network look like

The inland waterway network transports mainly liquid bulk, dry bulk and containers. Important types of dry bulk are sand, stone, gravel, coal and iron ores. Many of these cargoes are transported through the Rhine corridor which connects the Netherlands to Germany and Switserland, and the North-South corridor which links the Netherlands to Belgium and the north of France.

Approximately 8500 ships and another 3000 coupled units sail in this region. The size of the vessels varies from the smallest '*spitsen*' of less than 40 m, to coupled units with 9 barges measuring up to 285 m in length. The CEMT classes indicate how large the vessels operating on certain waterways can be. A more general distribution can be made between small vessels , medium vessels and large vessels. Small vessels are up to 650 ton payload or up to 55 m in length, medium vessels range from 650 to 1500 ton or up to 85 m in length, and the large vessels are ships and Coupled units with more than 1500 ton payload.

The inland fleet is quite old. Small vessels are the oldest group, averaging 70 years. The long lifespan of tangible assets in the inland waterway transport can also been seen in the age of engine. These are often replaced after about 70,000 running hours (which is after 35 years for many ships).

There is currently overcapacity in the inland waterway transport market which is leading to low freight tariffs. These tariffs are used to cover the costs and expenses of inland vessels. These are voyage expenses like fuel and port fees, operational expenses like maintenance, capital costs like depreciation, and administrative costs. The low freight tariffs are thus impacting the owners of inland vessels in a negative way. The vast majority of these owners are captain-owners who own only one ship. The number of shipping companies that own and operate more than 5 ships is limited. The financing of (changes to) vessels is more difficult is this market. This is because banks and financial relations still want to have the same level of securities, but it is harder to show them that a vessel will have a healthy income. Especially owners of vessels that operate in the spot market may have a hard time convincing banks of their secure financial outlook. Long term contracts like time charters and bareboat charters offer a more stable revenue, but are less common in the industry. This is because it requires vessel operators to give up some of their autonomy.

2.5.2 What is the current status of the environmental performance of the inland waterway transport industry

Inland vessels have a good fuel economy when compared to other transport modalities. However, because diesel engines are replaced only once every 35 years, many vessels are still running on old diesel engines which have high NOx and PM emissions. In addition to these high emissions of these old engines, the emission platforms for new inland shipping engines have not evolved at the same pace as those for engines in the automotive industry. This means that the emission of NOx and PM of modern inland vessels is worse than that of modern lorries, both in gr/kWh as gr/tonkm. The inland shipping industy's concern is growing about its environmental performance being worse than that of road transport. This is an especially delicate subject since the inland waterway transport's environmental performance has historically been better than that of road transport.

Stricter European emission requirements are expected to go into effect in 2020 (Stage V engines). Initiatives that will affect the emission requirements for all vessels have been announced as well. The port of Rotterdam intends to allow only vessels which meet the CCNR2 requirements, starting 2025. The inland shipping industry is thus not only challenged to reduce the CO2 emissions, but also other exhaust gas emissions like SOx, Nox and PM.

Chapter 3

The stakeholders influencing environmental innovations

This chapter answers the research question: 'who are the stakeholders in the Dutch inland waterway transport network'. First, an overview of the types of stakeholders is provided and, very briefly, the type of innovations these stakeholders are related to are also introduced. More information on the innovations is provided in Chapter 4 but first, this chapter provides in-depth analyses of the most influential stakeholders. A conclusion which answers this chapter's research question ends the chapter.

3.1 The overview of stakeholders in the inland shipping network

Several of the inland shipping market's stakeholders have been mentioned in the previous sections. Ship owners, banks and freight owners, for example, have been mentioned in Chapter 2. But these are not the only stakeholders of the inland shipping industry.

The stakeholders which are indispensable to inland waterway transport can be classed into eight categories. Table 3.1 shows these categories and provides some examples of the stakeholders and the type of innovations they relate to. A more extensive visual network of stakeholders is included in Appendix F. More information on the innovations which are listed in the table, can be found in Chapter 4.

To clarify the role in the inland shipping network of the stakeholders which are mentioned in Table 3.1, a visual representation of their position in the transport chain is given in Figure 3.2. The figure shows that cargoes are transported by inland waterway transport from their origin to their destination, and that some pre- and after-transport may be needed to do so. The stakeholders mentioned in Table 3.1 are shown at their corresponding position in the transport chain: from the origin of the cargo to its destination.

Rather than just listing the stakeholders and showing their position in the transport chain, the following subchapters include a stakeholder analysis for each of the actors shown in the overview. The stakeholder analyses are based on the method of Business Model Canvas Studies which is an established tool to make stakeholder analyses (e.g. [Ostervalder and Pigneur, 2010]). This method has been used previously in other publications looking into stakeholders of the inland shipping industry (e.g. [Posthumus et al., 2012])[1]. The aspects which are discussed in this chapter are:

- The stakeholders' core activities
- The stakeholders' value proposition
- The stakeholders' revenue model
- The stakeholders' relations to other stakeholders
- The stakeholders' drivers towards improving inland waterway transport's environmental performance
- The stakeholders' attitude towards environmental innovations
- The stakeholders' considerations in the adoption of environmental innovations

Each of these aspects is discussed in the following subchapters and at the end of each subchapter, a concise overview of the main findings is given in a table.

[1]Numerous stakeholder analyses techniques exist. [Bryson, 2004] for example introduces 15 different stakeholder identification and analysis techniques. The business model canvas method is chosen because it is a modern but well-known technique in the Dutch research and consultancy context. By basing this research on a BMC, other researchers are enables to easily compare the findings of this research with other publications focusing on the stakeholders of Dutch inland waterway transport.

Table 3.1: The overview of stakeholders of the Dutch inland shipping industry. Own composition.

Category	**Stakeholders**	**Innovations**
Vessel operators	Captains, crew, owner-operators, operators, shipping companies, ...	Training of captains, cold ironing, ...
Demand-side actors	Freight owners, freight forwarders, freighters...	Network integration, planning tools, ...
Supply-side actors	Ship yards, suppliers of equipment, vessel brokers, ...	New engines, alternative propellers, ...
Regulating authorities	IMO, EU, CCNR, the Netherlands, Port of Rotterdam, ...	Taxes and charges, prohibitions and requirements, ...
Financial relations	Banks, private investors, partners in commercial partnerships, ...	Related to all the innovations
Operational relations	Transhipment hubs, terminals, ports, waterway infrastructure manager, ...	Advanced route planning, IT support, policy measures, ...
Competitors	Other operators of inland vessels, road, rail, air, deep sea shipping, short sea shipping,...	Hubs, planning tools, ...
Society	Advocacy groups, (end-) users of transported cargo, people in vicinity of waterways, NGO's, ...	Related to all the innovations

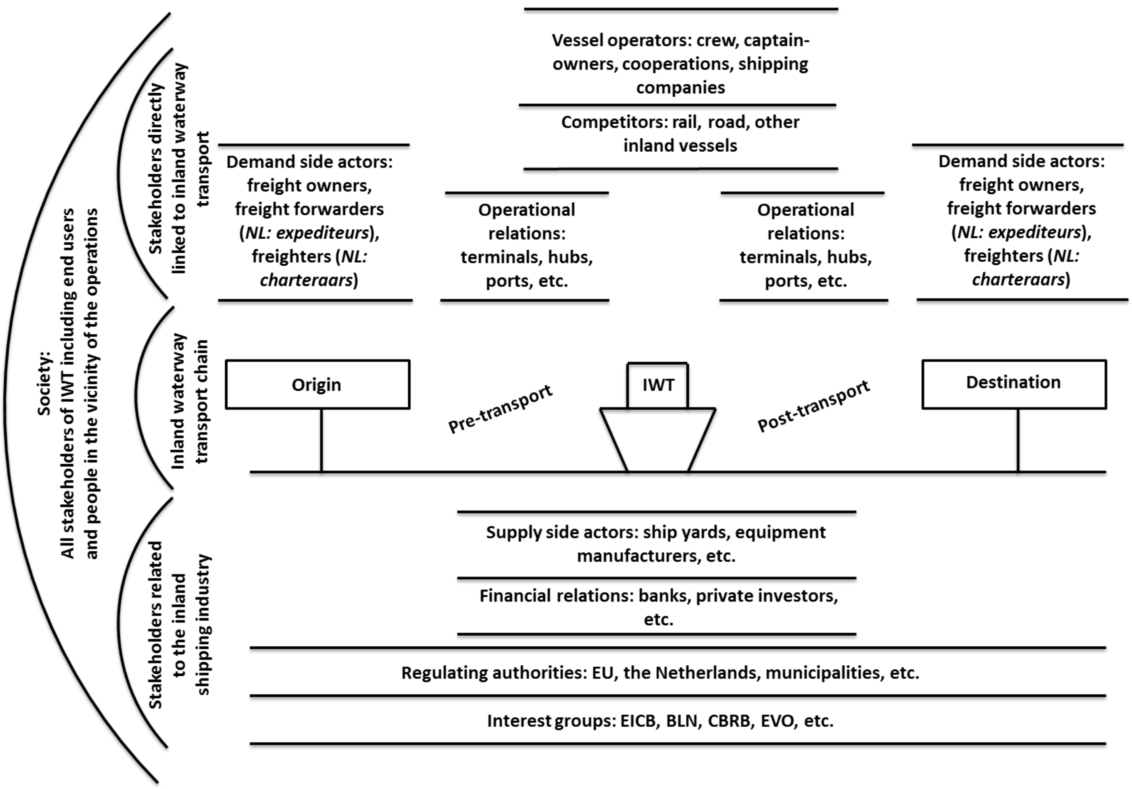

Figure 3.1: The stakeholders of the inland shipping transport network. Own composition.

3.2 The owner-operators of vessels

The core activity of owner-operators of inland vessels is taking care of the actual physical transport of cargoes. Owner-operators are the captain-owners, cooperations and shipping companies and their crews which are introduced in Chapter 2.3.1. They are the ones who are responsible for the physical transport of cargoes by inland waterways from their origin to their destination. The loading and unloading of the vessels may or may not be their responsibility.

The value proposition of owner-operators is their availability to transport cargoes. The size of their vessels is crucial in this: the cargo capacity in terms of weight and volume must be large enough for the cargoes, but the dimensions of the vessels determine if they can reach the loading and unloading locations safely. Owner-operators compete on their freight price and how quickly they can transport a cargo. The interviews reveal that owner-operators pay attention to maintain the reputation of a reliable partner. This is because freight owners who doubt if the owner-operators will meet the agreements, may prefer to contract another owner-operator for the transport.

The revenue model of owner-operators has been introduced in Chapter 2.3. The chapter clarifies that owner-operators get paid according to their freight contracts. The types of these freight contracts are described in Chapter 2.3.3. The freight tariffs they receive for transporting the cargo, are used to cover their expenses. Chapter 2.3.4 provides some information on the voyage expenses, operational expenses, capital costs and administrative costs of owner-operators.

Owner-operators have many relations to other stakeholders in the inland shipping industry. First of all, they have contact with freight owners to get freight contracts. Intermediary partners may be used for this, these are freight forwarders and freighters who can link owner-operators to freight owners. During their operations, owner-operators have contact with their operational relations such as ports, terminals and the operators of locks. During their operations, they must comply with the rules of several regulating authorities. When they unload their goods they can also be in direct contact to the owner of the cargo. This can be the case when, for example, a load of coal is delivered to a power plant: the coal is unloaded by the plant's private facilities at its own unloading berth. Apart from these relations to the other actors in the transport chain, owner-operators also have contact with the other stakeholders of the inland waterway industry. Especially when they acquire a new vessel or retrofit their existing vessel, they have contact with supply-side actors and their financial relations.

When it comes to the environmental performance of inland waterway transport, owner-operators have an internal motivation to improve their own fuel consumption and thus the emissions. This is because any reduction of their fuel consumption has a direct impact on their voyage expenses. The focus of owner-operators lies in reducing their emission of CO2 which is directly related to the fuel consumption. However, the financial situation of many owner-operators is under a lot of pressure. Their liquidity is limited and many actors have a poor financial perspective.

On the downside, owner-operators have no direct internal drive towards the reduction of pollutants such as NOx, SOx, VOC's and PM. The interviews clearly show a different attitude towards the reduction of pollutants, most owner-operators only wish to reduce these emissions to meet the requirements and to safeguard the continuity of their business. However, there is a group of owner-operators which is noticeable motivated to invest in these technologies. These are, generally speaking, in a relatively strong financial position (e.g. with long-term contracts in the container market) and are aiming to ensure their vessel's long-term continuity. They too do not want to experience any problems when stricter regulations go into effect and more importantly, they want to be prepared for when their clients start to demand improvements in the environmental performance of their transport.

With respect to the adoption of environmental innovations, owner-operators are very careful when considering to take risks. Their risk-averse nature towards new technologies is mentioned in different publications, including [Kansen and Visser, 2015], and is underwritten by the interviews. Owner-operators prefer not to be the first to try a new technology out and are likely to wait until a concept has proven itself. That is why owner-operators try to stay informed about the experiences of others in the industry and follow the results of pilot projects and demonstrators. To stay informed, they maintain good relationships with their contacts in the industry and they read up on the industry-specific news. This can be offered by advocacy groups and sector organisations.

The interviews also reveal that owner-operators tend to consider new technologies when the lifespan of their components are nearing their end, or when they believe they could considerably reduce their expenses. Other important considerations to vessel operators are the living and working comfort they experience on board. Systems which require little maintenance, changes which reduce the wear on the vessel's components, and adaptations which directly improve the operators' on-board experience (noise, vibrations, smoke) are found interesting. Some owner-operators also see the adoption of environmental innovations

The opinions about operational innovations are quite diverse, in contrast to logistical innovations which consistently seem to be a bridge too far for most owner-operators. The architectural changes of transport chains are not seen as something they have an influence over, while owner-operators do acknowledge the large potential of these changes. Policy measures and support from advocacy groups are perceived to be some of the main drivers in the adoption of environmental innovations. Subsidy programs in particular are found to be essential.

Table 3.2: The stakeholder analysis of owner-operators' position in inland waterway transport

Aspect	**Description**
Core activities	Taking care of physical transport of cargoes
Value proposition	Being available to transport cargo, having enough cargo capacity, being able to reach the origin/destination, offering low prices, providing fast transport, being reliable
Revenue model	Freight tariffs cover voyage expenses, operational expenses, capital costs and administrative costs
Main relations	Demand-side actors are the client. Aksi related to operational relations, supply-side actors, financial relations and regulating authorities
Drivers towards environmental innovations	The reduction of fuel consumption is the main driver. Owner-operators are focussed on CO2 reduction rather than on the reduction of pollutants
Attitude towards environmental innovations	Risk averse but willing to invest if innovations perform well on their considerations. Their willingness to invest is highest at a natural moment to replace a component. Focussed on technical and operational innovations.
Considerations	Minimising investment costs, reducing expenses, improving living and working comfort, moderating maintenance, mitigating risks

3.3 The demand-side actors

The demand-side actors are the freight owners and the intermediary partners linking the freight owners to vessel operators: freight forwarders and freighters. This means that freight owners do not have the transport of goods as one of their core activities. Transport is just required for them to perform their core activities. The example of a power plant receiving coal can illustrate this. The core activity of the original owners of the coal is mining coal, that of the destination's freight owner is producing energy. Transporting coal is thus merely a derivative of the demand-side actors' core activities.

Whichever core activities the freight owners may have, their value proposition is often the same: offering superior services or goods at a competitive price. The freight owners therefore focus on a low price of transport, and they always prefer to have their cargo transported sooner rather than later. The interviews reveal that, the environmental impact of the transport hardly gets any attention from freight owners. Only in some cases have the respondents of the stakeholder interviews noticed that the freight owners were interested to know the carbon footprint of the transport. Even while the respondents expect the freight owners' interest in the environmental performance to grow, up until now they do not experience any willingness of freight owners to pay (even a bit) extra for transport which has a better environmental performance. There does seem to be a drive towards low freight tariffs and thus fuel-efficient vessels.

Apart from sometimes dealing with operational relations such as ports and terminals, freight owners usually only have contact with freight forwarders, freighters and vessel owner-operators.

Freight forwarders offer the service of taking care of the transport of cargo. They can be compared to a regular postal service. The client pays for its 'package' to be delivered without having to worry about anything. In other words: freight forwarders are contracted by freight owners to take care of their transport. Freight forwarders can have direct contact with owner-operators, but they can also use the services of freighters to find vessels which can transport the cargo.

These freighters have a more limited service than freight forwarders do. Freighters (also called charterers) link freight owners with owner-operators and they are an intermediary partner during freight contract negotiations. For their service they receive a commission which is usually about 2.5 % of the freight tariff. Freight owners can also play an intermediary role in the process of paying freight tariffs. In that case, their commission usually doubles to 5%.

Some freighters, mainly in the container segment, have a slightly different role. They have some long-term contracts with owner-operators to guarantee regular calls at certain terminals. Freight owners in this case have a contract with the freighter rather than with the owner-operators. These freighters could be described as shipping companies that do not own any vessels of their own. Most freighters, however, operate on the spot market and do not have any long-term contractual commitments with owner-operators.

The interviews reveal that freight forwarders and freighters do not yet seem to experience any internal drivers towards improving the industry's environmental performance. However, they are convinced it will not take long for their clients to ask for environmentally friendly transport. The carbon footprint of the transport is something some of their clients are already interested in, albeit rarely. The further growth of this interest will give freight forwarders and freighters a direct interest in the environmental performance of the industry. They will actively need to contract vessels with a demonstrable superior environmental performance to not lose any of their clients. Still, both freight forwarders and freighters currently have a rather distant attitude towards environmental innovations in the inland shipping industry. They are convinced that they will be able to match the demand-side actors to the supply-side actors of environmentally friendly inland waterway transport.

Even though they are generally indifferent towards environmental innovations, freight forwarders and freighters do have an internal drive towards improving the share of inland waterway transport in the modal split. The interviews reveal that these actors are actively trying to convince (new) freight owners to choose inland waterway transport by highlighting its benefits. The low costs, low $CO2$ emissions and the high reliability of the arrival time are the main arguments they use to promote inland waterway transport. They make this effort because it is an opportunity to expand their business.

While freight forwarders and freighters do seem to agree on this point, the interviews show they also differ at certain points. The considerations they have in their decision making processes, for instance, are quite different. While freighters focus on having a reliable, constant, frequent service, freighters focus on maintaining good relations with owner-operators and freight owners. Contrary to their negative image of being opportunistic money grubbers, they try to find a balance between how satisfied freight owners and owner-operators are about the freight tariffs they help to negotiate. This is because they may lose business when one of the negotiation partners is repeatedly disappointed: if their clients are often unsatisfied by the freight tariffs they will contact another freighter instead which would mean they miss out on this business.

Table 3.3: The stakeholder analysis of freight owners' position in inland waterway transport

Aspect	**Description**
Core activities	Producing goods and/or offering services
Value proposition	Offering superior goods or services at a competitive price
Revenue model	Sales revenue covers the cost of production, transport and other costs
Main relations	They are the client of freight forwarders, freighters and owner-operators. Also related to operational relations
Drivers towards environmental innovations	Internal drive towards low freight tariffs and thus fuel-efficient vessels. The carbon footprint in gaining attention slowly
Attitude towards environmental innovations	Many are not (yet/often) willing to pay extra for transport with a better environmental performance
Considerations	Minimising cost of transport, reducing speed of transport

Table 3.4: The stakeholder analysis of freight forwarders and freighters' position in inland waterway transport

Aspect	**Description**
Core activities	Matching freight owners with owner-operators and negotiating freight tariffs
Value proposition	Being a reliable partner with reasonable freight contracts and tariffs
Revenue model	Commissions or freight tariffs cover the various costs
Main relations	Freight owners are their client and they themselves are the client of owner-operators. Also related to operational relations
Drivers towards environmental innovations	Internal drivers towards improving the share of inland waterway transport in the modal split, but no internal drivers towards improving the environmental performance of inland waterway transport itself. The growing interest of freight owners in this may change this.
Attitude towards environmental innovations	Often an indifferent attitude towards innovations.
Considerations	Good long term relations, improving continuity, reducing costs

3.4 The supply-side actors

Supply-side actors are related to the production and the keeping in service of vessels. Ship yards, vessel brokers and suppliers of equipment are all supply-side actors.

Vessel brokers are not analysed in this research because they do not have an active role in the adoption of environmental innovations in the inland shipping industry. Vessel brokers only come into play when vessels are sold. This process of inland vessels being sold to new owner-operators is not related to any technological, operational or logistical changes. Vessel brokers do not influence the adoption process of environmental innovations and are therefore not further considered.

Opposite to vessel brokers, ship yards and equipment suppliers do have an influential role in the adoption process of environmental innovations in inland waterway transport. The suppliers of equipment are the ones who offer innovative technologies and they try to exploit the commercial potential of environmental innovations. Equipment suppliers include engine manufacturers, companies providing navigation software, companies which offer ship design services, enterprises offering biofuels and many others.

The core business of these companies is producing their products and selling their services, but since they often work on innovative technologies, they also invest in research and development. Their value proposition is often to offer superior products and services. Depending on the type of equipment and services they offer, this may be: less costly to operate, cheaper to purchase, faster to install, complying to rules and regulations, easier to operate, and so on. The value proposition of ship yards is similar. The most important factors that vessel owners take into account when they decide on a ship yard is their availability, their cost, and how fast they can do the work. These topics are what ship yards focus on.

When it comes to the revenue model of these companies, their main source of income is the revenue created by the sales of their products and services. The relations to other actors in the inland waterway transport industry are mainly their (potential) clients. Suppliers of equipment and ship yards also keep track of their market competitors' activities, to stay informed of the market developments which may influence their activities.

Both the literature and the interviews reveal that supply-side actors have an entrepreneurial approach when it comes to improving the environmental performance of inland waterway transport. They see the market potential of environmental innovations and believe it is a way for them to earn money. Supply-side actors also keep in contact with advocacy groups. The criteria in their decision making processes revolve about maximising profits. This can be accomplished by lowering costs and increasing the revenue. An important factor in this, is increasing the number of clients. Therefore supply-side actors need to build good relations with their clients so mouth-to-mouth advertising will give them a solid reputation.

One important aspect to point out in the discussion of supply-side actors is related to the cost of R & D and the limited size of the inland shipping market. The stakeholder interviews reveal that in many cases, especially in the case of companies which are primarily focussed on the deep sea shipping industry, the cost of developing technologies suitable for the inland shipping industry does not weight upto the market potential of these products. While it is of a matter of developing the products based on research which has been performed while targeting its other markets, this cost or effort is found to be not financially interesting enough by engine manufacturers. Developing diesel engines which meet ambitious emission norms for the limited market of the inland shipping industry is apparently not considered economically viable for several of the large engine manufacturers. Suppliers mention this themselves and regulating authorities are forced to take this into account when creating their policy.

Just to indicate the size of the inland shipping markets: there are 8,372 inland ships operating in the Rhine countries as shown in Table 2.2 while there are 104,304 merchant ships sailing the oceans [IMO Maritime Knowledge Centre, 2012]. The reluctance of supply-side actors to invest in products for what they consider a small niche market, is therefore understandable. This problem of a limited is gaining attention in the inland shipping industry [CBRB, 2014]. Even so, some companies are focussed on this niche market and are able to maintain a healthy business in the inland shipping industry.

Table 3.5: The stakeholder analysis of the suppliers of equipment's position in inland waterway transport

Aspect	**Description**
Core activities	Creating and distributing equipment and systems, and offering related services
Value proposition	Offering superior goods or services at a competitive price: less costly to run, cheaper to purchase, faster to install, complying to certain requirements, easier to operate, ...
Revenue model	Sales revenue covers the cost of production, R & D and other costs
Main relations	Competitors, owner-operators, ship yards, advocacy groups
Drivers towards environmental innovations	internal interest to exploit the commercial potential of environmental innovations
Attitude towards environmental innovations	Entrepreneurial approach
Considerations	Increasing market potential, maximising profits, maintaining a good reputation

Table 3.6: The stakeholder analysis of ship yards' position in inland waterway transport

Aspect	**Description**
Core activities	Designing and building new vessels, repairing and retrofitting existing vessels
Value proposition	Being available, having competitive prices, quickly completing the work
Revenue model	Prices cover the cost of materials, working hours and other costs
Main relations	Vessel owners are their clients. They are clients of suppliers of equipment. Also related to regulating authorities
Drivers towards environmental innovations	Internal interest to exploit the commercial potential of environmental innovations
Attitude towards environmental innovations	Entrepreneurial approach
Considerations	Good long-term relations, reducing costs, maintaining healthy order book

3.5 The regulating authorities

There are several regulating authorities related to inland waterway transport, as introduced in Chapter 1. Before zooming in on some of them, an overview of the various regulating authorities and their most important regulations is given in the Table 3.7. This overview is based on information provided by [EURLex, 2015], [Rijksoverheid, 2015], [CCNR, 2015a], [Zeilcollege, 2014], [Port of Rotterdam, 2015] and [Port of Amsterdam, 2015].

The CCNR and the EU are international authorities that create rules and regulations related to inland waterway transport. Rules of the CCNR are generally directed to navigation on the Rhine while the EU's rules are applicable to all the waterways of its member states. Note that the EU is a very broad organisation, and that DG MOVE and DG CLIMA are most relevant to the adoption of environmental innovations in inland waterway transport.

The CCNR has a rich history which dates back to the early 1800's (e.g. [CCNR, 2015b]), which makes the CCNR considerably older than the EU which only goes back to the 1950's (e.g. [EU, 2015b]). The EU's core business is creating European policy through democratic mechanisms. The CCNR's core activities nowadays are coordinating and advising different parties related to inland waterway transport. The EU, and the CCNR in particular, carry out research to national differences in the inland shipping market. The CCNR also makes market observations and develops instruments to monitor the economic situation of inland waterway transport. Its cooperation with the European Union has never been so intensive. This can be attributed to a shift in responsibilities: the CCNR will not be making the next emission norms for engines in the inland shipping industry, it is the EU which will decide on them soon. However, due to its valuable experience with regulations targeting the inland shipping industry, the CCNR is able to advise the EU when it comes to new regulations.

The value propositions of the EU and the CCNR are similar. They both try to safeguard high safety standards for both the navigation and the environment. To EU and the CCNR both work on having a unified and fair regulation system for the inland shipping industry, but there are, obviously, some differences. While the CCNR aims to ensure the prosperity of inland navigation on the Rhine, the EU must also consider the other transport modalities in its decisions.

The revenue model of the EU is rather complex. It is mainly funded by contributions of all its member states and by import-duties of products being brought into the EU [EU, 2015c]. The CCNR receives funds from its member states and the European Commission [CCNR, 2015c]. The resources available for sustainable innovations in the inland shipping industry are much greater in the EU than in the CCNR

The evolution of the relation between the CCNR and the EU has recently accelerated. In 2013 the CCNR and DG MOVE have signed an agreement to cooperate on their common objectives [CCNR, 2015c]. However, the stakeholder interviews reveal that there do seem to be some areas of friction. The plans of the EU concerning the emission norms of inland shipping engines are an example of this. These plans are believed to

Table 3.7: The most influential authorities and some of their policies which are relevant to Dutch inland waterway transport

Authority	**Regulations**
European Union	2006/87 EC, 2006/137 EC: Technical requirements vessels
	2007/414 EC: Technical guidelines RIS (River Information Services)
	2008/181 EC: Promotion of inland waterway transport
	1999/32 EC: Reduction of sulphur contents
CCNR	Revised convention for Rhine navigation (herziene Rijnvaartakte/ akte van Mannheim)
	Convention on the collection, deposit and reception of waste produced during navigation on the Rhine and inland waterways.
	European agreement concerning the international carriage of dangerous goods by inland waterways
	Agreement on the social security of the Rhine boatmen
The Netherlands	Binnenvaartbesluit
	Scheepsafvalstoffenbesluit Rijn- en binnenvaart
	Goedkeurings- en uitvoeringswet verdrag inzake de verzameling, afgifte en inname van afval in de Rijn- en Binnenvaart
	Besluit tot verlenging van de vrijstelling accijns voor de binnenvaart
	Wet vervoer gevaarlijke stoffen
	(Tweede tijdelijke besluit laden en lossen binnenvaart; to expire in July 2015)
Regional	Scheepvaartreglement Westerschelde
	Scheepvaartreglement kanaal van Gent naar Terneuzen
	Binnenvaart politiereglement
	Rijnvaart politiereglement
	Scheepvaartreglement gemeenschappelijke Maas
	Scheepvaartreglement Eeemsmonding
Ports	Havenbeheersverordening Rotterdam/ Schiedam/ Dordrecht/ Zwijndrecht/ Papandrecht
	Havenverordening Amsterdam/ Velsen/ Beverwijk/ Zaanstad

be too ambitious so the CCNR is advising the EU to focus its efforts on more realistic options. Another interesting difference between the CCNR and the EU are its decision making processes. The decision process of the EU takes a long time but the countries do not have the power to halt decisions on their own. The faster process of the CCNR has as a downside that decisions must be taken unanimously so there is the risk that a single country may block a decision.

These points of difference are important to the third authority in Table3.7: the state of the Netherlands. The interviews show that the ministry of infrastructure and Environment must consider these differences when looking for partners in the realisation of regulations. The ministry has a large autonomy in creating its policy, but since environmental policies are mostly decided on a European level it is forced to find partners amongst its international relations. The Ministry of Infrastructure and Environment has similar interests as the EU and the CCNR. They are driven to improve the air quality and to reduce the emission of GHG emissions. This reduces the negative impact it has on public health and the environment.

The Ministry of Infrastructure and Environment works on safeguarding "*liveability and accessibility, with a fluent throughput in a well organised, clean and safe environment*" [Ministerie van Infrastructuur en Milieu, 2015]. Its focus area covers rails, roads, water and air in the Netherlands. A team within the ministry focuses on the management of inland shipping. This team tries to act in the best interest of the inland waterway transport industry. This means it works on improving the industry's environmental performance to keep it at a competitive level with road transport, but is also aims to protect the livelihoods of owner-operators which are discussed in Chapter 3.2.

The CCNR, the EU and the Dutch Ministry of infrastructure are convinced that new regulations are needed, and they are working on creating rules for navigation powered by alternative energy sources. When they create new regulations they try to formulate clear rules, which can be a challenge when dealing with complex matter like reducing various emissions. These regulating authorities are also starting to become careful about not repeating past mistakes. The Ministry of Infrastructure and Environment, for example, expects real-life emissions to become more important in regulations, in contrast to (theoretical) emissions measured at certain operating points of an engine. The actual work of checking if vessels comply with the rules is carried out by the inspection authories. Classification societies (such as DNV GL) also play a role in certifying vessels' compliance to rules. Apart from communicating with classification societies, regulating authorities also keep in touch with advocacy groups that represent the other stakeholders of the inland shipping industry.

The other regulating authorities mentioned in Table 3.7 are the regional authorities and Port authorities. Port authorities are discussen in Chapter 3.7 which focuses on the operational relations of vessel operators. The regional authorities are less relevant when discussing the adoption of environmental innovations. They role is more limited, their policies are often in line with the national direction set out by the Ministry of Infrastructure and Environment, and their budget available to support the adoption of environmental innovations is limited.

Table 3.8: The stakeholder analysis of the EU and CCNR's position in inland waterway transport

Aspect	**Description**
Core activities	Creating policy and monitoring the development of inland waterway transport
Value proposition	Safeguarding safety standards and fair regulations
Revenue model	Mostly contributions from member states cover the organisations' costs (staff, research, subsidy programs, ...)
Main relations	Plenty of contact with other regulating authorities. Also in contact with advocacy groups and research organisations
Drivers towards environmental innovations	Internal drive to improve air quality and its effects on public health. Also internal drive to reduce greenhouse gas emissions and its negative effect on the environment
Attitude towards environmental innovations	Setting ambitious goals, trying to find realistic ways to meet the goals, focus on both pollutants and greenhouse gases, stimulating inland waterway transport
Considerations	Ensuring continuity for owner-operators, lowering barriers the actors experience in the adoption process, providing incentives, making clear regulations, creating rules to include recent developments

Table 3.9: The stakeholder analysis of the Dutch state's position in inland waterway transport

Aspect	**Description**
Core activities	Working out regulations, influencing creation of policy in the CCNR or EU
Value proposition	Maintaining the livelihoods of people working in the inland shipping industry, keeping the industry's environmental performance at a competitive level with road transport
Revenue model	Funds from the state are attributed to the ministry. The state's revenue originates mainly from taxes
Main relations	Plenty of contact with other regulating authorities. Also in contact with advocacy groups and research organisations
Drivers towards environmental innovations	Internal drive to improve air quality and its effects on public health, also internal drive to reduce greenhouse gas emissions and its negative effect on the environment
Attitude towards environmental innovations	Focus on both pollutants and greenhouse gases, steering CCNR and EU policy towards real-life emissions, encouraging cooperation between stakeholders
Considerations	Making a trade-off between CCNR and EU policy creation processes, ensuring continuity for owner-operators, lowering barriers the actors experience in the adoption process, providing incentives, making clear regulations, creating rules to include recent developments

3.6 The financial relations

The most influential financial actors in the inland shipping industry, are the three banks which are introduced in Chapter 2.3.2: Rabobank, ING, and ABN AMRO. The departments in charge of inland waterway transport have as core business to decide on financing (changes to) inland vessels. Banks thus have a relation with vessel owners who (wish to) finance their vessel or finance costly changes to it. The banks also have a relation with each other. They discuss topics together in the Dutch Society of Banks (Nederlandse Vereniging van Banken). Due to this conversation with each other, they have a similar view on the situation of the inland shipping market. United in the NVB, they talk to BLN. BLN-Koninklijke Schuttevaer is the sector organisation for inland shipping. Apart from being related to vessel owner, other banks, and sector organisations, they are also related to their own regulating authorities. In their financing decisions they must also consider the rules from regulating authorities they must comply with themselves.

The revenue model of banks is complex. It is out of the scope of this thesis. Relevant literature on the subject includes the publications of the [OECD, 2013] and [Ayadi et al., 2014]. The complexities of the value proposition of banks is also discussed in specialised literature. In general, they compete on their willingness to fund a project. Banks will often have a preference for certain (niche) markets. They distinguish themselves with competitive tariffs and appealing terms and conditions.

The interest of banks in environmental innovations in the inland waterway transport is derived from their need to maintain the value of the vessels, which are their mortgage assets. If ships do not meet modern requirements and are forbidden to sail into a certain low-emission area for example, this negatively affects the value of this vessel. Since the vessel is financed with a mortgage, it is crucial for banks to maintain the value of these assets. Apart from this financial reasoning, banks are also focussing on sustainability more. This can be related to the influence of their regulating authorities and the growing interest in sustainability of general consumers. The Fair Finance Guide, for example, keeps track of how well banks perform on different aspects of sustainability [Fair Finance Guide International, 2015].

The stakeholder interviews reveal that banks' attitude towards the adoption of environmental innovations is objective and pragmatic. Any financing question they receive is evaluated on the business case of the applicant. The financial performance of the ship owner, the securities through long term contracts, the membership in shipping cooperations, and the solid track record of the applicant are crucial in this.

Even though banks do not believe they have changed any of their policies towards granting loans and mortgages, interviews reveal that applicants are experiencing that it is more difficult to obtain a loan. This can be attributed to the overcapacity in inland waterway transport. This overcapacity makes it much harder for vessel owners in the affected market segments to show banks that they will be able to make the payments. More information about the overcapacity in the inland shipping industry is presented in Chapter 2.2.4

The economic situation of the inland waterway transport market is a concern for banks. They are well aware that this makes it harder for owner-operators to maintain their business financially healthy. Banks realise that this is also making the adoption of costly environmental innovations harder. They do acknowledge their role in the adoption process and are therefore constructively discussing with advocacy groups which innovations have a positive outlook.

Table 3.10: The stakeholder analysis of financial relations' position in inland waterway transport (banks)

Aspect	**Description**
Core activities	Financing projects (newbuilds, retrofits and new equipment on board of inland vessels)
Value proposition	Willingness to grant a loan in a certain (niche) market, competitive tariffs, terms and conditions
Revenue model	Complex revenue model from investments and financial activities
Main relations	Vessel owners are their clients. Cooperation with other financial organisations through Nederlandse Vereniging van Banken. Also in contact with advocacy groups (BLN)
Drivers towards environmental innovations	Derived interest to ensure vessels maintain their value.
Attitude towards environmental innovations	Objective attitude, only willing to fund when the expected financial performance of the vessel owner is good, focussed on operational and technical innovations
Considerations	Improving resilience during economic recessions, dealing with overcapacity in some market segments, safeguarding that existing investments can be recuperated

3.7 The operational relations

The operational relations include ports and terminals, but also the operators of bridges and locks. Ports are particularly interesting when considering the adoption of environmental innovations. This is because they have the authority to create and enforce rules which are applicable in their port.

The core business of ports is to manage all the operations in their port. The development of their port and the safety of the industrial activities on their property are important considerations in their decision making process. Reliable and fast connections to the hinterland are also an important consideration for ports. The fast and reliable turnaround of goods is a part of ports' value proposition. But Their value proposition is more than that. It also includes having a good location close to the hinterland, having enough space for large facilities and being able to handle hazardous products. Obviously, offering competitive prices for their services is another part of ports' value proposition.

The revenue model of the Ports is complex. The main sources of income originate from the leasing of letting real estate in the port (land with or without facilities), and the port duties which are paid by ships that visit the port.

The main ports in the Netherlands are closely related to the communities they are located in. The port of Rotterdam, for example, is owned for 70% by the municipality of Rotterdam, and the remaining 30% is from the Dutch state. This means that the position of the port, when it comes to sustainable development, is quite similar to that of the municipality and the state of the Netherlands. The ports tend to focus on local air quality more than on the emission of GHG'es. This is because they have to meet air quality norms, and aim to improve the health of the public living in the vicinity of the port.

However, the interviews reveal there are some differences of opinion between ports and the Dutch state. The port of Rotterdam, for example, means to refuse entry to inland vessels with engines which do not meet certain engine requirements; the socalled CCNR2 engine requirements. The Dutch state cannot yet fully support this policy as it is worried about its adverse effects on captain-owners. Other methods which ports use to reduce the emissions of inland waterway transport, include differentiated port tariffs and information campaigns.

Besides ports, other operational relations which can play an influential role in the adoption of environmental innovations, are terminal operators. Terminal operators, just like ports, can facilitate logistical innovations like the creation of hubs, the use of advanced planning tools and even network integration. The interviews reveal that operators of container terminals at least appear to be willing to work together with other partners in these innovations. As long as they have enough long-term security about business continuity, they're willing to constructively work together. This is because terminal operators and port authorities are linked to regional politics, and they are convinced about the added value of better information sharing between different partners in the chain of transport.

Table 3.11: The stakeholder analysis of port authorities' position in inland waterway transport

Aspect	**Description**
Core activities	Manage operations in the port
Value proposition	Having reliable hinterland connections, having fast turnaround times, being able to handle certain products, offering competitive tariffs
Revenue model	Port duties and the leasing and letting of real estate cover the ports' costs (developing new facilities, staff, ...)
Main relations	Closely related to regulating authorities(municipalities and Dutch state are shareholders). Supply-side actors are their clients. Demand-side actors in their port are their clients and in some cases their partners in the development of the port.
Drivers towards environmental innovations	Internal drive to improve air quality in their port area
Attitude towards environmental innovations	In line with the national and regional policy, focussing on pollutants instead of CO2, facilitating logistical innovations, providing incentives for technical and operational innovations
Considerations	Staying within their area of jurisdiction, not demanding the impossible, avoiding (too much) resistance from vessel operators

3.8 The societal relations

The last category of stakeholders which can be analysed, includes the societal relations of the inland shipping industry. This group is quite diverse, but what they have in common is that they do not influence the inland waterway transport industry directly. However, they do have the ability to influence the actors of the inland shipping industry. Several societal relations can be identified. These relations include, but are not limited to advocacy groups, research organisations, end users of the transported goods, NGO's and people living in the vicinity of inland waterways and ports.

Some of these societal relations have close ties to the inland shipping industry. Research organisations like Marin, TNO and TU Delft have specific knowledge which they can use to aid in the R & D phase of environmental innovations in the inland shipping industry. Several advocacy groups with a unique tie to the inland shipping industry exist as well. Examples of such organisations are: BLN, EVO, BVB, CBRB, Schuttevaer and EICB. These organisations either represent a certain group of actors in the industry, have as main objective to aid in the development of the industry, or play a role in the spreading of information about/ within the inland shipping industry.

Because this category of societal relations is so diverse, no analysis is made of each stakeholder separately. Let it be clear that they each have their own core activities, value proposition and revenue models. Their main relations with other stakeholders of the inland shipping industry differ, as do their drivers towards improving the environmental performance of the industry. Their attitudes towards the environmental innovations are different, and their decision making criteria are different as well.

What they do have in common, is that they can influence the actors which are analysed in the previous subchapters. They can thus, indirectly, affect the inland shipping industry and its environmental performance. More information on their role in this process, is given in Chapter 5.

3.9 Chapter conclusion

The conclusion to this chapter provides an answer to the research question: 'who are the stakeholders in the Dutch inland waterway transport network'. The previous subchapters give an overview of the stakeholders and present a stakeholder analysis of them.

3.9.1 Who are the stakeholders in the Dutch inland waterway transport network

Figure 3.2 shows the various stakeholders related to inland waterway transport.

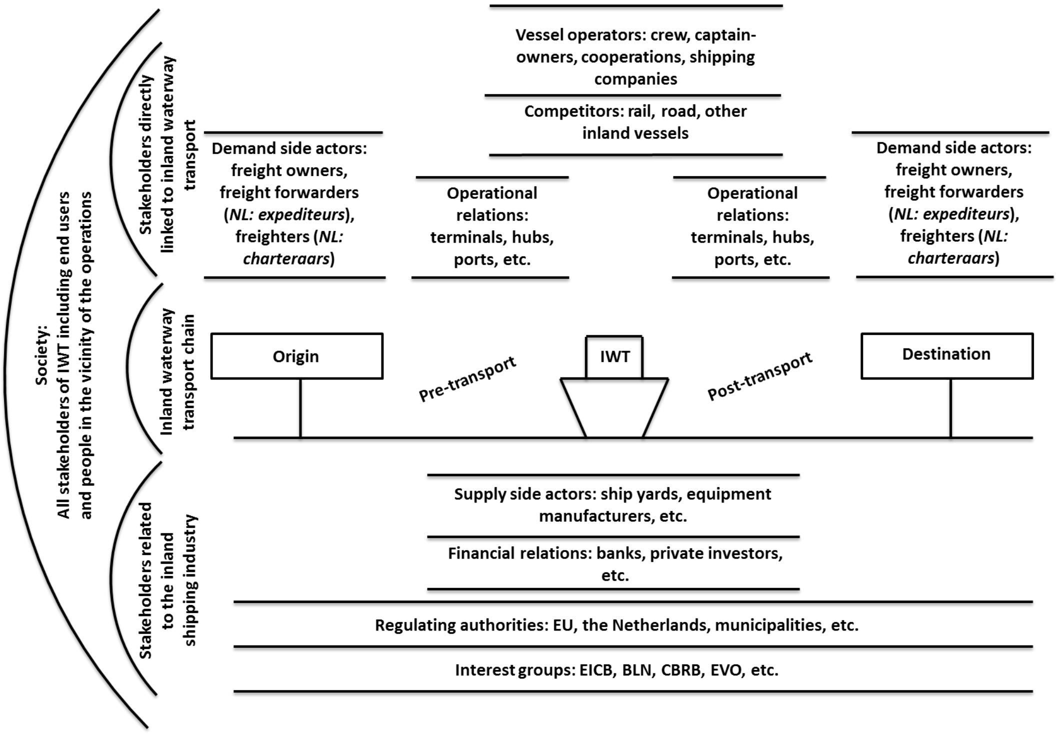

Figure 3.2: The stakeholders of the inland shipping transport network. Own composition.

The stakeholder analyses show a great diversity on various aspects. The stakeholders have different core activities, value propositions, revenue models, decision-making criteria and relations to other stakeholders.

When it comes to the stakeholders' drivers towards improving the environmental performance of inland waterway transport, almost all stakeholders have internal drivers in this process. Owner-operators want to reduce their fuel expenses meaning they are eager to reduce their fuel consumptions and consequently reducing their exhaust gas emissions. They are thus focused on the emission of CO2. Demand-side actors wish to reduce their transportation costs and are also focused on reducing this CO2 emission.

Other stakeholders are more focused on reducing the other pollutants like NOx and PM. The regulating authorities and operational relations (ports) are internally driven to focus on pollutants because they want to improve the air quality and to decrease the negative effects of pollutants on public health. They know that supply-side actors and demand-side actors are internally driven to reduce the emission of GHG'es, hence they concentrate on reducing the pollutants as well.

Financial relations have an indirect interest in improving the environmental performance of the inland shipping industry. They are particularly concerned about maintaining the value of the vessels in their portfolio, and are thus driven to make sure the vessels meet (future) requirements. This is because the value of vessels which do not meet the requirements drops, meaning their mortgage assets would lose a considerable part of their value.

The drivers towards improving the environmental performance of the inland shipping industry core activities are diverse, and so are the stakeholders' attitudes towards environmental innovations.

Most owner-operators would rather wait to adopt a new technology until they are certain there are no problems with it. They are focussed on technical and operational innovations. Financial relations are also aiming their attention to technical and operational innovations. Regulating authorities are working on effective regulations (both realistic and ambitious) for pollutants and are stimulating cooperation between the different stakeholders. The majority of demand-side actors is still indifferent to the innovations.

3.9.2 The relation to following chapters

The information presented in this chapter is used in the next parts of this research. In Chapter 4 these insights help to understand the main drivers, main barriers and level of market adoption for the innovations. Understanding the stakeholders' considerations is also essential for Chapter 5, which evaluates which innovations are most promising for the inland shipping industry.

Based on the desire of owner-operators to reduce costs it is expected that the most promising innovations for the inland shipping industry have a fuel-saving effect.

Based on owner-operators' wish to wait until a new technology has proven itself, it is expected that the most promising innovations for the inland shipping industry will not be innovations in their first stages of market adoption.

Chapter 4

The Inventory and analysis of environmental innovations for inland shipping

This chapter answers two research questions: ‘which are the environmental innovations relevant to Dutch inland waterway transport’ and ‘how is the market adoption of environmental innovations’. First, an introduction gives some information on the categorisation of innovations and on the market adoption process of innovations. Next, the innovations are systematically analysed.

4.1 An introduction into the market adoption of innovations

The adoption process of innovations is often illustrated by the model of technology adoption which was described by [Moore, 1991]. Image 4.12 shows a representation of Moore's adoption model. It shows that innovations are usually firstly adopted by a small market and then by the larger group of mainstream clients. The 'chasm' indicates that there is a difficult transition to get an innovation adopted by mainstream clients.

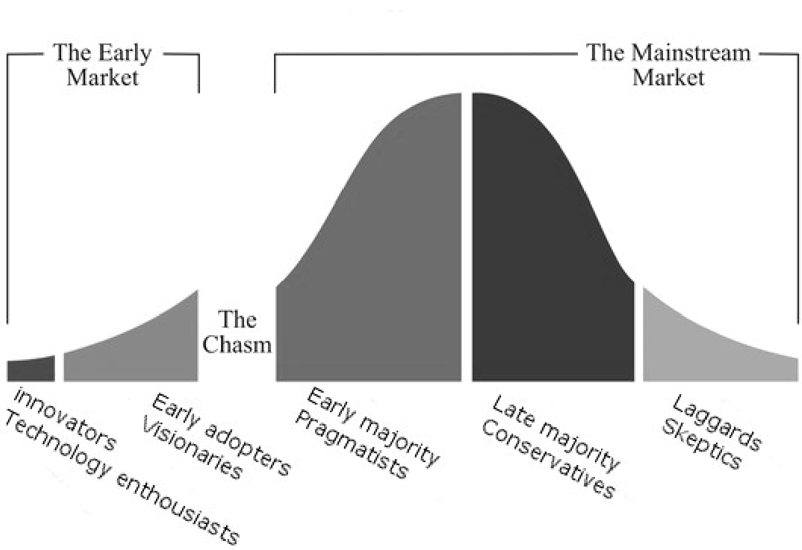

Figure 4.1: The market adoption model of technologies by Moore. Image adapted from [Meetup, 2014] and [Mohr et al., 2010]

The differences between the types of clients in the market adoption process are explained carefully by [Mohr et al., 2010]. The first group, the innovators, are clients which are often motivated by the idea that they can make a change in the industry. This people in this group are often called technology enthusiasts because they are willing to accept some initial problems with a new technology. The adoption process of innovations then reaches the early adopters. These clients want to have a competitive advantage over their competitors and are therefore willing to adopt breakthrough technologies. The early majority is interested in adopting incremental innovations, but is not interested in disruptions of their operations. The early majority often only adopts a new technology once a trusted partner has recommended it to them. The late majority is a group of clients which are risk averse. These clients can only be persuaded to acquire fail safe technologies when they are offered at a sensible price. the market adoption of an innovation is complete when even the sceptics adopt a new technology. These customers only adopt new technologies when they believe their alternatives are worse, and when the costs of these new technologies can easily be justified.

In this explanation of the adoption process of new technologies, the word 'innovations' is used. So what is meant with this?

Innovations, in this research, are defined as new techniques which are aimed to improve existing products or practices, or which are aimed at solving a problem. In day-to-day communication, innovations are new and clever products or services which are rapidly adopted by the market. This is a much narrower concept than what is commonly understood in the literature, which acknowledges that innovations may require quite some time to be adopted. [Mohr et al., 2010], distinguish several categories of fundamentally different types of innovations. These are:

- Incremental versus breakthrough (radical) innovations
- Product versus process innovations
- Architectural (platform) versus component (modular) innovations
- Sustaining versus disruptive innovations
- Several types of organisational innovations

These categories of innovations are rather general and can be used in any context. The next subchapter provides categories more directed to the environmental innovations of inland waterway transport.

4.2 An overview of the categories of environmental innovations

Figure 4.2 visualises the categories of innovations which are considered in this research.

The figure shows that this research distinguishes three main categories of innovations: technical innovations on board the ship, operational innovations and logistical innovations. The first category, technical innovations, are innovations which are related to changes in the energy source of vessels, to its drive chain, energy demand and exhaust gases. The next category are operational innovations. These are innovations which can be executed by only one actor in the transport chain: the owner-operators. These operational innovations are thus changes in the use of vessels. The third category of innovations are logistical innovations. These innovations require an effort of several actors in the inland waterway transport chain.

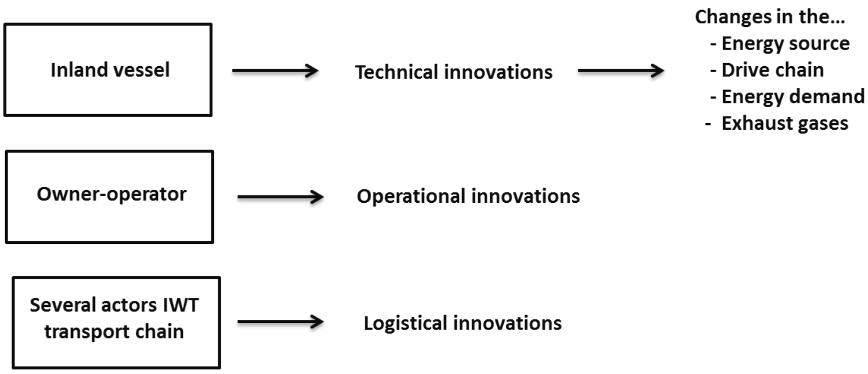

Figure 4.2: The overview of categories of environmental innovations relevant to inland waterway transport

Some may argue that certain innovations are missing from the following subchapters. "What about the optimisation of the on-shore loading and unloading equipment?" Although there are indeed more methods to improve the environmental performance of the inland waterway transport, they are not considered in this research. The scope of this research is limited to the innovations which are directly related to inland vessels and their operations. These two factors (innovations and being related to inland vessels) are the criteria for including innovations in this research.

As far as on-shore equipment goes: this is not directly related to inland vessels. Innovations which are beneficial to the transport chain, but not to (the operations of) inland vessels are out of the scope of this research. This is also why innovations in the automotive industry are not considered, for example. They can indeed have a positive effect on the environmental performance of the lorries doing the pre- post transport of inland waterway transport, and they can have a positive effect on the inland waterway transport chain's performance, but they are out of the scope of this research.

Concerning the innovations which are considered in this research, the information presented in the following subchapters is based on an extensive literature research and on the findings of the stakeholder interviews. The methodology of the stakeholder research is introduced in 1.3 and Appendix 1.4. Important publications which were analysed are from two recent studies to innovations in the European inland shipping industry: 'Move-iT!' and 'IDVV Schone Schepen'. Appendix G lists the reports of these studies which have been analysed for this research. Additional references are also provided in the analyses in the next subchapters. [1]

The analyses of the innovations in the next subchapters are aimed at giving an insight into how the innovations work, how (much) they can improve the environmental

[1] It must be noted that not all the reference material is specific to the inland shipping industry. Some of the publications referred to, target other transportation branches like the automotive industry and the deep sea shipping industry. This is because several of the innovations which are relevant to the inland waterway transport market are also relevant to these other markets.

performance of the inland shipping industry and which factors are influencing their adoption process. This includes the innovations' costs and expenses, their technological maturity, their drivers and their barriers in their market adoption. To provide an analysis that covers each of these aspects, the next topics are discussed for each innovation:

- What is the working principle of the innovation
- What does the actual implementation of the innovation entail
- Which type of innovation is it: well to tank or tank to propeller and incremental or breakthrough
- How large is the innovation's reduction potential of the emissions
- What is the innovation's effect on the costs and expenses
- Which market segments are particularly relevant to the innovation
- What is the level of maturity and market adoption of the innovation
- Which are the main drivers and benefits stimulating the adoption of the innovation
- Which are the drawbacks and barriers experienced by the stakeholders in the adoption of the innovation

Finally, a concise overview of the findings is added at the end of each analysis.

4.3 The technical innovations

The first category of environmental innovations which is discussed, are the technical innovations on board of vessels. Figure 4.3 shows that there are four subcategories of technical innovations. Figure 4.4 clarifies why these four categories are distinguished. The first category of technical changes to the vessel relate to the energy source used to power the vessel. This energy source is used by the drive chain to deliver power. Changes which can improve the performance of the power generation system are thus the second category of innovations. The next category are the innovations which can reduce the power which is demanded from the power generation system. And finally, the fourth category includes innovations which focus purely on reducing the exhaust gas emissions.

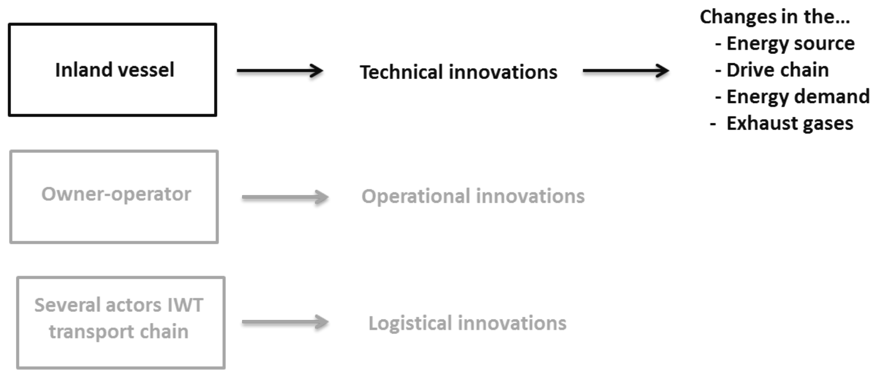

Figure 4.3: Technical innovations: the first category of environmental innovations relevant to inland waterway transport

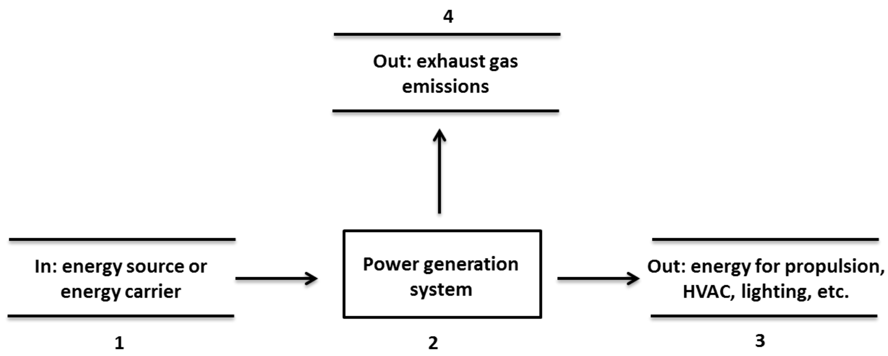

Figure 4.4: The overview of technical innovations on board of vessels

4.3.1 Changes in the energy source

The technical innovations which are essentially a change in the energy source of inland ships, are described in this subchapter. These innovations include: an improved fuel quality, diesel and lubrication oil additives, biofuels, CNG, LNG, GTL, full electric powering, solar energy, wind energy and hydrogen fuel cells.

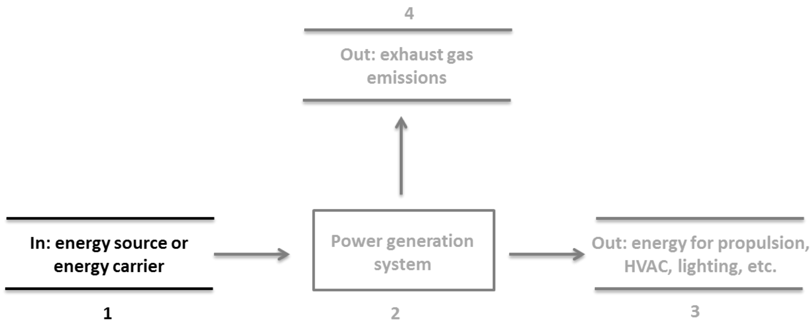

Figure 4.5: Changes in the energy source: the first category of technical innovations

4.3.1.1 Improved fuel quality

In general, inland vessels use marine gas oil (e.g. [Vermeire, 2007]). Several authors, including [Stapersma and Klein Woud, 2008], explain that the most important properties of diesel fuel are its density, viscosity, heating value and its ignition properties. However, numerous other properties are also relevant to the quality of the fuel. These include the carbon residue, ash content, aluminium content, vanadium content, cloud point and the water content of the fuel (e.g [UFA, 2015] and [Stapersma and Klein Woud, 2008]).

The requirements to all the diesel fuels are described in the European CEN 590 Norms. However, apart from the maximum sulphur contents of the fuel, there are no norms included that apply to fuels in the inland shipping industry (e.g. [Kattenwinkel et al., 2007]). In the Netherlands, it is customary that diesel fuels comply with the standards of the VOS (Vignet Olie Scheepsvaart) [Arntz, 2010]. Even so, several authors, including [Stapersma and Klein Woud, 2008] and [Martinez, 2015], mention clearly that there are variations in the fuel composition even within the same type or grade of fuel. The stakeholder interviews conducted for this research confirm that there is a great variety in fuel quality, both in VOS as non-VOS fuels. [2]

These differences in the fuel composition cause differences in the (efficiency of the) combustion process in the engine, causing variations in the (amount of) exhaust gas emissions. Little is known about how large these differences in the fuel composition can be. There is hardly any knowledge of its effect on the fuel consumption and the emissions. Only recently a comparative study has started to the differences in the quality of automotive fuels [Ligterink, 2016]. No similar research can be found to the differences in fuels which are used in the inland shipping industry.[3]

Due to this lack of research and reliable data, it is at this point in time not possible to

[2] Shippers report colour differences of the smoke, changes in the smell of the exhaust gases, and higher levels of residue on the exterior surfaces of their ship.

[3] The fuel specifications of [Stichting VOS, 2011] show that for several components there is only a maximum or minimum level. This explains why there can be considerable variations within the same class of fuel. While suppliers of fuel have in-house research that may show the superior quality of some of their products, the lack of transparency of their research makes it impossible to accept this as objective research. The research of [Ligterink, 2016] at TNO will give an unbiased insight into the variations of the fuel composition of automotive fuels. The preliminary results show a large variety in the fuel specifications.

make substantiated statements about the effectiveness of this innovation. It is impossible to say what the effect on the tank-to-propeller emissions is. It is also impossible to make substantiated statements about the cost of using these high-quality fuels. That being said, the interviews reveal that vessel operators do sometimes notice differences in the fuel quality. They notice this mainly by the amount of smoke coming out of the exhaust, revealing that there may be a large effect on the emission of particulate matter.

If research demonstrates that there are considerable positive effects on the emissions and fuel consumption of vessels, this innovation could be relevant to all the market segments of inland waterway transport. The regulating authorities could sharpen their fuel standards, suppliers of fuel will have to make sure their inland fuels meet these requirements, and vessel operators will simply be able to purchase these fuels. If these fuels are elective rather than standardised for all marine gas oils, owner-operators will be inclined to adopt them when the benefits outweigh the drawbacks. That is, when the fuel savings compensate for the higher fuel price. This innovation thus requires an effort of the regulating authorities and the suppliers of fuel, but hardly any effort of owner-operators or any of the other stakeholders.

It is believed that this innovation is rather easy to implement in the inland shipping industry. The adoption of low sulphur fuels proves that improved fuels can be adopted rather quickly, and that the effect on the fuel price may not even be noticeable to the vessel operators (e.g. [van Ommeren, 2012] and [IVR, 2013]). But just as with the adoption of low-sulphur fuels, the effect on the lubrication and wear on diesel engine and fuel system components must be researched before this innovation is implemented.

Table 4.1: The analysis of innovations: improved fuel quality

Aspect	**Description**
Working principle	Improved fuel composition affects combustion and consequently emissions
Actual implementation	Suppliers of fuel offer the superior fuels, no changes for vessel operators
Type of innovation	Incremental, tank to propeller
Reduction potential	Unknown reduction of fuel consumption and all exhaust gas emissions
Costs and Expenses	Fuel prices may rise slightly
Market segments	All market segments
Level of market adoption	Before market introduction
Main Drivers	Requires hardly any changes from vessel operators
Main barriers	Before anything knowledge development is required

4.3.1.2 Diesel and lubrication oil additives

Additives can be added to a ship's fuel tank by manually. The chemical composition of the additives may change the combustion of the fuel in the cylinders of the diesel engine. It is thus comparable the previous innovation: the improved fuel quality: the improved combustion process positively affects the efficiency of the engine, reducing the fuel consumption of the vessel and reducing the emissions. The oil additives which are added to the oil reservoir, would have a similar effect on the inner workings of the diesel engine. Lubrication oil additives are mostly focussed on reducing the engines' friction and wear of their components. While some lube oil additives may affect the emissions as well, they are mainly targeted to elongate the engines' life span.

The suppliers of fuel additives claim that the fuel consumption may be reduced by up to 10 %. This figure is also mentioned several times during stakeholder interviews, and [Confidential information, 2015] underwrites that suppliers mention even higher savings potentials. While some users experience that additives have a positive effect on their fuel consumption, others have not noticed any positive effect on the fuel consumption or the engine performance (e.g. [Smart Feeder, 2015], [TESO, 2014] and [Mol, 2015]). The fact that there are some companies who have experience with additives, reveals that this innovation is being given a try by the early market (innovators and early adopters).

However, no concrete data from any independent research organisations are available on the effect of additives. The effectiveness is therefore still hard to quantify, which is also the case for the costs. Even though the fuel prices fluctuate, the additional costs of these additives can be expressed as an increased fuel cost. [Confidential information, 2015] reveals that the fuel cost for one litre of fuel goes up with 1.2% when using diesel additives. Fuel additives may or may not save vessel-operators some money, depending on how much their fuel consumption foes down. There is thus quite some ambiguity about the financial incentive for vessel operators to adopt this innovation.

That being said, if independent research was to show that the emissions are indeed lowered considerably by fuel additives, the outlook may be positive. Regulating authorities could include additives in their regulations, and vessel operators may use them to meet their environmental requirements. In that case, the simplicity of this innovation would mean that it could rapidly be adopted by vessel operators. This is because it does not require large changes to their day-to-day operations, something the early and late majority finds important.

For now, the most important barriers to the market adoption of additives is the lack of knowledge on their effectiveness. Several suppliers of additives may disagree with this statement, as they sometimes use SGS emission measurements to prove otherwise. Other organisations may not accept this as valid research, as it is often not transparent and is suspected to be biassed.

Table 4.2: The analysis of innovations: diesel and lubrication oil additives

Aspect	**Description**
Working principle	Additives change the chemical composition of fuel, which affects the combustion process and emissions
Actual implementation	Vessel operators add additives to the fuel tank or oil reservoir
Type of innovation	Incremental, tank-to-propeller
Reduction potential	Less than 10% reduction of fuel consumption and all exhaust gas emissions
Costs and expenses	The fuel expenses rise with 1.2% when using diesel additives
Market segments	All market segments
Level of market adoption	Early market
Main drivers	Requires hardly any changes from vessel operators
Main barriers	Before all, knowledge development is required

4.3.1.3 Biofuels

Biofuels are made from renewable organic materials, these are fatty acid methyl esters (FAME). Because these biofuels are produced from renewable resources like plants and recycled frying oil, they are seen as a sustainable alternative to fossil fuels. Biofuels can be delivered as blends with marine gas oil, or in their pure form of 100% biofuel. Interviews reveal that the availability of biofuels for inland shipping purposes is quite limited.

When it comes to tank-to-propeller CO2, these biofuels do not realise a reduction of GHG emissions. Biofuels have an effect on the well-to-tank emissions when the CO2 of renewable sources is considered to be zero, or CO2 neutral. There is also an effect on other tank-to-propeller emissions. Some authors, including [Kalligeros et al., 2002] and [TSB, nd], indicate that the emission of NOx and PM are lowered when running on biodiesel. The reduction of SOx, PM and NOx seems to be significant. However, according to [Verbeek et al., 2015b] "the current state of knowledge does not allow a reliable quantification of [the] emission effect of biofuels". This statement was made with regards to road transport, an industry which has more experience with biofuels than the inland shipping industry. This opinion is also valid for biofuels for inland waterway transport and has not changed since publication in 2008 [Verbeek, 2015a].

There is not only ambiguity when it comes to the effectiveness of biodiesels in lowering the emissions, there are also several uncertainties when it comes to concerns about the growth of micro-organisms in biodiesel. Vessel operators and other stakeholders are not convinced of biofuels because they believe the organisms present in biofuel will start to bloom, spoil the fuel, and cause all kinds of problems with engine. This is a problem which is less relevant in the automotive industry, where fuel never stays in the tank very long. The refueling intervals in the inland shipping industry are much longer than in the automotive industry and the blooming of organisms may therefore be much worse in this industry. This fear is also worsened because engine suppliers are not willing to extend their guarantees when the engines are run on biofuels. This is because biodiesels exacerbate the wear on engines and fuel system components (e.g. [van Zyl et al., 2014]).

Even if the problems of blooming organisms and warranties are resolved, there is still another issue with biofuels. The discussion about the life cycle assessment of these fuels is ongoing. Even though the resources which are used to produce the biofuels are renewable, the production of the fuels may still be unsustainable. This could be attributed to the transport required to distribute these fuels, the vast areas of land which are required to grow the crops and which are reducing ecological biodiversity in certain regions, and which are being grown at the expense of local food production. These aspects have lead biofuels to be the subject of politicised discussions (e.g. [Bouma, 2015] and [Greenpeace et al., nd]).

The interviews reveal that the attitude of most stakeholders is, because of these issues, not very positive about biofuels. Uncertainties about blooming organisms in biofuels which are left in fuel tanks for a prolonged period of time, must be clarified if stakeholders are to consider this innovation seriously. Currently, the availability of biofuels is also insufficient for it to be adopted by more vessel operators and the fuel is more expensive than regular marine gas oil. Research of [Florentinus et al., 2012] shows that it is about 60% more expensive, but the price evolutions of fuels is volatile. These are all reasons which are keeping back the adoption of this innovation.

Table 4.3: The analysis of innovations: biofuels

Aspect	Description
Working principle	Biofuels are produced from renewable resources, making them CO2 neutral
Actual implementation	Suppliers of fuel must offer biofuels, no changes for vessel operators
Type of innovation	incremental, well-to-tank and tank-to-propeller
Reduction potential	Reduction depends on the blend ratio and the type of biofuel, up to 100% CO2 reduction, a reduction of SOx and NOx up to 20% and PM up to 60%
Costs and Expenses	biodiesel is more expensive than marine gas oil, about 60% higher
Market segments	All market segments
Level of market adoption	Innovators are experimenting with it
Main drivers	Requires hardly any changes from vessel operators
Main barriers	Uncertainties about blooming organisms must be clarified and knowledge on the life cycle emission reduction must be developed, availability of biofuels is insufficient

4.3.1.4 Natural gas: LNG, CNG and GTL

LNG and CNG are two energy sources which are chemically the same product. CNG is –the name says it all- natural gas which has been compressed and LNG is the same products but in the liquid state. CNG is kept at about 200 bar in pressurised tanks and LNG, which is cooled until -162 degrees C to let the gas become liquid, is kept in special cryogenic tanks. These LNG tanks allow the product to remain cold and thus liquid.

Several authors, including those listed in Appendix G and [Paalvast and Consuegra, 2010], look into the use of LNG in the inland shipping industry. There are several examples of LNG driven vessels in the deep sea and short sea shipping industry, but the adoption of this innovation in the inland shipping industry is still limited to only a handful of ships. Compared to marine gas oil. natural gas has a higher energy density, which makes it an interesting energy source.

However, when CNG and LNG are compared to each other and to diesel,the space which is required for the tanks and the other auxiliary installations which are needed to operate on these fuels is more important than than the energy density of the it. The amount of space required to have a similar operating range to that of a vessel running on marine gas oil, is larger for CNG and LNG. This additional space which is required for the systems has a negative impact on the cargo capacity of vessels, which has a direct influence on the financial performance of the vessels. Because the space which is required for a CNG installation is even larger than that of an LNG system, LNG is considered to be a more promising option than CNG for the powering of inland vessels. That is, if the operating range is to be similar to that of a conventional vessel running on marine gas oil. Vessels that have short operating ranges and frequent calls in port (like ferries and vessels operating in ports), could be refueled more often and would not have this drawback of a reduced cargo capacity. CNG and LNG are thus particularly interesting for these market segments.

When looking into the use of LNG in inland shipping, one will notice that there are different types of LNG engines. There are engines which run solely on LNG (these are the so called lean burn engines) and there are those which can run on (a combination of) diesel and LNG. In some cases these can be retrofitted regular diesel engines. The cost of new LNG engines, the tank and the auxiliary systems is higher than the cost of an equivalent system with a diesel engine, and the use of these installations requires considerable changes in the design of the vessel. The investment cost for a certain installation is estimated to be about 2000 to 2500 EUR/kW by [Hekkenberg, 2013b].

[Hekkenberg, 2013b] also shows that the environmental impact on the exhaust gases is significant. The emission of CO2 would drop by about 25%, NOx would drop about 80% and the emission of PM would drop up to 99% with engines running on LNG alone. However, the 25% CO2 reduction as presented by [Hekkenberg, 2013b] must be nuanced. The interviews reveal that the CO2 equivalent tank-to-propeller emissions remain almost unchanged. This is because the exhaust of CO2 goes down, but the emission of methane (another greenhouse gas) goes up. LNG must thus not be seen as a GHG reducing measure, but as a measure to reduce other harmful emissions.[4]

The significant reduction of these emissions is why regulating authorities are currently working on creating a regulatory framework that will allow the use of LNG as an energy source. A first barrier in LNG and CNG's market adoption is that current regulations do not allow it and the inland vessels operating on these fuels are doing so with an exemption from the classification societies. Another barrier in the adoption of LNG is that this technology is only suitable for large inland vessels. The engines and auxiliary equipment is too large for smaller inland vessels (e.g. [Hekkenberg, 2013b] and [Gille et al., 2013]). A third obstacle holding back the adoption of LNG is the limited distribution of the fuel. While suppliers are not willing to invest in bunkering facilities while the demand is not high, vessel operators are not convinced to switch to LNG while there are not many bunkering options. This chicken-and-egg story must be resolved. A fourth barrier is the high investment to make the ship suitable to operate on LNG or CNG. Related to this, the pay back period of these investments is highly uncertain and hard to evaluate. It is closely related to the price difference between CNG/LNG and marine gas oil, and there is a lot of uncertainty about the future evolution of this price difference. The pay back period also depends on how much fuel the vessel consumes, revealing that these

[4]Methane slip and the CO2 equivalent emission of engines that run on natural gas are hot topics of debate. There is quite some ambiguity about the well-to-tank and tank-to-propeller emission of CO2 and methane in the literature and the interviews. This discussion is complicated because there are various types of engines: dual fuel, bi-fuel and lean burn engines may have different results. Engines of different manufacturers may also have different emission levels, just like the different production processes of the fuels have an effect on the well-to-tank emissions.

innovations are particularly interesting to vessels which have many running hours a year.

Even with these obvious hurdles to overcome, and its suitability to very specific market segments of inland waterway transport, LNG is believed to be a promising innovation by several of the actors in the industry. Regulating authorities, banks, and some industry associations are convinced of its potential and seem willing to make an effort in the adoption of LNG as marine fuel for inland shipping purposes. The recent position paper on the marine fuel mix of [Visie Duurzame Brandstoffenmix, 2014] clearly shows the broad support for transitioning to natural gas. This support works to the advantage of these innovations.

Another fuel related to CNG and LNG is GTL. GTL is less documented even though it there are already some experience with it in the automotive industry, and there are even some inland vessels operating on this fuel already [Winkel et al., 2013]. Several authors, including [Reuss, 2012] and [Tsikata, 2012], explain what GTL is. Gas-to-liquids are gaseous hydrocarbons which are converted into liquid hydrocarbons. This is done by chemical processes, including the Fischer-Tropsch process or a Mobil process. The biggest difference between GTL and LNG is that LNG remains chemically unchanged when compared to its original product before it was liquified, while the chemical composition of GTL is altered. The natural gas is literally changed into a liquid fuel. Shell is the largest producer of GTL and clarifies that this fuel reduces the exhaust gas emissions drastically: PM emissions would go down with 20%, and the emission on NOx would decline with 12% (e.g. [Utilities, 2012]).

The price and availability of GTL seem to be the biggest barriers in its adoption process. Because the fuel is relatively unknown, there is hardly any unbiased and transparent research to it, and there are no policy measures to stimulate the adoption of GTL, it may take a while before the mainstream markets will be convinced to adopt it. Shell's announcement to cancel a large GTL project because of the uncertainties related to the cost difference with gas and oil, reveals another hurdle in the adoption of GTL (e.g. [Dodgem, 2014] . The unpredictable price difference with MGO. Even so, the biggest benefit of GTL is that it requires little to no changes in the operations and design of the vessel and its equipment. GTL can be bunkered like regular marine gas oil and can be stored in the same tank, the same diesel engines can operate on it.

Table 4.4: The analysis of innovations: LNG

Aspect	Description
Working principle	Natural gas has less impurities than marine gas oil, causing less emissions to be formed when it is burnt
Actual implementation	A new or retrofitted engine and a special tank must be installed on the ship, the fuel must be made available
Type of innovation	radical, tank-to-propeller
Reduction potential	CO_2 equivalent emission stays about the same (CO_2 reduction of 25% is cancelled out by the heightened emission of methane), NO_x reduced by 80%, PM reduced by 99 %
Costs and expenses	Considerable investment costs for the engine and tank of about 2000 to 2500 EUR/kW, price difference with diesel is volatile
Market segments	Large ships that have high utilisation rates
Level of market adoption	Innovators are adopting it
Main drivers	Several influential stakeholders are convinced of its potential and are working on stimulating the adoption
Main barriers	Regulations are lagging behind, bunkering facilities are limited, only suitable for particular market segments, high investment costs and high uncertainty about the pay back period

Table 4.5: The analysis of innovations: CNG

Aspect	**Description**
Working principle	Natural gas has less impurities than marine gas oil, causing less emissions to be formed when it is burnt
Actual implementation	a new or retrofitted engine and a special tank must be installed on the ship, the fuel must be made available
Type of innovation	radical, tank-to-propeller
Reduction potential	CO_2 equivalent emission stays about the same (CO_2 reduction of 25% is cancelled out by the heightened emission of methane), NO_x reduced by 80%, PM reduced by 99 %
Costs and expenses	Considerable investment costs for the engine and tank of about 2000 to 2500 EUR/kW, price difference with diesel is volatile
Market segments	Ships with a high utilisation rate but a higher frequency of calls in port
Level of market adoption	Innovators are adopting it
Main drivers	Several influential stakeholders are convinced of its potential and are working on stimulating the adoption
Main barriers	Regulations are lagging behind, bunkering facilities are limited, only suitable for particular market segments, high investment costs and high uncertainty about the pay back period

Table 4.6: The analysis of innovations: GTL

Aspect	**Description**
Working principle	Natural gas has less impurities than marine gas oil, causing less emissions to be formed when it is burnt
Actual implementation	Suppliers must offer the fuel, no changes for vessel operators
Type of innovation	Radical, tank-to-propeller
Reduction potential	PM reduced by 20%, NOx reduced by 12%, CO2 equivalent emission is unclear
Costs and expenses	Price difference with diesel and gas is uncertain
Market segments	All market segments
Level of market adoption	Innovators are adopting it
Main drivers	Several influential stakeholders are convinced of its potential and are working on stimulating the adoption
Main barriers	unknown to the market, independent knowledge development is required, limited number of suppliers

4.3.1.5 Full-electric powering, solar and wind energy

Instead of having a fuel-burning engine on board, full-electric vessels have batteries on board which they use to store electric energy. This electric energy is usually loaded onshore at charging stations which are connected to the electric grid. Since full-electric vessels have no exhaust gases they have no tank-to-propeller emissions.

The concept of full-electric powering seems particularly suitable for tour boats and other small vessels with regular calls in port. This is because the capacity of battery packs is limited. To store a similar amount of energy as what is loaded in fuel tanks, would require unrealistically large and heavy battery packs to go on board of ships. The operating range of full-electric vessels is therefore limited, even tour boats would need to be recharged on a daily basis. A couple of ships in this market segment are already full electric vessels. (e.g. [Operatie Boeggolf, 2014])

The ambition of the municipality of Amsterdam to have a full-electric zero-emission tour boat fleet by 2025 is a driver in the adoption of full-electric concepts. There is however not a lot of experience with the installation of these systems on board of ships and there is a lack of clear guidelines for the implementation of battery packs on inland vessels. Regulating authorities and classification societies are working on creating comprehensive guidelines for these installations. If the adoption of full-electric powering is to go smooth, some research is required to the implications related to full-electric powering: how to organise the charging stations, what about fire hazards, and so on (e.g. [Operatie Boeggolf, 2014])

The most important barrier in the adoption of full-electric powering, even in the segment of tour boats, is the cost of installing battery packs. When compared to installing a new diesel engine on board of a tour boat, the pay back period of full electric powering is at least 12 years [Verbeek and van Mensch, 2014]. [Hekkenberg, 2013b] also estimates that the investment costs are very high, ranging up to 5000 EUR/kW.

Other ways of using electric power on board of vessels are: cold ironing when vessels are in port, using solar panels to produce electric energy, and producing wind energy on board the vessel. Cold ironing is discussed in Chapter 4.4.4 since this can be classified as an operational innovation. The use of solar panels and wind energy does not substantially contribute to the reduction of harmful emissions. This is because of the small area which could be covered by solar panels, and the restricted height that wind turbines could have on board of inland vessels. This limited energy production combined with the high investment cost of these systems, solar energy and wind energy are currently not perceived as a cost-effective way to improve the environmental performance of inland waterway transport. This not only surfaces during the stakeholder interviews, it is also mentioned in several publications, including the report of [Lindstad et al., 2015] on the effect of environmental innovations on several types of deep sea and short sea vessels. One aspect that solar and wind energy do have going for it, is that these systems are very visibly present on board of vessels. This means that they can position vessel owner as

Table 4.7: The analysis of innovations: full electric powering

Aspect	**Description**
Working principle	Battery packs replace combustion engines, eliminating exhaust gas emissions
Actual implementation	Battery packs are installed instead of a diesel engine, onshore charging stations allow vessels to recharge their battery packs
Type of innovation	radical, tank to propeller
Reduction potential	100% of all exhaust gas emissions
Costs and expenses	Very high costs up to 5000 EUR/kW, fuel expenses are replaced by charging expenses (from about 1.05 EUR/l to 0.12 EUR/kWh)
Market segments	Tour boats and other vessels with frequent calls in port
Level of market adoption	Early market
Main drivers	High effectiveness in reducing exhaust gas emissions
Main barriers	Regulations are lagging behind, charging facilities are limited, only suitable for particular market segments, high investment costs, requires considerable changes in ship design and operations

Table 4.8: The analysis of innovations: wind energy and solar energy

Aspect	**Description**
Working principle	Renewable energy is produced on board, reducing the demanded power from the engine and lowering the fuel consumption and emissions
Actual implementation	A wind turbine or solar panels are installed on the vessel (along with a battery)
Type of innovation	radical, tank to propeller
Reduction potential	Less than 5% of all exhaust gas emissions
Costs and expenses	About 1500 EUR/kW installed power, fuel expenses reduce accordingly
Market segments	All market segments
Level of market adoption	Early market
Main drivers	High effectiveness in reducing exhaust gas emissions
Main barriers	Only for auxiliary power due to the small energy production, high investment costs

4.3.1.6 Fuel cells

There are several types of fuel cells (e.g. [Fuel Cell 2000, 2015]). Hydrogen fuel cells are, in the Netherlands, commonly seen as the most advanced type of fuel cells (e.g. [Senter Novem, 2005] and [Bruun Ludvigsen and Ovrum, 2012]) so this analysis focuses on hydrogen fuel cells.

Hydrogen fuel cells bind hydrogen to oxygen, creating water as a product of this process. This bonding process of hydrogen to oxygen also releases energy which is delivered in the form of electric energy. Fuel cells are thus comparable to batteries, because they also store chemical energy. However, fuel cells also resemble regular diesel engines because as long as hydrogen is being added to the fuel cell, it can keep on producing energy. The hydrogen is stored in cryogenic tanks in its liquid form, or as a gas in pressurised tanks. Note the similarity with natural gas being stored as CNG or LNG. Hydrogen storage is however even more extreme: the temperature of the cryogenic tank is not at -162 degrees celcius like for LNG, but at about -238 degrees celcius [US Department of Energy, 2008]. Storing hydrogen is still considered high-tech. This is also the case for fuel cells themselves and for the auxiliary systems which are needed [Verbeek, 2015b].

Even though fuel cells have a 100% tank-to-propeller reduction of the exhaust gas emissions, they are currently not considered to be a very suitable option for the inland shipping industry. This is stated in the literature (e.g. [Bolech et al., 2011]) and is also confirmed during the stakeholder interviews. The complexity of fuel cell technology and the steep investment costs make it an unattractive option for the inland shipping industry. Fuel cell technology may cost up to 7000 EUR/kW according [Hekkenberg, 2013b]. [Bruun Ludvigsen and Ovrum, 2012] conclude that the adoption of fuel cells is likely to start in the market of short sea ferries because these ships have frequent bunkering possibilities, and the deep sea cruise industry because these ships would benefit from the reduction of noise and vibrations. Up until this point, the application of hydrogen fuel cells on vessels is limited to a number of demonstrators [Verbeek, 2015b].

Table 4.9: The analysis of innovations: hydrogen fuel cells

Aspect	Description
Working principle	In fuel cells, hydrogen reacts to oxygen and produces electric energy (and water)
Actual implementation	Fuel cells and hydrogen tanks are installed on board instead of a diesel engine and fuel tank
Type of innovation	radical, tank- to-propeller
Reduction potential	100% of all exhaust gas emissions
Costs and Expenses	Up to 7000EUR/kW, unclear price evolution between hydrogen and MGO
Market segments	deep sea and short sea shipping segments rather than inland shipping
Level of market adoption	innovators are trying it out
Main Drivers	High effectiveness in reducing exhaust gas emissions
Main barriers	High investment costs and complexity of the technology

4.3.2 Changes in the power generation system

The innovations in the previous subchapter relate to changes in the energy source of vessels. This subchapter continues with another type of technical innovations: changes to the power generation system. These are changes which are all applicable to vessels with conventional powering with a diesel engine, and are thus focussed on reducing the emissions by having a better power generation system. The innovations which are discussed are: the maintenance and renewing of components, diesel-electric drive chain, part load efficiency, exhaust gas recirculation, waste heat recovery, and specialised diesel engine innovations.

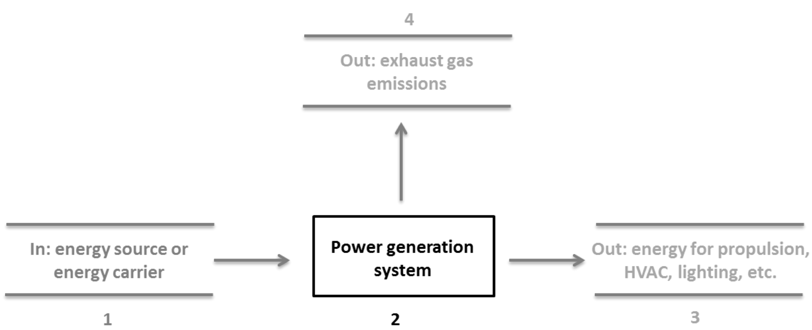

Figure 4.6: Changes in the power generation system: the second category of technical innovations

4.3.2.1 Improved maintenance

Doing regular maintenance or large overhaulings of the installed components (like the diesel engine, transmission and auxiliary systems) will often mean an improved efficiency (e.g. [Winkel et al., 2013]). This is because components wear down over time and their efficiency starts to decline. By having good maintenance practices the wear of these components can be minimised, safeguarding the good performance and efficiency of the diesel engine. Alas, no recent and reliable research can be found which quantifies the effect of the quality of maintenance on the amount of exhaust gas emissions in the inland shipping industry. No similar research can be found in the automotive industry either [van der Mark, 2015]. However, the stakeholder interviews reveal that vessel operators can experience a noticeable difference it their engine performance after maintenance has been carried out. This strengthens the stakeholders' believe in the potential of improved maintenance schemes.

The main observations when it comes to the stakeholders' attitudes about the maintenance of engines and drive chain components, is that they feel like they are already doing the best they can. They all seem to acknowledge that there is a potential to reduce the emissions with maybe a couple of percentage points, but they do not feel like it would be 'worth it' financially. The interviews reveal that the regular maintenance of a 1.400 kW diesel engine may cost 10,000 EUR (anno 2016). This is done every 10,000 running hours and after about 40,000 running hours the engine would receive a larger overhauling which costs about 150,000 EUR. Since there are no data on the effectiveness of improved maintenance schemes, the owner-operators can currently not be convinced about the cost-effectiveness of improving the maintenance scheme.

Table 4.10: The analysis of innovations: improved maintenance

Aspect	**Description**
Working principle	By reducing the wear on components their efficiency can be kept high
Actual implementation	Smaller maintenance intervals and improved maintenance techniques
Type of innovation	Incremental, tank-to-propeller
Reduction potential	Less than 5% of all exhaust gas emissions
Costs and expenses	Unknown
Market segments	All market segments
Level of market adoption	Early market
Main barriers	Maintenance: knowledge development is required to give an insight in the cost-effectiveness Replacement of components: other considerations are more important in owner-operators' decision

4.3.2.2 New components

Even when the maintenance is done thoroughly, the performance of the components will decline over time and they will need to be replaced eventually. In most cases, by changing a component for a newer one, its performance can be upgraded. The most obvious example where this is the case, is in the installation of a new diesel engine (see Chapter 2.2.3). Modern diesel engines are more fuel efficient than old diesel engine that are worn out. The environmental performance of the ship can thus be improved by replacing an old engine by a new one.

It must be noted that it appears that new diesel engines which meet the so called CCNR2 emission requirements, have a slightly higher fuel consumption that the slightly older diesel engines. To explain this, one must know that these engines are designed to have lower emissions of NOx and PM. The formation of NOx is reduced by lowering the peek temperatures in the cylinders of the diesel engine. However, this also means that the fuel efficiency of the engine goes down a couple of percentage points. Another element to add to this discussion, is the good performance of slow-running diesel engines. While not many of these slow-running diesel engines are being used in the inland shipping industry, the users are reporting a high fuel economy (and thus relatively low emissions).

When it comes to replacing components of the drive chain, there are other factors which seem to be determinative in the decision making process of owner-operators. The price of the components (the price of a diesel engine of 1.400 kW starts at about 300,000 EUR for example), their own experience with a brand, the accounts of trusted partners with certain brands, and the simple fact that they are used to one particular type of component can be enough to overrule considerations related to emissions. 'As long as my choice meets the requirements' is the general approach. This goes for diesel engines, transmission components, propellers and auxiliary systems.

Even so, suppliers of these components are working on developing new technologies to improve the components' performance. Examples of this with diesel engines are two stage turbo charging, Miller timing, water injection into the cylinders, and hydrogen injection into the cylinders. Turbo charging [5] is an example of an innovation which has been around for a while and has already reached the late majority. Apart from focussing on fuel economy and the reduction of exhaust gas emissions, engine manufacturers also focus on safeguarding and improving the reliability of their engines and reducing the maintenance they require.

Specialised diesel engine innovations often originate in the automotive and deep sea shipping market. This is because these markets are much larger and R & D costs can be earned back more easily (see Chapter 3.4. It therefore usually takes longer until specialised diesel engine innovations are also applied in engines suitable for inland ships. It goes without saying that these innovations are implemented in the inland shipping industry rather slowly, because they are only considered by owner-operators when the

[5] The air intake of turbo charged diesel engines is compressed. More oxygen goes into the cylinders allowing more fuel to be burnt during one stroke. The power output of turbo charged diesel engines is therefore higher. Even though the efficiency of the engine reduces slightly, the power density per volume or weight of the engine block is higher. More information on the principle of turbo charging diesel engines can be found in [Stapersma and Klein Woud, 2008] and [Stapersma, 2010]

engines need to be replaced. The market adoption of these specialised innovations may happen unnoticed by owner-operators. Engine manufacturers may simply implement them into the engines they offer and these specialistic innovations may thus be seen as normal incremental improvements of diesel engines.

Table 4.11: The analysis of innovations: new components

Aspect	**Description**
Working principle	New components usually have a higher efficiency and lower emission levels
Actual implementation	An old component is removed and a new component is installed on board
Type of innovation	Incremental, tank-to-propeller
Reduction potential	Less than 10% reduction of fuel consumption and all related exhaust gas emissions
Costs and expenses	Depends on which component in replaced, installing a modern engine costs about 200 to 400 EUR/kW, a new propeller of about 1,65 m in diameter costs about 30,000 EUR. The fuel expenses reduce in relation to the reduced fuel consumption
Market segments	All market segments
Level of market adoption	Various stages, crossing the chasm is not often a problem
Main drivers	Allows owner-operators to meet new requirements and to reduce their expenses by saving fuel
Main barriers	Slow market adoption because new components are usually only acquired when it's time to replace them anyway

4.3.2.3 Diesel-electric drives and part-load efficiency

Diesel-electric drives could fit into the innovations related to the changes in the energy source rather than this section about changes in the power generation system. However, since most diesel-electric drives get their energy from the same fuel as regular electric-drives, this is categorised as a change in the drive chain instead of a change in the energy source.

Diesel-electric drives are still considered to be an innovative concept (e.g. [Winkel et al., 2013]). This concept of using diesel generators and an electric transmission to power the propeller has been implemented numerous times in deep sea shipping, short sea shipping and in inland shipping (e.g. the Carpe Diem and the Amulet). The interviews reveal that the vast majority of the stakeholders is convinced that more and more vessels with diesel-electric drives will emerge. Owner-operators also seem to have accepted diesel-electric drives as an established method to power inland vessels. One could say that diesel-electric drives are a matter of time: the longer the wait, the more engines need to be replaced, the more diesel-electric vessels will be out there.

Owner-operators who come at the 'natural' point to replace their engine, will already consider to switch to diesel-electric drives. This is because the benefits are convincing enough, and the additional costs have drastically dropped over the past years.

It must be noted that there is quite some ambiguity about the effectiveness of diesel-electric drives. Some believe it may save up to 25% of the fuel consumption (e.g. [Blaauw, 2009]) while other estimate it has a negative effect on the fuel consumption due to the conversion losses. The rather positive observations from the interviews are quite different from what is found by [Hekkenberg, 2013b], [CE Delft et al., 2013a] and [Gille et al., 2013] for example. These authors agreed that the implementation of diesel-electric drives was not yet cost-effective for implementation on existing inland vessels. They concluded this because the systems would require extensive changes to the ship design. These changes do not seem to scare off owner-operators when they are faced with changing their engine at a normal interval.

This shift in the attitude towards diesel-electric drives may be attributed to the growing awareness of 'part load efficiency' with smaller engines and the importance of a case-specific propulsion system. The idea of part load efficiency is that one single diesel engine does not often operate at its optimal working point. The engine's efficiency is optimal at this working point, but is thus not often achieved. By working with several smaller diesel engines, the fuel consumption could be reduced. This is accomplished when the diesel engines are working at this optimal point more often. In other words: instead of one large engine seldom running at its optimal working point, a smaller engine work at its optimal working point as often as it can and when extra power is required another engine is switched on rather than cranking the first engine up over its optimal working point. This concept is related to diesel-electric drives because the application of part load efficiency is often implemented as a diesel-electric system.

Some stakeholders (correctly) question if the heightened transformation and transmission losses are compensated by the improved engine efficiency. Most owner-operators however, seem to be convinced that a decent study of their propulsive requirements and and to the ideal set up is a prerequisite to having an efficient power generation system. Also, the flexibility of such a set up and the considerably lower prices of small diesel engines are aiding the market adoption of diesel-electric drives. The interviews reveal that for small vessels in particular, diesel-electric drives with considerably cheaper automotive engines are also being experimented with.

Table 4.12: The analysis of innovations: diesel-electric and part load efficiency

Aspect	**Description**
Working principle	Electric transmission allows part load efficiency: smaller engines which operate on their optimal working point more often. This reduces fuel consumption and emissions simultaneously
Actual implementation	Instead of one diesel engine, several smaller diesel engines are installed on board and an electric transmission powers the propeller
Type of innovation	Radical, tank-to-propeller
Reduction potential	Between -10 and +10% of all exhaust gas emissions
Costs and expenses	Depends on the configuration, range from 200 to 1200 EUR/kW, fuel expenses follow the effect on fuel consumption
Market segments	Small and medium sized vessels
Level of market adoption	crossing the chasm
Main drivers	Flexible operations, vibrations in the ship are easier to dampen, in some cases less expensive than a conventional setup
Main barriers	Slow market adoption because it is only considered when an engine reaches its life time and is to be replaced

4.3.2.4 Exhaust-gas recirculation

Exhaust gas recirculation is a method which is starting to be applied in the automotive industry, but which has not yet been applied in the inland shipping industry. In the EGR concept some of the exhaust gases are mixed with fresh air in the intake of the engine. This causes the inlet air to be warmer when it goes into the cylinders of the diesel engine. These higher intake temperatures can cause the peek temperatures during the combustion process to go down and these reduced peek temperatures can reduce the amount of NOx which is formed. On the downside, other emissions may go up because the fuel consumption may rise. (e.g. [Winkel et al., 2013] and [Gille et al., 2013])

Because there is not yet any experience with EGR in the inland shipping industry, there are no data about the cost of EGR systems or the effectiveness of these systems. Some obstacles in the adoption of EGR systems in the inland shipping industry, are the size of the EGR systems, and the high investment costs of engines with EGR systems(e.g. [Move-iT!, 2012]). These high investment costs may seem contradictory to the increasing market adoption of EGR systems in the automotive industry. This can be explained by the automotive industry's mass-production. This mass production and the large market for vehicles (with EGR) allow suppliers to earn back the R & D costs. This is however not the case for inland vessels.

Table 4.13: The analysis of innovations: exhaust gas recirculation

Aspect	Description
Working principle	EGR reduces peek temperatures in the cylinders, lowering NOx emissions
Actual implementation	An diesel engine equipped with an EGR system is installed on board
Type of innovation	Radical, tank-to-propeller
Reduction potential	CO2 and PM may rise, NOx reduction between 40 and 60%
Costs and expenses	between 60 and 200 EUR/kW, fuel expenses may rise
Market segments	All market segments
Level of market adoption	Before market introduction
Main drivers	Proven method in the automotive industry, very effective in lowering NOx
Main barriers	Increased fuel consumption, only reduction of NOx which is often not enough to meet all engine requirements

4.3.2.5 Waste-heat recovery

The idea behind waste heat recovery is rather simple: the warmth of the exhaust gases of a diesel engine can be partially recuperated. This is done by using an installation which extracts energy the exhaust gasses and which heats up thermic oil. Other waste heat recovery installations maintain steam cycles. Either way, these systems can reduce the emissions of inland vessels because they allow to reduce the use of a heat boiler or generator.

The concept has already been applied in the deep sea shipping industry with mixed results. There is one company offering waste heat recovery systems for the inland shipping market, targeting large inland vessels.

Waste heat recovery systems are only effective for vessels which need heat for their operations. Chemical tankers that need to be able to heat up their cargo come to mind.

Waste heat recovery systems have high investment costs and there is only limited experience with these installations on inland vessels. The payback period of such systems seems to be quite long. This is because it must be earned back through the fuel savings of a boiler or generator, and these are generally speaking not large amounts of fuel when compared to the amount of fuel which is used to power the vessel. Since these savings depend on the operational profile of a vessel, it is hard for suppliers and owner-operators to get a good understanding of its pay back period or total cost of ownership.

Table 4.14: Tha analysis of innovations: waste heat recovery

Aspect	**Description**
Working principle	Recuperating heat from the exhaust gases reduces the use of boilers or generators used for heat production
Actual Implementation	Heat interchanging system is installed on board
Type of innovation	Radical, tank-to-propeller
Reduction potential	Less than 10%
Costs and Expenses	between 300-600 EUR/kW, fuel expenses follow the fuel consumption
Market segments	Large and newbuild tankers
Level of market adoption	Early market
Main drivers	International recognition of its potential
Main barriers	Not suitable for many market segments, high investment costs, additional system on board that requires attention

4.3.3 Changes in the energy demand

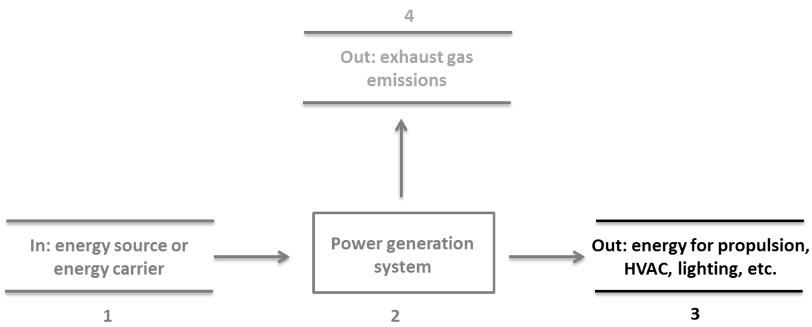

Figure 4.7: Changes in the energy demand: the third category of technical innovations

Image 4.7 shows that the previous subchapters on technical innovations go into changes of the energy source and changes to the drive chain. This subchapter relates to changes to the vessel which are focussed at reducing the energy which is demanded from the power generation system. The innovations which are analysed in this subchapter are: alternative propulsors, hull shape optimisation, flexible tunnels, air lubrication, LED lighting, drag reducing coatings and propeller optimisations.

4.3.3.1 Drastic changes to the ship design

Some innovations which are often mentioned in the literature include alternative propulsors (like Voidth Schneider propellers, Whale Tails and pods), hull shape optimisation, flexible tunnels and air lubrication. These are all innovations which are aimed at reducing the resistance of vessels. They require substantial changes in the ship design, making these innovations mostly suitable for newbuilds. Because these innovations are not only drastic in terms of ship design, but they are also very costly. The price of a CFD hull shape optimisation may easily cost between 10,000 and 15,000 EUR and would save about 5% of the fuel (e.g. [Blaauw, 2009] and [van der Meij, 2014]). But this cost of 15,000 EUR is not the entire cost for an existing ship: it must also be retrofitted accordingly. Taking the vessel out of operation and altering the vessel raises the costs significantly. These options are thus, generally speaking, not an option for existing vessels. Since this research focuses on finding innovations which can be implemented in short term and in a cost- and effort effective way, this means these innovations in the ship design are almost certainly excluded.

These resistance-reducing methods is that many of them are in the earliest stages of development (e.g. air lubrication and alternative propulsors). There are hardly any reliable data available on the effectiveness of these innovations to reduce the emissions.

Table 4.15: The analysis of innovations: drastic changes to the ship design

Aspect	**Description**
Working principle	The hull resistance is lowered or the propulsive energy is increased, reducing fuel consumption and emissions
Actual implementation	The ship design (lines plan) is optimised by CFD calculations and the hull is built accordingly. Special attention goes to the front and aft of the ship
Type of innovation	Radical, tank-to-propeller
Reduction potential emissions	Less than 10%
Costs and expenses	Additional ship design costs between 10,000 and 15,000 EUR, shipbuilding costs may rise, fuel expenses will be lower
Market segments	Newbuilds in all market segments
Level of market adoption	Innovators
Main drivers	Relatively inexpensive method to reduce fuel consumption for newbuilds
Main barriers	Slow market adoption due to high costs and radical changes to the ship design, only suitable for newbuilds

4.3.3.2 LED lighting

LED lights require only a fraction of the power regular lights do. The prolonged lifespan of these LED lights often allows the higher investment costs to be paid back over the long run. There are also hardly any barriers to the adoption of LED lights, the initial issues about the limited colour depth have been resolved already. LED lights can be installed in regular light fixtures whenever a regular lamp needs to be replaced. Even though LED lights are more expensive than regular lights, the cost difference is marginal when put into perspective. Off course, this is also the case for its reduction potential of exhaust gas emissions. While there are no clear barriers holding back the adoption of LED lighting, the adoption is not going very fast. This is because many owner-operators do not even consciously consider their choice of lights. One could say they make their choice on auto-pilot.

This innovation is not specific for inland waterway transport. [Lindstad et al., 2015] show for several vessels in the deep sea and short sea industry that LED lighting can have short pay back periods. Other industries and even regular households can all adopt LED lights. As the adoption process picks up over several of these industries, the economies of scale will further reduce the investment cost of LED lights. This is bound to happen, as simple calculation reveal that even for regular households the pay back period is short (e.g. [LED Verlichting Eindhoven, 2015]).

Table 4.16: The analysis of innovations: LED lighting

Aspect	**Description**
Working principle	LED's require less energy than conventional lamps
Actual implementation	LED lights are installed instead of regular lights
Type of innovation	Incremental, tank-to-propeller
Reduction potential emissions	less than 1%
Costs and expenses	Less than 5 EUR price difference with regular lights, fuel expenses reduce slightly
Market segments	All market segments
Level of market adoption	Early market
Main drivers	Simple, easy to install, cheap, requires no operational changes from owner-operators
Main barriers	Marginal emission reduction potential and marginal costs mean that owner-operators often make their choice of lights on auto-pilot

4.3.3.3 Friction-reducing coatings

The use of drag reducing coatings is another method that reduces the resistance of vessels. Antifouling has been around for many years and is by now an established method to maintain the resistance of deep sea shipping vessels as low as possible (e.g. [Deltares and TNO, 2015]). Several types of coatings are used on inland vessels: epoxy coatings, and bitumen coatings are particularly popular in the inland shipping industry. Most owner-operators use some type of friction-reducing coating, so this innovation has reached the late majority. This may be why [Lindstad et al., 2015] and other authors do not include it in their list of innovations. However, there is little research to the effect of an increased frequency of applying the coatings. There may still be some potential in this innovation. See Capter 4.3.2.1 which goes into some more detail about the maintenance of inland vessels

Table 4.17: The analysis of innovations: friction-reducing coatings

Aspect	**Description**
Working principle	Coatings keep the hull smooth which keeps the vessel's resistance low
Actual implementation	During maintenance the coating is applied to the hull (spraying or painting)
Type of innovation	Incremental, tank-to-propeller
Reduction potential emissions	Less than 10%
Costs and expenses	unknown costs, reduced fuel expenses
Market segments	All market segments
Level of market adoption	Late majority
Main drivers	Proven technique which the stakeholders are familiar with
Main barriers	No barriers, knowledge on the effect of a shortened application interval may reveal if there is still some potential left

4.3.3.4 Propeller optimisation

Buying a new propeller costs about 25,000 to 30,000 EUR. This is hardly ever done however. If a propeller creates vibrations it is usually mended with regular welding and steel working techniques [den Haan, 2015]. However, buying a new propeller may be financially interesting when the propeller is not appropriate for the vessel. The number of variables which determine the propeller's performance are countless: the number of blades, the pitch, the shape of the blades, and whether it is a ducted propeller or not, are just some of these variables [Watson, 2002]. To choose the right propeller the specialised help of suppliers and yards is usually required. Other organisation can also provide in-depth studies to which propeller would be optimal. Ordering a propeller study at Marin costs about 150,000 EUR while it may only save up to 2% [Blaauw, 2009]. This would give the investment a pay back period of about 17 years.

The interviews show that this steep pay back period does not appeal to owner-operators. Even for newbuilds this investment is not often considered. What is remarkable, is that owner-operators seem to have a strong preferences when it comes to their propeller and rudder. One may be excited about a modern double ducted setup, while another owner-operators may not want anything else but the conventional single screw setup. Manouevrability, noise and vibrations are important factors in the choice of propeller. Even if a certain propeller may save fuel, these other considerations may be deemed more important.

Table 4.18: The analysis of innovations: propeller optimisation

Aspect	**Description**
Working principle	The efficiency of propellers depends on many factors, getting an efficient propeller can save fuel and emissions
Actual implementation	A screw with a higher efficiency is sought, bought and installed
Type of innovation	Incremental, tank-to-propeller
Reduction potential emissions	Less than 2%
Costs and expenses	180,000 EUR investment, reduced fuel expenses
Market segments	All market segments
Level of market adoption	innovators are paying more attention to the propeller
Main drivers	Proven techniques, requires no operational changes
Main barriers	High costs, other considerations like manoeuvrability may be found more important

4.3.4 Changes in the exhaust of engines

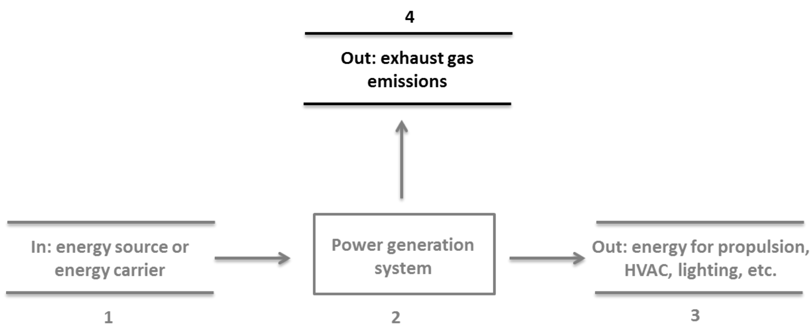

Figure 4.8: Changes to the exhaust of engines: the fourth category of technical innovations

The last category of technical innovations for inland vessels are changes to their exhaust. Three types of after treatment are relevant to the inland shipping industry: SCR catalysts and particle filters. Water injection is often mentioned in this category of pre- and after-treatment, but this research categorises water injection as a specialised diesel engine innovation. These innovations are briefly discussed in Chapter 4.3.2.2.

4.3.4.1 SCR and particle filters

SCR catalysts can be used to reduce the amount of NOx. This is done by adding vaporised ammonia or urea to the exhaust gas. The catalyst is usually installed in the engine room, and the ammonia or ureum is stored on board in tanks. SCR catalysts have proven their effectiveness in reducing NOx emissions by 70 to 90% and have been applied numerous times already in the inland shipping industry. To give owner-operators an incentive to install SCR catalysts on board of their ship, regulating authorities are granting subsidies and other benefits (e.g. [Provincie Zuid Holland, 2014] and [Boone, 2014]). This is making it financially interesting to invest in an SCR system.

Particle filters are used to reduce the emission of PM by up to 95%. They do tend to increase the fuel consumption a bit, since the engine must be able to push the exhaust gases through the fine-mazed particle filters. The engines must thus overcome a resistance in the flow of exhaust gases. Particle filters are at the same level of market adoption as SCR catalysts, as these systems are often installed together. The SCR system is installed to reduce the emission of NOx and the particle filter reduces the emission of PM.

These systems are a comprehensive method for vessels with old engines (CCNR0 and CCNR1) to meet stricter norms (CCNR2 and future requirements). The space requirements are limited and the investment costs are relatively low when compared to installing a new engine. For a large vessel with a 1,400 kW engine, the installation of an SCR system and a particle filter costs about 150,000 EUR, while a new engine costs about 300,000 EUR (anno 2015).

Table 4.19: The analysis of innovations: SCR catalysts and particle filters

Aspect	**Description**
Working principle	SCR: ammonia or urea are added to the exhaust gases, reacting with NOx and lowering its emission Particle filter: exhaust gases pass through a filter and most particles are caught in the filter
Actual implementation	An SCR katalyst and urea or ammonia tank is installed on board and a particle filter is installed on the exhaust
Type of innovation	Radical, tank-to-propeller
Reduction potential emissions	SCR: up to 90% of NOx Particle filter: up to 95% of PM
Cost and expenses	about 100 EUR/kW for installing both systems on board, some additional expenses for the urea or ammonia
Market segments	All market segments
Level of market adoption	Early market
Main drivers	Complying to new rules is less expensive with SCR and a PM filter than with a new engine
Main barriers	High investment costs, added maintenance, space requirements

4.4 The operational innovations

The previous subchapter analyses the technical innovations which can be implemented on board of vessels, and does this for four categories of innovations. This subchapter analyses the operational innovations relevant to inland waterway transport. These are the innovations which are related to how the vessels are used by their owner-operators. These innovations are all techniques that can be carried out by the owner-operators themselves, independently of their operational partners like ports, terminals, and demand-side actors. The innovations analysed in this subchapter are: advanced route planning, training of captains and crew, and cold ironing.

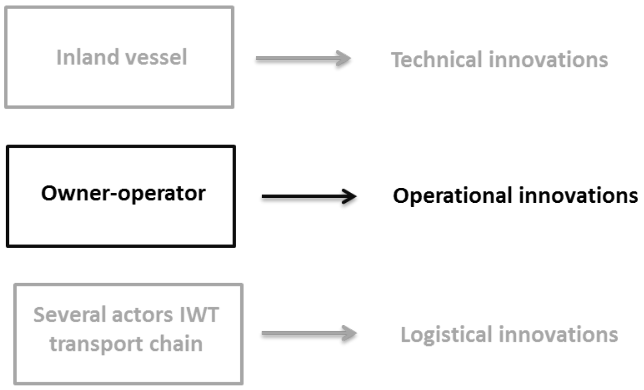

Figure 4.9: Operational innovations: the second category of environmental innovations relevant to inland waterway transport

4.4.1 Advanced route planning

Advanced route planning gives individual vessel operators detailed information on which route to sail and how fast to sail. Suppliers of navigation software may improve their planning software by further developing the underlying computational models. They may develop the software to take into account several factors which influence the vessel's resistance and other framework conditions. Advanced route-planning software may help vessel operators to reduce their fuel consumption and to improve their environmental impact. This can be done by working out the effect of several factors on the fuel consumption: the local water velocity, detailed water depth information, the hull shape of a vessel, information on the vessel's power generation system, detailed loading information, hydrodynamical undeep water effects, and so on. Real time depth measurements and feedback on the optimal way to sail is another way that advanced route planning can have an effect.

Some initiatives have already been set up to improve the navigation advice which is given to vessel operators through these software packages. The Dutch program IDVV already focussed on how to improve the digital sharing of waterway information between different actors in the transport chain. Some spin-offs of this program are booking good results.

The Economy Planner for example uses detailed water-depth measurements to advise the vessel-operator on the optimal route and velocity. The navigation software combines hydrodynamical calculations with water-depth-measurements on board some ships. The Economy planner could save up to 5% in the fuel consumption (e.g. [Blaauw, 2009] and [van Wirdum et al., 2014]).

Aside from vessel-specific route planning, there is also a large potential in fleet-level route planning software. This is particularly interesting for the market segment of tankers and container vessels where there is a higher number of shipping companies and a certain degree of knowledge about the upcoming transports. Fleet-level advanced route planning could be used to determine which combination of routes, vessels, and freights would be the most fuel-efficient. Most shipping companies have developed their own way of doing this because it is such an important aspect of their core business. Fleet planning is a day of their day-do-day operations. They do however acknowledge that they are constantly improving their route planning methods and they are convinced there is still a large potential left in this.

The main barrier in the adoption of advanced route planning techniques is the confidence that owner-operators have in their own established way of route planning. They may find it hard to accept that they can do better. Research to the effect of adopting more advanced route planning techniques is needed to provide vessel operators with proof that they can save fuel by adopting new ways. On the other hand, these options are not very expensive to install on board. Advanced navigation software for one vessel costs less than 500 EUR (e.g. [PC Navigo, 2015]). Implementing fleet-planning software tools will cost some more. similar fleet-level technologies are however very common in the automotive industry.

Table 4.20: The analysis of innovations: advanced route planning

Aspect	Description
Working principle	Smart navigation advice and fleet planning can reduce the fuel consumption of a vessel or fleet
Actual implementation	Software is installed on board
Type of innovation	Incremental, tank-to-propeller
Reduction potential	Less than 10%
Costs and expenses	Less than 2,000 EUR, fuel expenses are reduced
Market segments	All market segments, shipping companies in particular
Level of market adoption	Early majority
Main drivers	Part of the core business of inland shipping companies so little resistance to the adoption, relatively inexpensive method to reduce fuel consumption, broad support of stakeholders, several operators report good results
Main barriers	Vessel operators have confidence in their own performance, irrefutable proof of the effect of advanced route planning is still lacking

4.4.2 Fuel-efficient sailing techniques

By educating and training the captains (and crew) of inland vessels on how to sail on a fuel efficient way, they can reduce their vessel's fuel consumption and exhaust gas emissions. Efficient sailing methods are already getting attention in the formal education of captains and crew, and several initiatives exist to stimulate crews on to learn about these matters. The program of e-courses called 'Voortvarend Besparen', for example, is already stimulating inland captains to adopt fuel efficient sailing techniques [EICB, 2015d]. Apart from providing classes in which vessel operators learn about fuel-efficient sailing techniques, they could be offered trainings where they practice this knowledge. Simulation-based learning can be a helpful tool in this.

The savings potential of adopting improved sailing techniques is about 7%. [Confidential information, 2015] reveals that even higher percentages can be reached when this learning process is linked to an internal (but collegial) competition. By sharing the performance of different participating vessels, the vessel operators can be challenged to do better. Another method that could heighten this 7% is OBM. Vessel operators could be given real-time feedback on their engine's performance, which they could use to improve their performance. This IT support is already discussed briefly in Chapter 4.4.1.

The main barrier to the adoption of fuel-efficient sailing techniques, is that it requires vessel-operators to change their habits. This may be difficult, especially since many captains are convinced that they're already doing a good job. While this may be true, these vessel-operators will not know if they are right if they never give it a try. Also, the voluntary nature of the offered education (and the lack of control if operators indeed adopt these sailing techniques when they are asked to do so by their shipping company for example), are making it easy for reluctant operators to not make an effort. Another important barrier to the adoption of fuel-efficient sailing techniques, is that they are often a trade off between the vessel's fuel economy and sailing speed. Whenever a strict schedule requires it, owner-operators will not stick to the fuel-efficient sailing techniques they have learned.

Table 4.21: The analysis of innovations: education about fuel-efficient sailing techniques

Aspect	**Description**
Working principle	Certain sailing techniques reduce the fuel consumption and thus the emissions
Actual implementation	Vessel operators follow a course on fuel efficient sailing techniques and implement it when sailing
Type of innovation	Incremental, tank-to-propeller
Reduction potential	7%, even more with OBM
Costs and expenses	About 300 EUR for one course, fuel expenses decrease
Market segments	All market segments
Level of market adoption	Early majority
Main drivers	Inexpensive way to reduce fuel consumption, requires no space on board
Main barriers	Requires operators to change their habits, operators already have confidence in their own performance

4.4.3 On board monitoring

An aid to both levels of advanced route planning (vessel and fleet) and to aid in fuel-efficient sailing methods, is the use of 'on board monitoring' (OBM). This is the use of sensors and measurements to monitor the performance of vessels, and showing this to the vessel operators (and planners). An OBM system can also incorporate emission measurements. The vessel operators can then see in real time what the emissions are, what the engine performance is, what the fuel consumption is, which systems are using energy, and so on. OBM provides information to vessel operators which they can then use to their advantage. This could be compared to a regular tachometer in an car: it provides information which enables the driver to make substantiated choices. In the case of a car's tachometer this information can allow the driver to shift gears at a suitable moment. In the case of inland vessels with OBM, the vessel operators could see what the effect is of their manipulation of the throttle is and they can see how their manoeuvring affects their vessel's fuel consumption and emissions.

An added advantage of OBM which measures emissions, is that these emission measurements could be used in a regulatory framework as an alternative to the existing regulations. The current regulations are based on laboratory emission measurements at certain operating points of an engine. This can give a distorted view of the actual emissions. This difference between theoretical emissions and the practical emissions can be seen in the automotive industry and regulating authorities are trying to correct this difference. This movement is expected to speed up due to the developments of the so called 'dieselgate'. In inland waterway transport, OBM could be a tool in the creation of real-life emission standards. The Green Deal which is being set up by several stakeholders of the inland shipping industry to work out how OBM could be implemented and how it could be incorporated into regulations, reveals that there is a broad support for it. The European Horizon 2020 research program PROMINENT is also looking into OBM certification options.

An OBM system with emission measuring sensors costs about than 10,000 EUR. The effect of OBM on the fuel consumption of a vessel could be equal to the effect of fuel-efficient sailing methods, which is about 7%. This makes OBM a relatively inexpensive way to reduce the fuel consumption and emissions of inland waterway transport.

Table 4.22: The analysis of innovations: on board monitoring

Aspect	**Description**
Working principle	OBM provides information about the vessel's performance and the emissions which can be used by the vessel operators
Actual implementation	Software and some sensors or measuring tools are installed on board
Type of innovation	Incremental, tank-to-propeller
Reduction potential	When combined with fuel-efficient sailing techniques less than 10%
Costs and expenses	Less than 10,000 EUR, fuel expenses are reduced
Market segments	All market segments, shipping companies have more to gain
Level of market adoption	Early majority
Main drivers	Part of the core business of inland shipping companies so little resistance to the adoption, relatively inexpensive method to reduce fuel consumption, broad support of stakeholders
Main barriers	Vessel operators have confidence in their own performance, knowledge on the effect of advanced route planning and OBM is required to show how large the potential (still) is

4.4.4 Cold ironing

The last operational method to be discussed, is cold ironing. Cold ironing is when inland vessels are in port and they use an electric power supply from shore instead of having their own generator running. Since the diesel generator is not running, the vessel has no exhaust gases and is thus not emitting any exhaust gas emissions. Because cold ironing is a change in the energy source of a vessel, it was briefly mentioned in Chapter 4.3.1 which. Because it is also a change in how vessel operators use their vessel, it is further analysed in this subchapter.

It are exactly the operational changes which are experienced as barriers in the adoption of cold ironing. When cold ironing in the Port of Rotterdam became mandatory for inland vessels (whenever there was the possibility to use power from the shore), there was quite some critique to it. The hassle involved with plugging in and plugging out the power supply was not to the liking of many vessel operators. While operators have by now accepted this way of working, they are not happy that there is no standardised way of cold ironing for all the inland ports and terminals they frequent. The interviews reveal that vessel operators and some regulating authorities would much rather prefer one standardised method of cold-ironing.

Overall, the attitude of vessel operators towards cold ironing is not very positive. This is because they do not like that it is being imposed. They are also not satisfied by the price they have to pay for the electric energy they use. Research of [de Vos and van Gils, 2011] concludes that in some cases the cost of cold ironing is lower while in other cases it is higher than the cost of generating the power on board. But this conclusion is questioned by several vessel operators. This may be attributed to the study taking into account the the cost of maintenance of the power generation system. Owner-operators may not factor this in, they mainly look at the direct cost of the fuel compared to the cost of the power from the quayside.

Table 4.23: The analysis of innovations: cold ironing

Aspect	**Description**
Working principle	In port, vessels use electric power from the shore instead of power they generate on board with their diesel-fuelled power generation system
Actual implementation	Ports create cold ironing infrastructure, vessel operators connect to the grid when they lie ashore
Type of innovation	Incremental, tank-to-propeller
Reduction potential	100% during cold ironing
Costs and expenses	Comparable to regular on-board generated power
Market segments	All market segments
Level of market adoption	Early majority
Main drivers	Eliminates all exhaust gas emissions while vessels are moored
Main barriers	Hassle to plug in and out, disapproval of the costs, lack of standardisation

4.5 The logistical innovations

The previous subchapters analyse the technical innovations which can be implemented on board of vessels, and the operational innovations which can be implemented by vessel operators. This subchapter analyses the logistical innovations. These innovations require an effort of several actors of the inland waterway transport chain. The innovations analysed in this subchapter are: hubs and hops, integration of fairway infrastructure planning, planning integration between chain partners, and network cooperation.

Note that the emission reduction potential of the technical and operational innovations is expressed in gr/kWh or gr/tonkm for one vessel. The emission reduction potential of logistical innovations is in gr/tonkm of several vessels.

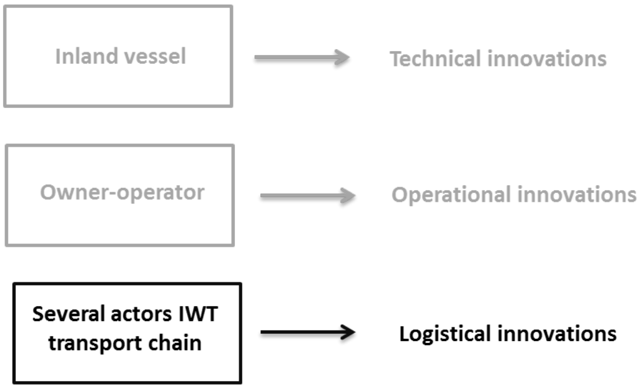

Figure 4.10: Logistical innovations: the second category of environmental innovations relevant to inland waterway transport

4.5.1 Hubs & spokes and hops

Hub are the fixed locations where cargo bundling can occur. Often, storage is an essential part of the operations occurring at hubs. By creating hubs, the distribution of products can be rearranged. This allows cargoes to be distributed differently. The concept of hubs and hops can be visualised as shown in Figure 4.11. The multi-port calling network is what is customary in the market segment of container transport. For example: a vessel is loaded with containers in a port and unloads them at several inland terminals. The second option, the direct-calling network is customary in most other market segments. In the sand and gravel market, for example, freight for only one destination is loaded into a vessel. Cargoes with other destinations are loaded on different vessels.

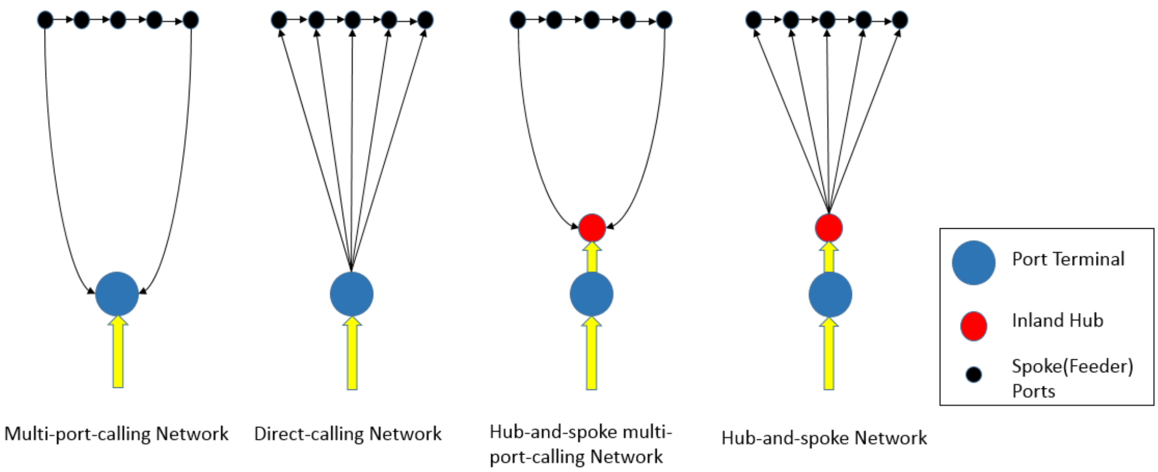

Figure 4.11: The distribution structures in inland waterway transport. Image from [Veenstra et al., 2015]

The use of inland hubs have the potential to reduce the number of vessel movements, reducing the fuel consumption and the emissions required to transport the cargoes. This is because hubs can centralise vessel operations. This can enable the economies of scale and improve the load factor of inland vessels with drastic emission reductions up to 40% as a result (e.g. [Veenstra et al., 2015]).

Hops are closely related to hubs. They are comparable to liner services in de deep sea shipping industry, or a regular city bus service which allows people to get on and off at different stops on a fixed route. Just like the bus service, in hop-concepts a vessel picks up cargoes at several terminals (which may be very close to each other), and then continues its journey to a hub or a large port (where it may call at various terminals as well). Hop concepts are particularly relevant to the container industry, but also exist with other types of cargo.

Hops allow to reduce the fuel required to transport the total amount of these cargoes because the number of empty sailing hours can be reduced. This is the result of cargo being loaded whenever the vessel arrives, rather than a vessel sailing to a location to go pick up cargo when this is asked. It can thus improve the overall load factor of the fleet. However, the fuel savings are closely linked to how far the terminals are apart from each other and how much cargo is loaded at each terminal. This is because the economies of scale do not always add up for the case of hops. Hops with smaller vessels may perform better than hops with large vessels because the cargo capacity and the turnaround time of the hop-vessels must match with the amount of cargo which is loaded at the terminals in the hop-network.

The stakeholder interviews revealed that most actors in the inland shipping industry agreed that there is indeed a large emission reduction potential for hubs and hops, but that there are also quite a lot of barriers in the creation of hubs. There must be a durable trust in the other partners and a willingness to share information with them. Only then can the business cases of the partners be discussed to reach an agreement on how the costs and benefits will be distributed. Finally, the creation of legal agreements requires time and is a labour-intensive process. All in all, setting up hubs and hops requires a high degree of organisation and cooperation form several actors. This complexity of several stakeholders working together makes these innovations difficult to implement.

Table 4.24: The analysis of innovations: hubs & spokes

Aspect	**Description**
Working principle	Hubs can centralise the operations, reducing the number of vessel movements and improving their load factor. This reduces the fuel consumption and emissions.
Actual implementation	hubs are created in inland ports or terminals and the transport network is changed
Type of innovation	Radical, tank-to propeller on fleet level
Reduction potential emissions	up to 40% (per tonkm of the overall transported cargoes)
Costs and expenses	Various value cases for the different network partners, generally a reduction of expenses
Market segments	All market segments, container transport in particular
Level of market adoption	Innovators
Main drivers	Win-Win for hub and hop partners, improved turnaround times, reduced costs
Main barriers	Requires a high degree of cooperation and trust from partners, how to spread the costs and benefits between the partners, setting it up is a labour-intensive process

Table 4.25: The analysis of innovations: hops

Aspect	**Description**
Working principle	Vessels in hops sail a fixed route ans make fixed calls where cargo can be loaded or unloaded. This allows to reduce the number of unloaded sailing hours of vessels, reducing the fuel consumption and emissions.
Actual implementation	Liner services are set up on popular routes
Type of innovation	Radical, tank-to propeller on fleet level
Reduction potential emissions	up to 40% (per tonkm of the overall transported cargoes)
Costs and expenses	Various value cases for the different network partners, generally a reduction of expenses
Market segments	All market segments, container transport in particular
Level of market adoption	Innovators
Main drivers	Win-Win for hub and hop partners, improved turnaround times, reduced costs
Main barriers	Requires a high degree of cooperation and trust from partners, how to spread the costs and benefits between the partners, setting it up is a labour-intensive process

4.5.2 Sharing fairway-infrastructure information

Advanced route planning was presented in the previous subchapter on operational innovations. Its bigger brother requires information sharing with the operators of fairway infrastructure. In the current situation, vessel operators reach locks and bridges only to ascertain that they've got to wait until they can pass.

By sharing information, these waiting times can be reduced. With a ticketing Vessels operators can adjust their sailing speed to avoid waiting times. For this to be workable, some kind of pre-announcing system must be set up which allow vessels to get a spot in the queue. Then, by reducing their speed to arrive at the bridge or lock just in time, they can save fuel and they can reduce their exhaust gas emissions. Some flexibility of operational relations may also be beneficial to the inland waterway transport's environmental performance. Consecutive bridge operators could be informed about the pending arrival of inland vessels, and they could time the opening of the sequential bridges to create a 'blue wave' (comparable to a wave of green lights for road transport). This way, the vessels need not stop and wait at each of the bridges.

While some degree of information sharing already exists, like for example the sharing of waterway depths with COVADEM, there is often no incentive to improve on this aspect. The business of inland waterway transport has always had these waiting times and accepts them as is. While vessel operators and infrastructure managers do realise there is a potential to improve the environmental performance of the industry by sailing slower and by reducing the number of stops, there is no real drive to change the current situation. For instance, the operators of inland vessels believe that if they can reduce their fuel consumption in this way, their clients will want to see the effect of it in the freight prices. This reduced fuel consumption would not necessarily improve their financial situation.

Another fairway-infrastructure-related subject that can be improved by information sharing, is providing information on the availability of berths in inland harbours for vessel operators to stay overnight. The interviews revealed that owner-operators would very much like this information to be available.

Table 4.26: The analysis of innovations: fairway infrastructure information sharing

Aspect	**Description**
Working principle	Sharing information between fairway infrastructure operators and vessel operators can allow to improve the vessels' planning, and reduce their fuel consumption
Actual implementation	IT based information sharing service is updated by infrastructure operarators and can be consulted by vessel operators
Type of innovation	Incremental, tank-to propeller
Reduction potential emissions	Less than 10% (per tonkm)
Costs and expenses	Costs for the creation of the IT information sharing service, reduced fuel expenses for vessel operators
Market segments	All market segments
Level of market adoption	Early market
Main drivers	Broad support from different stakeholders, proven technology in automotive industry, requires few changes from vessel operators
Main barriers	Requires a high degree of digital information sharing, requires high degree of organisation from several partners, no clear incentives to improve the current situation

4.5.3 Integrating chain-partner planning

Similar to information sharing by fairway infrastructure operators, information could be shared between the different actors in the transport chain. It now occurs that vessels sail until they reach a terminal to then have to wait until they can be (un-) loaded. In some market segments this waiting time is even covered with demurrage, a financial compensation to the vessel operator for these delays. This shows how common it is for inland vessels to have to wait at the terminals.

Also, for some demand-side actors the time of delivery of their goods is in reality flexible. Whenever it is acceptable for their operations to receive the goods later, they could communicate this to the vessel operator who is on his way with the cargo. The vessel operator could then decide to sail slower and save some fuel. Off course, not all owner-operators who would be allowed to deliver a freight at a later time, would do so. This is because they may prefer to start on their next voyage over saving some fuel on their current voyage.

The benefits and drawbacks for the planning integration of chain partners are similar to those of information sharing by waterway infrastructure operators: IT tools must be developed and a certain degree of organisation is required. It also requires a high degree of trust in the partners to share information with them, and there is not always a clear incentive to work on improving the current situation. This is because the current individual planning is so deeply engrained into the industry that it is not seen as a problem that needs solving. This is the case for other environmental innovations which are focused solely on reducing exhaust gas emissions. On the other hand, all the stakeholders seem convinced that there is a large potential to integrated chain partner planning. Especially in the market segment of container transport there seems to be a willingness to work on ways to integrate the planning of several transport chain actors.

Table 4.27: The analysis of innovations: planning integration with chain partners

Aspect	**Description**
Working principle	Sharing information between actors in the transport chain
Actual implementation	An IT based information sharing service which can be updated and consulted by the different partners
Type of innovation	Incremental, tank-to propeller
Reduction potential	Less than 10% (per tonkm)
Costs and expenses	Costs for the creation of the IT information sharing service, reduced fuel expenses for vessel operators
Market segments	All market segments
Level of market adoption	Early market
Main drivers	Requires few changes from vessel operators, relatively inexpensive method to reduce fuel consumption
Main barriers	Requires high degree of organisation from the chain partners, requires high levels of trust, requires IT tools for digital information sharing,

4.5.4 Various types of network cooperation

Network cooperation can happen both horizontally as vertically. With horizontal network cooperation, actors with the same position in the transport chain work together. With vertical cooperation this happens between actors with a different position in the transport chain. Creating hubs and sharing information to improve the planning of vessels can thus be seen as examples of vertical network integration. An example of horizontal network integration is already introduced in Chapter 2.3.1 which discussed the various types of ownership of inland vessels: cooperations.

Various other types of cooperation are possible. [Gille et al., 2013] and [Schrijvershof et al., 2015] go into detail about the differences between several options. The next types of network cooperation can be identified:

- Cooperations between owner-operators (cooperations as discussed in Chapter 2.3.1

- Pools with owner-operators with a centralised decision-making group
- Cooperations between vessel operators and freighters (and freight forwarders)
- Cooperations for the collective purchase of fuels
- Cooperations to share information and integrate planning between several stakeholders (see previous subchapters of Chapter 4.5)
- Cooperations for the insurance of inland vessels
- Cooperations through advocacy groups like BLN, EICB, CBRB, etc.

These various types of network cooperation can improve the environmental performance of inland waterway transport networks because they are aimed at either increasing the efficiency of the distribution network, at increasing the load factor of the cooperating vessels, or at using the advantages of the economies of scale. Network cooperation is often also focused on simplifying and improving the customer services which the vessel operators can offer or receive themselves.

The main benefits of network cooperations between owner-operators (and freighters) are the heightened security of work. The freight tariffs are more stable and cooperations have a competitive advantage over single-ship operators because they can offer a higher capacity. Cooperations usually have higher levels of planning and punctuality, and they can offer a transport guarantee. This also gives cooperations a competitive advantage over single-ship operators. In addition to this, cooperations strengthen the financial position of owner-operators, as they can more easily attain a loan from a bank when they're in a cooperation.

Some drawbacks of these cooperations is that it requires high levels of trust and organisation between the partners. Additional IT tools are required to guide the operations, and staff must be hired to take care of this. Many owner-operators want to keep as much of their liberties as possible and will not consider becoming a member of a cooperation. The interviews reveal a major reason why many owner-operators keep on sailing on an individual basis: when looking at the freight tariffs over a period of several years, there is no clear difference between owner-operators sailing individually or in a cooperation. There is thus no financial incentive to join a cooperation and many owner-operators prefer having volatile freight tariffs over giving up some of their liberties.

Table 4.28: The analysis of innovations: network cooperation

Aspect	Description
Working principle	Horizontal and vertical cooperation can increase the network's efficiency, improve the vessels' load factor, improving the efficiency of the transport network
Actual implementation	Organisations, cooperations and legal agreements are set up between the partners
Type of innovation	Radical, tank-to propeller (fleet level)
Reduction potential	up to 20% of all emissions (per tonkm)
Costs and expenses	Costs for the initial setup of the organisations and agreements, some additional administrative costs
Market segments	All market segments
Level of market adoption	Early market
Main drivers	Economies of scale is widely recognised as an effective tool, creates a competitive advantage over other vessel-operators
Main barriers	Requires a high degree of trust from partners, it is a labour-intensive process to set up collaborations, requires high degree of digital information sharing and organisation, requires partners to give some of their liberties

4.6 Chapter conclusion

The research questions which are answered in this chapter are: 'which are the environmental innovations relevant to Dutch inland waterway transport' and 'how is the market adoption of environmental innovations'. Each research question is answered separately in the next subchapters.

4.6.1 Which are the environmental innovations relevant to Dutch inland waterway transport

The categories of innovations are technical innovations, operational innovations and logistical innovations. Technical innovations in this research can be implemented on a vessel. Operational innovations can be implemented by the owner-operators of a vessel. For the implementation of logistical innovations, the effort of several stakeholders is required. This research goes into 28 different innovations, and makes a sub-categorisation of the technical innovations: changes in the energy source, changes in the power generation system, changes in the energy demand, and changes in the exhaust of engines.

Each of these innovations is analysed. The aspects which are discussed provide a technical understanding of the innovations, clarify their reduction potential and costs, and analyse to which market segments they are particularly relevant. The analyses show a large diversity of innovations. Some innovations have a particularly high reduction potential (like full electric powering) while others have a marginal reduction potential (like LED lighting). Some require high investments (like propeller optimisation) while others are remarkably inexpensive to implement (like advanced route planning).

Other conclusions related to the environmental innovations are that some innovations are suitable as retrofit option (e.g. OBM and LED lighting) and other are practically speaking only a newbuild option (e.g. hull shape optimization). Unrelated, some innovations reduce the fuel consumption (e.g. anti fouling and fuel efficient sailing techniques) while others do not (e.g. SCR catalysts and PM filters). A final conclusion could be that some innovations create a tank-to-propeller emission reduction (e.g. advanced route planning) while others have a well-to-tank effect (e.g. biofuels).

4.6.2 How is the market adoption of environmental innovations

The market adoption of the environmental innovations is at various stages. Figure 4.12 shows that the market adoption of innovations evolves from the early market to the mainstream market.

Some of the innovations are in the earliest stages of market adoption. Improved fuel quality is an example of this: this innovation has hardly been researched and knowledge development is still required. Other examples of innovations in inland waterway transport which are in the early market, are drastic changes to the ship design and on board monitoring. Innovations which have reached the mainstream market but which still have the potential to (furtjer) improve the environmental performance of the inland shipping industry, are the use of friction-reducing coatings and advanced route planning.

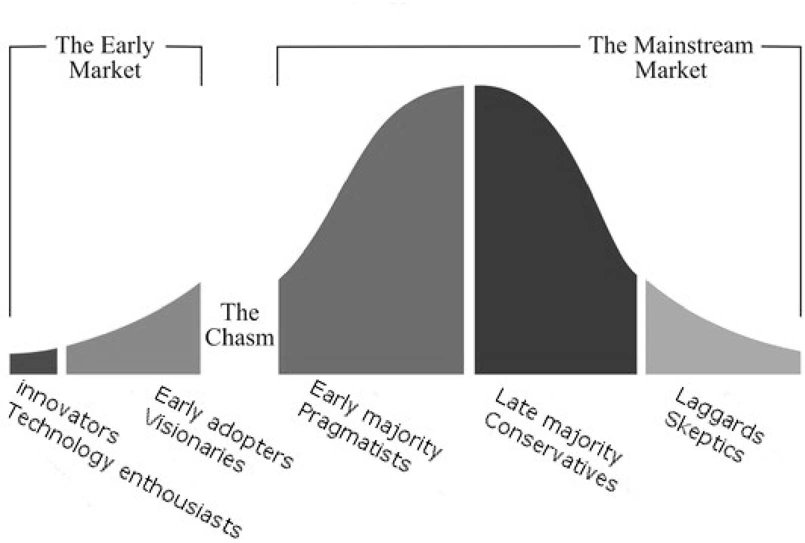

Figure 4.12: The market adoption model of technologies by Moore. Image adapted from [Meetup, 2014] and [Mohr et al., 2010]

The speed of the innovations' market adoption can be related to the innovations' drivers and barriers. Some of the drivers with a frequent occurence are that the innpvations' require few changes in the vessel operations, that they reduce the expenses by reducing the fuel consumption and that the innovations are broadly supported by different stakeholders. Some of the frequently occuring barriers are the innovations' high investment costs, their lack of clear regulations, and the slow adoption because of the long service life of components in inland vessels.

4.6.3 The relation to following chapters

Combined with the stakeholders' considerations, the information in this chapter is used in the next chapter of this research: the evaluation of which innovations are most promising for the inland shipping industry.

Based on the large variety in the characteristics of environmental innovations, it is expected that there will be innovations suitable for a fast, cost and effort effective adoption. Based on the large importance of the main barriers in the uptake process of innovations, it is expected that the most promising innovations will not be in the first stages of market adoption.

Chapter 5

The evaluation of the adoption of environmental innovations

This chapter answers two research questions: 'which measures are most promising for implementation by the industry' and 'what is needed (from the stakeholder) to improve the market adoption process'. This chapter uses the information provided in the previous chapters to evaluate the further implementation of environmental innovations. Because there are no 'one size fits all solutions' these evaluations are made for two market segments of the Dutch inland waterway transport

5.1 Methodological approach of the evaluation

Case studies are used to evaluate the adoption of environmental innovations. Within each case study the research process is to collect data, to do selective coding of these data, to analyse the themes which emerge as the crucial factors in the adoption process, to do a multi criteria analysis to find the most promising innovations, and finally to evaluate what is needed to ensure these innovations their successful adoption.

Case studies are needed because there are no 'one size fits all' solutions, as many authors already concluded, like [Posthumus et al., 2012], [Verbeek et al., 2015b], and [Lindstad et al., 2015]. This research therefore focuses on two market segments: the market segment of sand, stone and gravel, and the market segment of container transport. The choice for these case studies is motivated in Chapter 1.4 and is based on quantitative and qualitative considerations.

Other case studies can also be performed with the same research process which is used to evaluate the two case studies in this research, the process is described in Table 5.1. This research process follows the methodology of [Creswell, 2007] on how to perform case studies within qualitative research. Creswell's theories on how to perform qualitative research are well-established and are cited by several authors, including [Christiaans et al., 2004] and [Williams, 2007]. [Creswell, 2007] examines which theories exist on qualitative research and he compares his own theories to those of other well-established authors. Creswell for example compares the theories of [Jacob, 1987], [Munhall and Oiler, 1986], [Lancy, 1993] and [Strauss and Corbin, 1990] to his own. A short literature review to the proposed methods of doing case studies in qualitative research, reveals that the ideas of different authors are quite convergent. Creswell's widely accepted research methodology is chosen because it is cited frequently by handbooks on qualitative research, and may be seen as a standard within the field of qualitative research methods.

The theoretic framework used for the selective coding and the further evaluation of is the theory of [Suurs, 2009] on the essential functions for market adoption. This theory is the only one found to address the reasons why innovations are adopted. It goes into the prerequisites or 'necessary ingredients' for the successful implementation of innovations unlike traditional (marketing-inspired) theories which merely describe the process. One example of such a theory is the well-established theory of [Rogers, 1962] which is used in Chapter 4.3 to describe the current level of market uptake of innovations.[1]

Suurs explains that, in general, there are several functions which are essential to the development and market adoption of innovations. Table 5.2 provides the seven functions required for the market adoption of innovations. Note that Suurs does not state that these steps are always consecutive steps in the adoption process. Also, in some cases, some of these activities may not be required after all, while on the other hand additional activities may also be essential in the market adoption of certain innovations.

[1] Note the difference between describing something and giving reasons for it. Describing a pear for example could be: "it is a green and juicy fruit", while giving reasons would go one step further: "this variety has been bred to be juicy and green".

Table 5.1: The research process and methodology within each case study

Process step	**Description**
Data collection	Case specific data are gathered. Apart from a case-specific network model, no new information is presented. This step of data collection is thus a case-specific summary of the previous chapters about the current situation of IWT, the stakeholder analyses, and the analyses of the environmental innovations.
Selective coding	The collected data are coded and classified into categories. The categories which are used for this, are the essential functions for the market adoption of innovations as identified by [Suurs, 2009].
Analysis of themes	The conclusive criteria for adoption are identified. This is done by analysing the case studies' key issues and stakeholders with respect to each essential function for market adoption.
Multi criteria analysis	The innovations that meet the conclusive criteria are identified through a multi criteria analysis. Each innovation which meets all the conclusive criteria is one of the 'most promising innovations' for a fast, cost- and effort effective implementation. Note that is an analysis for the existing fleet and not for new-build vessels.
Evaluation	A discussion describes what is needed from the stakeholders to ensure the successful market adoption of the most promising innovations. This is based on the data which are presented in Chapter 4 (the potential environmental innovations).

Table 5.2: The essential functions for the market adoption of innovations. Table from [Suurs, 2009]

System function	**Description**	**Event types associated**
Entrepreneurial activities	At the core of any innovation system are the entrepreneurs. These risk takers exploit business opportunities and perform the innovative commercial experiments.	Projects with a commercial aim, demonstrations, portfolio expansions
Knowledge development	Technological research and development (R& D) are a source of variation in the system and are therefore prerequisites for innovation processes to occur	Studies, laboratory trials, pilots
Knowledge diffusion	The typical organisational structure of an emergent innovation system is the knowledge network, primarily facilitating information exchange.	Conferences, workshops, alliances
Guidance of the search	This system function represents the selection processes necessary to facilitate a convergence in development.	Expectations, promises, policy targets, standards, research outcomes
Market formation	New technologies often cannot outperform established ones. In order to stimulate innovation it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow.	Market regulations, tax exemptions
Resource mobilisation	Financial, material and human factors are necessary inputs for all innovation system developments.	Subsidies, investments
Support from advocacy coalitions	The emergence of a new technology often leads to resistance from established actors. In order for an innovation system to develop, actors need to raise a political lobby that counteracts this inertia, and supports the new technology.	Lobbies, advice

For the process of selective coding, the next aspects are identified for each of the functions.

Table 5.3: The aspects included in the selective coding of case studies

Category [Suurs, 2009]	**Aspects to categorize**
Entrepreneurial activities	How much entrepreneurial activity is required for an innovation to be considered by the owner-operator. Are there any considerations they have when it comes to their own entrepreneurial activity to adopt an innovation?
Knowledge development	How far must the knowledge be developed (or which level of 'technology readiness' is required) for an innovation to be considered by the owner-operators?
Knowledge diffusion	Which (level of) knowledge diffusion is required for an innovation to be considered by the owner-operators?
Support from advocacy groups	Which (level of) support from advocacy groups is required for an innovation to be considered by the owner-operators?
Guidance of the search	Which (level of) guidance (policy, targets, standardization) is required for an innovation to be considered by the owner-operators?
Market formation	To what extent is a market required for an innovation to be considered by the owner-operators?
Mobilising resources	Which resources must be available for an innovation to be considered by the owner-operators?

5.2 Case study: sand, stone and gravel market

This first case study goes into the sand stone and gravel market. The most promising innovations for this market segment are evaluated. The methodology which is used is presented in Chapter 5.1. This case study ends with a case-specific conclusion.

5.2.1 Data collection: a description of the case study's characteristics

Case-specific data for the sand, stone and gravel market is gathered. This is done by summarising the case-specific data that have already been presented in Chapter 2 and 3 of this research.

5.2.1.1 The current situation

The sand, stone and gravel market is characterised by project-specific transports. The cargoes are often picked up at a quarries' private terminals, and are sailed straight to the project site to be used in building projects. The overall evolution of the sand, stone and gravel market is thus linked to evolutions in the construction market.

Important loading regions are the provinces of Limburg, Düsseldorf, and Noord Brabant. The quantitative analysis of metadata from the [CBS, 2013] shows that cargoes originating from these regions represent 38% of all the sand, stone and gravel tonkm's which are transported in the Netherlands. Important unloading regions are Zuid-Holland, Noord-Brabant and Noord-Holland, which represent a combined share of 34% of the transports. In contrast to many other markets, not many of the cargoes go to the largest inland ports. The port of Rotterdam, for example, only represents 4% of all the cargoes in this industry. To put this into perspective: this figure is 40% for the entire inland waterway transport. A representative route for this case study would be a domestic voyage from Maastricht to Dordrecht.

A CEMT III vessel can represent this case study because there are quite a lot of small and medium-sized vessels operating in the market. This can be attributed to the location of quarries near small waterways, in Belgium for example. Building projects can also be located near small waterways.

5.2.1.2 The influential stakeholders

Figure 5.1 visually represents the stakeholders of the sand, stone and gravel market. Transports in this market are dominantly carried out by captain-owners operating on the spot market. These captain-owners often rely on freighters to find cargoes and to help them in the negotiations with the freight owner who is responsible for transporting the freight.

Some of the larger companies active in the sand, stone and gravel market therefore maintain a number of long-term contracts with captain-owners of small vessels. This is because these smaller vessels are essential to their business. Even so, it is still a minority of the vessels operating in this market that have long term contracts.

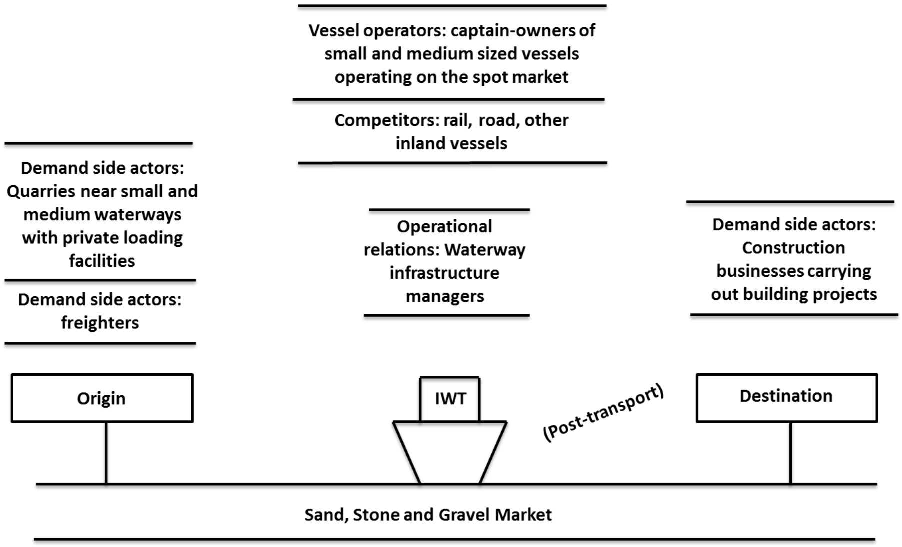

Figure 5.1: The transport network in the sand, stone and gravel market. Own composition

5.2.2 Selective coding: the status of the essential functions for market adoption

The previous subchapter gives an overview of the main characteristics of the sand, stone and gavel market. This subchapter continues with the second step in the evaluation of the case, which is coding these data. The categories which are used for this, are the essential functions for the market adoption of innovations (see Table 5.2.

Coding the information which is presented in the previous subchapter, allows the information to be restructured. The new structure is that of the categories of the essential functions for market adoption. While there is no new information in this subchapter, the information presented may seem new because it is now structured by each essential function for market adoption.

5.2.2.1 Entrepreneurial activities

A high level of entrepreneurial activities is required for an innovation to be considered by the captain-owners in the sand, stone and gravel market. The stakeholder analysis in Chapter 3.2 shows that captain-owners are, generally speaking, not innovators or early adopters of innovations. This explains why they do not consider innovations which still require entrepreneurial activities to be developed as serious options to implement on their vessel or in their operations. They prefer to wait and see how an innovations performs and gains importance in the market, meaning they often wait until it is readily available for different market segments of inland waterway transport which are typically sooner in adopting new technologies (like the segment of containers and liquid bulk). This attitude in adopting innovations is a general barrier in the adoption of innovations in the sand, stone and gravel market.

When it comes to the entrepreneurial activities of the captain-owners themselves to adopt an innovation, the adoption must be feasible by the captain-owner without cooperation of other captain-owners. This can be explained by the fragmented nature of the sand, stone and gravel market. Chapter 3.2 shows that captain-owners who operate in the spot market are very focussed on their personal freedom and individual operations. The interviews reveal it is unrealistic to expect of the actors in this individualistic context to work closely together with other actors in the inland waterway transport network.

5.2.2.2 Knowledge development

A high level of knowledge development is also required for an innovation to be considered by the captain-owners in the sand, stone and gravel market. The same argument as for the entrepreneurial activities holds up: captain-owners prefer to wait and see which innovations work well.

5.2.2.3 Knowledge diffusion

A high level of knowledge diffusion is necessary for the adoption of an innovation in the sand, stone and gravel market. It is only through knowledge diffusion that most captain-owners will be convinced of the innovations their performance and reliability. This is shown in Chapter 3 that goes into the stakeholders and confirmed in Chapter 4 that goes into the innovations. The information channels for effective knowledge diffusion are in place, as shown by the stakeholder interviews performed for Chapter 3.

5.2.2.4 Support from advocacy groups

Support from advocacy groups can be useful, but is not a prerequisite for an innovation to be adopted in the sand, stone and gravel market. Innovations which satisfy the other functions will be adopted even if there are low levels of support from advocacy groups.

As shown by the interviews performed for Chapter 3, support is found helpful (for example in the case of paperwork procedures which many captain-owners find confusing). The current state of support from advocacy groups is something captain-owners seem pleased with: they can usually find support when they want it. The existing advocacy groups appear to be effective in their role of offering information and support to the captain-owners.

5.2.2.5 Guidance of the search

A high level of direction is required for captain-owners of the sand stone and gravel market to consider an innovation. This applies to standardisation and the creation of rules and regulations, which is already mentioned in Chaptet 3.

Chapter 4 shows that directing the search process is a difficult process for many innovations. Rules and regulations often lag behind on the innovations and do not include clear guidelines. The rules can even forbid the innovations, requiring captain-owners to arrange exemptions if they want to install these innovations. Another aspect related to this difficult direction-giving function, is the creation of industry standards: this often occurs quite late. The slow creation of standards does not help to convince captain-owners of the performance and reliability of the innovations. Furthermore, the lack of standardisation with certain innovations makes captain-owners hesitant to adopt an innovation, as they would rather wait and see which technology becomes the standard one.

5.2.2.6 Market formation

Innovations need an established market to be adopted by the captain-owners of the sand stone and gravel market. This is closely related to the knowledge development and the entrepreneurial activities which need to be present. If these two functions are met, it usually means a market in other inland shipping segments has already been established, reducing the need for market stimulation specifically for the sand, stone and gravel market.

If there is not yet an established market, there is the need to artificially stimulate the market uptake of environmental innovations. Chapter 3 shows that policy measures from regulating authorities can provide a clear incentive to adopt an environmental innovation, but can be experienced as unrealistic and paternalistic. This may create resistance from the captain-owners, slowing down the adoption of an innovation.

5.2.2.7 Mobilising resources

The interviews reveal that this function is currently experienced as the most pressing factor in the sand, stone and gravel market. All but of the 18 respondents indicated that while ship owners do seem to be willing to invest in some of the more established environmental innovations, they feel like their hands are tied when it comes to the financial investment required to adopt these innovations. They simply do not have the liquidity which is needed for large investments, as shown in Chapter 3.

Related to the problems of mobilising resources, is the economic uncertainty in the industry which is forcing ship owners to be focussed on their short term financial performance. Short-term cash flow is currently a major concern for many captain-owners, as indicated in Chapter 3. Several innovations which captain-owners do believe in and are also willing to install, are not being considered as actual implementation options: their investment is too high. A vessel operator who is struggling to see how he can make it through the next year will simply not be willing to make an investment of thousands of euros with a pay back period of years. Banks and financial relations will not grant loans to captain-owners in such financial situations either.

5.2.3 Analysis of themes: which are the conclusive criteria for market adoption

The previous subchapters gather information about the case study and categorise it into the essential functions for market adoption of innovations. This subchapter continues with the third step in each case study: the analysis of the themes which can be identified. The following main criteria can be formulated based on the categorisations.

Table 5.4: Themes emerging from the selective coding

Essential function	Themes
Entrepreneurial activities	Innovations must not still require entrepreneurial activities to be developed
	Innovations must be able to implemented individually (with input from ship yards and suppliers of the technology)
Knowledge development	Innovations must not still require R& D
Knowledge diffusion	Innovations must have a well-established knowledge diffusion
Support from advocacy groups	Support from advocacy groups is helpful, but not experienced as an essential function for the adoption of innovations
Guidance of the search	Innovations must not require exemptions from regulations
	Standardisation is helpful, but not experienced as an essential function for the adoption of innovations
Market formation	Market formation can be helpful but is not experienced as an essential function for the adoption of innovations
Mobilising resources	Innovations must have low investment costs
	Innovations must have low pay back periods (and thus save fuel)

Some of the essential functions are not experienced to be an essential function by captain-owners in the sand, stone and gravel market. This is remarkable, the reasons for this are already explained in the previous subchapters. In general, these functions (support from advocacy groups, market formation and standardisation) start to develop after the entrepreneurial activities, knowledge development and knowledge diffusion are already going on in other market segments of the inland shipping industry. It is this chronological sequence which may explain why these essential functions are not experienced as essential functions: the others usually come first.

5.2.4 Multi criteria analysis: which innovations meet the conclusive criteria

Many of the innovations mentioned in Chapter 4 do not (yet) meet the criteria for successful implementation in the sand stone and gravel market. The main findings of each innovation with respect to the criteria are listed in the next table.

Table 5.5: The criteria analysis of the innovations' performance

Innovation	**Main performance on the criteria**
Improved fuel quality	Knowledge development is still insufficient
Diesel and lubrication oil additives	Knowledge development is still insufficient
Biofuels	Knowledge development is still insufficient, as well as entrepreneurial activities (insufficient availability) and there is no pay back period (more expensive fuel)
LNG	Entrepreneurial activities for the segment are insufficient, as well as guidance of the search and the financial resources
CNG	Entrepreneurial activities for the segment are insufficient, as well as guidance of the search and the financial resources
GTL	Knowledge diffusion and knowledge development are insufficient
Full electric powering	Insufficient entrepreneurial activities and guidance of the search, among other insufficiencies like financial resources
Wind energy and solar energy	Insufficient entrepreneurial activities (only auxiliary power) and other insufficiencies (like financial resources)
Hydrogen fuel cells	Insufficient mobilization of financial resources
Improved maintenance	Knowledge development is still insufficient
New components	Insufficient mobilization of financial resources
Diesel-electric and part load efficiency	Knowledge development is still insufficient
Exhaust gas recirculation	Insufficient market formation
Waste heat recovery	insufficient entrepreneurial activities for the segment of sand stone and gravel, as well as insufficient resources
Drastic changes to the ship design	Insufficient mobilization of financial resources
LED lighting	Meets all criteria
Friction-reducing coatings	Knowledge development is still insufficient
Propeller optimisation	Insufficient mobilization of financial resources

Continued on next page

Table 5.5 – *Continued from previous page*

Innovation	Main performance on the criteria
SCR catalysts and particle filters	Insufficient mobilization of financial resources
Advanced route planning	Meets all criteria
Fuel-efficient sailing techniques	Meets all criteria
On-board monitoring	Meets all criteria
Cold ironing	Meets all criteria
Hubs and spokes	Insufficient on entrepreneurial activities because requires cooperation
Hops	Insufficient on entrepreneurial activities because requires cooperation
Fairway infrastructure information sharing	Insufficient on entrepreneurial activities because requires cooperation
Planning integration with chain partners	Insufficient on entrepreneurial activities because requires cooperation
Network cooperation	Insufficient on entrepreneurial activities because requires cooperation

The innovations that do meet all the criteria are the following:

- LED lighting
- Advanced route planning
- Fuel-efficient sailing techniques: education, training, simulation
- On board monitoring
- Cold ironing

Apart from LED lighting, these are all operational measures. Some technical innovations may be added to this list once additional research confirms the innovations' good performance. These innovations are: improved fuel quality, biofuels, diesel and lubrication oil additives, improved maintenance of drive chain components, diesel-electric drives and friction-reducing coatings.

The next section is the last part of this case study's analysis and evaluates what is necessary to ensure the successful implementation of these innovations in the sand, stone and gravel market.

5.2.5 Evaluation: what is needed to improve the market adoption process

The adoption of the most promising innovations (LED lighting and the operational innovations) can reduce the fuel consumption and emissions of vessels by up to 20 to 30%. The investment needed for this reduction is in the magnitude of 10.000 to 15.000 EUR for one vessel.[2]

The main challenges in the adoption of these most promising innovations are shown in Table 5.9. This is based on the main barriers which are identified in Chapter 4.

Table 5.6: What is needed in the sand, stone and gravel market to ensure the successful implementation of the most promising innovations

Innovation	**What is needed**
LED lighting	Raising awareness of the cost-effectiveness of LED lighting
Advanced route planning	Incorporation of modern insights into planning software and encouraging captains to carry out the planning mindfully
Fuel-efficient sailing techniques and OBM	Showing and convincing captains that they can still improve their -already good- navigation techniques
Cold ironing	Agreements on the standardisation of the cold ironing procedures and techniques

5.2.5.1 Elaboration

This is an elaboration on the evaluation of what is needed to ensure the successful implementation of the most promising innovations in the sand, stone and gravel market.

LED lighting[3] only has a small potential to reduce the emissions and the investment costs are marginal. Because of this small effect many captain-owners in the sand, stone and gravel market do not even take the time to consider their choice of lights, something which is supported by the stakeholder interviews. To change this, awareness must be created. Fortunately, LED lighting is an innovation which can be implemented in many markets, including regular households and public buildings. This means that campaigns to create awareness need not focus on this particular segment of inland waterway transport alone. General, broad campaigns to create awareness of LED lighting can be effective in reaching several industries at once. The producers and distributors of LED

[2]This range is indicative, based on the savings potential and cost estimates which are identified in Chapter 4. No detailed figures are provided in this research since the operations and expenses of individual captain-owners are so diverse. An extensive analysis of the savings and costs would require operational data, technical data, and financial data of an inland ship, and would require careful processing of the multi level effects of energy savings. The author strongly believes that a numerical example of the savings potential and cost effects for one particular inland vessel contradicts one of the main conclusions of this research: that the inland shipping industry is too diverse for 'one size fits all' solutions and that all the stakeholders must understand this and act accordingly.

[3]LED lighting is iscussed in Chapter 4.3.3.2

lights are already advertising the benefits of these products to the general public, and additional information may be provided by advocacy groups, knowledge institutions and regulating authorities. Stimulation policies may provide additional incentives to adopt LED lighting, which can further speed up the adoption process. Similar policies already exist, as shown by the phasing out of regular incandescent light bulbs in Europe.

Advanced route planning for individual vessels[4] can reduce exhaust gas emissions by up to 10% at a cost of less than 2000 EUR. The further development of planning software is mainly driven by the commercial companies who supply the existing navigation software. Cooperations between these companies and knowledge institutions can assure that the latest research insights are incorporated into the software. Support groups and regulating authorities can stimulate captain-owners to use this software mindfully. This is because captain-owners who experience a reduction of their fuel consumption by for example slow steaming, may feel like they have 'earned' to steam at sail power every now and then. This compensation effect may counteract the decreased fuel consumption and production of exhaust gas emissions. Because it has been mentioned by various stakeholders during the interviews, these compensation effects must be taken into account during the implementation of advanced route planning.

Fuel efficient sailing techniques[5] and on-board-monitoring[6] have as main obstacle to overcome that captain-owners are confident about their own sailing practices. They have often grown up on board a ship and have learned to navigate from a young age. It must be emphasized that care must be taken not to underestimate their skilful navigation techniques while trying to convince them that they can most likely still learn new techniques to further improve their performance. Even so, teaching experienced captains new habits may be trickier than expected. Setting up training programs must therefore be done by teaching professionals along with skilled inland captains.

Cold ironing[7] is the fifth environmental innovation which is identified as one of the most suitable for implementation by the sand, stone and gravel market. It can eliminate all exhaust gas emissions of vessels which are moored at the quay. While ports are independently erecting the facilities to make cold ironing possible in their area, many captain-owners seem rather unhappy with this development which is often paired with the prohibition of generating electric power on-board. The Port of Rotterdam for example acknowledges the initial problems when its policy was enforced in 2009. The problems ranged from technical difficulties for certain vessels to use shore-power, to operational complaints about the hassle of plugging in and out, and negative feedback on the system to pay for the power. Many captain-owners are still dissatisfied by the port's rules which take away their freedom of choosing how they power their vessel. Captain-owners are pointing out the monopolistic character of the cold ironing system in which they cannot choose their supplier of electric energy. To make things worse, vessel operators also feel like they are paying more for the electric bills of cold ironing than what it would cost

[4] Advanced route planning is analysed in Chapter 4.4.1
[5] Fuel efficient sailing techniques are discussed in Chapter 4.4.2
[6] On-board monitoring is discussed in Chapter 4.4.3
[7] Cold ironing is discussed in Chapter 4.4.4

them to produce the energy themselves. This critique could not be refuted by the comparative study performed by [de Vos and van Gils, 2011], which had to conclude that in some cases it may be more expensive while in other cases it may not be.

This predominantly negative attitude of captain-owners towards cold ironing must not be played down. It is an important factor in the adoption process of cold ironing as it may have lead other inland ports and terminals to be more cautious and hesitant in the creation of their own cold ironing facilities. These actors are now also challenged to find a standardised way of offering cold ironing, as captain-owners are already voicing their concerns about being faced with different methods and procedures at different locations.

What is currently recommended to ensure the fast spreading of cold ironing, are agreements on its standardisation. Ports and terminals who (are planning to) invest in cold ironing facilities will most likely need a boundary-exceeding mediator in this process: the CCNR or the EU could play a role in this. The suppliers of the equipment necessary to connect vessels to the grid also have a role in this creation of standards, as well as knowledge institutions who can support the different parties with unbiased information on the subject.

5.2.5.2 Other promising innovations

The innovations which *almost* meet the criteria for the innovations which are most suitable for a fast, cost-and effort effective implementation still require some additional research to their effect on the costs and expenses, their effectiveness in reducing the emissions and the other implications their adoption may have for the stakeholders. The main challenges in the adoption of the *almost most promising* innovations is shown in Table 5.9. This is based on the information provided in Chapter 4. An elaboration on what is needed for these innovations' successful implementation is provided in Appendix H.

Table 5.7: What is needed in the sand, stone and gravel market to ensure the successful implementation of other promising innovations

Innovation	**What is needed**
Improved fuel quality	Research to the effect on emissions
Fuel and lubrication oil additives	Research to the effect on emissions is needed
Improved maintenance of drive chain components	Simulation and modelling based research
Diesel-electric drive	Vessel-specific R & D to the optimal drive
Friction-reducing coatings	Modelling and simulation based research

5.2.6 Case-specific conclusion

This research; which takes into account stakeholder considerations, technical implications, financial factors and established theories on the adoption of innovations; concludes that the most promising innovations for the sand, stone and gravel market are the operational innovations and LED lighting. At the cost of approximately 10,000 to 15,000 EUR per vessel, the emissions can be reduced by about 20 to 30%. Table 5.8 shows the emission reduction potential and costs related to each innovation.

Table 5.8: The emission reduction potential and costs for the most promising innovations in the sand, stone and gravel market

Innovation	**Emission reduction potential**	**Costs**
LED lighting	less than 1 %	less than 5 EUR price difference per light
Advanced route planning	less than 10%	less than 2000 EUR
Fuel-efficient sailing techniques and OBM	less than 10 %	less than 10,000 EUR
Cold ironing	100% during cold ironing	Comparable to on-board generated power

It is remarkable that most stakeholders tend to focus primarily on the technological innovations. These innovations are not as promising as the identified most-promising innovations because they still require entrepreneurial activities, knowledge development, guidance of the search and more financial resources to be mobilized. The operational innovations and LED lighting meet all the criteria for the most-promising innovations.

The author therefore recommends stakeholders to not overlook the operational innovations. The economic reality of the sand, stone and gravel market urges the industry to invest its resources as effectively as possible, and the author suggests the stakeholders to shift their attentions to adopt these innovations first, rather than keeping their focus on technical innovations.

This research also shows that all the actors in the sand, stone and gravel market have a role to play in the successful adoption of environmental innovations. The captain-owners are the ones who are finally responsible to adopt the innovations. The suppliers of these techniques have a role in creating awareness. Regulating authorities and operational relations can stimulate the adoption of these innovations and advocacy groups can aid in the necessary spreading of knowledge. Knowledge institutions play a role in aiding the development of these innovations and also have a role in the spreading of this knowledge.

The main activities which are required to ensure the innovations their successful implementation, are shown in Table 5.9.

Table 5.9: What is needed in the sand, stone and gravel market to ensure the successful implementation of the most promising innovations

Innovation	**What is needed**
LED lighting	Raising awareness of the cost-effectiveness of LED lighting
Advanced route planning	Incorporation of modern insights into planning software and encouraging captains to carry out the planning mindfully
Fuel-efficient sailing techniques and OBM	Showing and convincing captains that they can still improve their -already good- navigation techniques
Cold ironing	Agreements on the standardisation of the cold ironing procedures and technique

This recommendation to focus on the operational innovations does not mean that the industry should reduce its efforts in the other innovations. This is because several technical innovations are particularly promising as they already meet almost all the criteria. They just lack research which demonstrates the innovations' effectiveness in reducing the emissions. This research could create clarity about the innovations' total cost of ownership which is an important factor in this market segment which is characterised by financial insecurity. Creating this knowledge is essential to further improve the environmental performance of the sand, stone and gravel market. Because researching technical innovations may be time consuming, and market adoption of the innovations will require even more time, it is key that this research is not postponed. Consequently, stakeholders with an exceptionally important role in aiding the adoption of the promising technical innovations, are financial relations and regulating authorities. It are these organisations which have the means to fund research which transcends the interests of individual shippers.

5.3 Case study: container market

The first case study goes into the sand, stone and gravel market. This case study evaluates which are the most promising innovations in the the container market. The same research methodology is used to analyse this case, it is presented in Chapter 5.1.

5.3.1 Data collection: a description of the case study's characteristics

In this subsection, the data which are specific to the container market are gathered. For this subchapter, no new information is presented. The data have previously been gathered through literature research and stakeholder interviews to answer the research questions in the previous chapters (2 and 3).

5.3.1.1 The current situation

In contrast to the project-specific cargoes of the sand, stone and gravel market, the container market has a more constant throughput. In many cases, the containers are picked up at several terminals in a deep sea port and are then shipped to several terminals along a fixed route, and back. In addition to these fixed liner routes, it is customary to contract extra vessels when large quantities of containers arrive in the sea port. This happens for example in the season before the holidays when many retailers are building up their stock and supplies, or when vessels like one of Maersk's tripple E's [8] calls in port.

Major loading and unloading regions of containers which are shipped over Dutch inland waterways, are the regions of Zuid-Holland (NL), Antwerp (BE), and Düsseldorf (DE). Metadata from [CBRB, 2014] show that 55% of all the container transports are loaded in these provinces and 70% is unloaded in these three provinces. The Port of Rotterdam plays an important role in the market of container transport, as 25% of the container transports originate from it and 34 % of them are destined to it.[9] A representative route for the container segment, is a vessel dropping off and picking up containers at the port of Rotterdam and sailing a route in the Rhine corridor, making stops at several inland terminals like for example in Emmerich, Duisburg and Düsseldorf.

Vessels used for container transports are often large Rhine vessels (CEMT Va). These vessels are much younger than the vessels used in other market segments. Another difference with vessels of most market segments is that container vessels are often operated continuously or semi-continuously. Container ships cover vast distances and book many operational hours. Container vessels are therefore relatively large consumers of fuel and have high voyage expenses.

[8]Maersk's ULCV Tripple E class of ships includes the largest vessels in the world. These container vessels measure 400 m in length and have a DWT of 165,000 metric tons. Tripple E ships have a cargo capacity of 18,000 TEU and regularly come to the Port of Antwerp and Rotterdam. [Maersk, 2014]

[9]No precise data on the Port of Antwerp have been found. The aggregation level of the data provided by the CBS does not allow to state how many of the transports from the Province of Antwerp originated from the port of Antwerp. Most likely it is 'the majority' meaning that the port of Antwerp has a similar importance to the port of Rotterdam.

5.3.1.2 The influential stakeholders

Figure 5.2 shows the transport network of the container market. The market is dominated by freight forwarders, shipping companies with their own vessels and freighting companies which have long term contracts with these shipping companies. Both the shipping companies and freighting companies contract captain-owners on the spot market for additional transports when they do not have the capacity to take care of the transport themselves. This is, however, only the case for a minority of the container transports. The container market has a much higher degree of organisation when compared to other market segments in inland waterway transport. The amount of long term contracts and shipping companies with more than one vessel are proof of this.

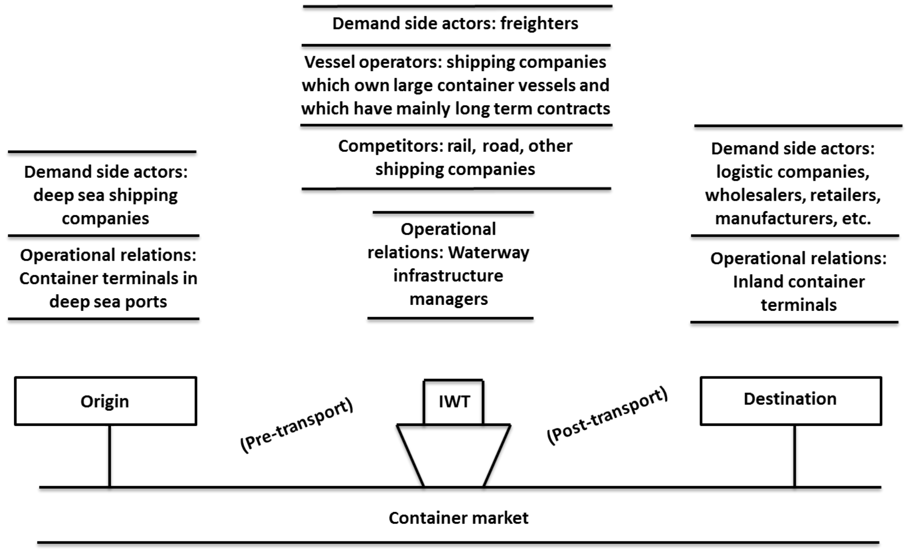

Figure 5.2: The transport network in the container market. Own composition

5.3.2 Selective coding: the status of the essential functions for market adoption

Chapter 5.3.1 gives an overview of the container segment's characteristics. This chapter continues with the second step in the evaluation of the case study: categorising information according to the essential functions for market adoption of innovations. Categorising the information is a way to restructure the information, in this research the categorisation results in the information being presented according to each essential function for market adoption.

5.3.2.1 Entrepreneurial activities

Innovations which have ;ow levels of entrepreneurial activities do not face problems in the container market. As mentioned in Chapter 3.2 when it comes to entrepreneurial activities several shipping companies in the container market have an active approach to the adoption of environmental innovations. These innovators and early adopters are willing to partake in demonstration projects with supply-side actors when they are convinced of an innovation's potential. They will use this opportunity to profile themselves as companies who are investing in sustainable development, and clever marketing around it may give them a competitive advantage over other shipping companies.

Another aspect particularly relevant to the market adoption of innovations in the container segment, is that the shipping companies are determined to create a competitive advantage over the other shipping companies and rail and road transport. A stable throughput of containers, punctual arrivals, good customer services and competitive freight tariffs receive high priorities within the container segment. The stakeholder interviews show that innovations which provide a shipping company with a unique position on all four of these aspects will be likely to be adopted sooner rather than later. Even more so: shipping companies will prefer to invest in these innovations than in others.

5.3.2.2 Support from advocacy groups

Support from advocacy groups is important in the container market. It plays an important part in the shipping companies' willingness to invest in environmental innovations. The interviews shows that shipping companies are sensitive to the opinions of these organisations and rely on these partners for various purposes. They rely on their expertise to help them decide which innovations to try out, to bring them into contact with suppliers of the innovations, to help them to find programs that can help fund the investment and to get some aid in the creation of a productive context between the various partners which may be involved in these innovation projects.

5.3.2.3 Knowledge development

Innovations with low levels of knowledge development are still likely to be adopted in the container segment. The willingness of container shipping companies to try out innovations, combined with the shipping companies' strong financial situation (as discussed in Chapter 2.3)and the support of advocacy groups makes the container segment unique: the market has a large potential in the development of innovations which are still in need of knowledge development. Pilot projects, trials and living labs in the container segment can accelerate the adoption of many technical innovations. Examples of such trials include: hybridization, LNG engines and electric ships.

5.3.2.4 Knowledge diffusion

Knowledge diffusion is not experienced as an essential function in the container segment because it is a generally well-informed market segment. This may be because knowledge diffusion is closely related to knowledge development in the container market. It is often one of the goals of living labs and demonstrator projects.

The interviews show that knowledge diffusion within the container segment happens relatively fast. This can be explained as follows: due to the presence of large shipping companies, the total number of actors to reach is low. Since these actors have on-shore staff it is also easier for these actors to gather during meetings, trade shows, and other events meaning they can share information easier. Knowledge diffusion is therefore not experienced as an essential function: information is usually well-spread in this market segment.

5.3.2.5 Mobilising resources

Mobilising resources is relatively easy for shipping companies in the container market. They have the revenue of several vessels, they have long term contracts, and the market outlook for the container segment is positive. This makes it easier to get loans from banks and to find alternative financial partners. For the container segment, gathering the high investment costs of innovations is thus less of a struggle than for most market segments.

The interviews confirm this, as they show that more attention is given to the pay back period of investments than the required investment costs. This means that environmental innovations which reduce the fuel consumption are most likely to be chosen in this market, since the financial impact of saving fuel is relatively large in the container segment.

5.3.2.6 Guiding of the search

An aligned direction is required for environmental innovations in the container market. (Lack of) Direction is experienced as an issue in the container segment. The interviews show that the lack of long-term outlooks on emission policy and the unfit regulations for many innovations are a problem. However, because shipping companies in the container segment are organised quite well they do seem to have a better position in arranging classification exemptions when they want to adopt an innovation, and they are even taking an active position in raising awareness of the regulations which are lagging behind.

This may be because shipping companies seem to maintain closer contacts with the inland shipping's advocacy groups and regulating authorities. Because of these contacts, shipping companies seem to have a different attitude towards directing the search process than the actors in most segments. The container shipping companies feel more like they take part in this process and have some influence over it. The difficulties of directing the search process in the container segment lie within aligning different ideas on the direction, rather than providing a direction. The innovations about which regulating authorities or knowledge institutions have a clear directional idea, are more likely to be adopted quickly.

5.3.2.7 Market formation

Market formation goes relatively easy in the container segment. This can be explained because the segment has quite a few eager innovators and early adopters. The mere fact that one shipping company can adopt an innovation an apply it on several vessels at once, aids the natural market formation of new techniques. From the supplier's side this is clear: by convincing one client, a much larger number of vessels can be reached. This also provides shipping companies with a good position in price negotiations, stimulating suppliers to work on their value proposition and revenue model.

5.3.3 Analysis of themes: which are the conclusive criteria for market adoption

The previous subchapters gather information on the container market and analyse these data by categorising the information into the essential functions of innovations. This subchapter continues with the third step in the evaluation of the case study and identifies which criteria can be used to find the innovations which are most suitable for a fast, cost- and effort effective implementation by the container market.

By analysing the main trends in the categorised information in Chapter 5.3.2, the next criteria for the most promising environmental innovations can be formulated

Table 5.10: The themes emerging from the selective coding

Essential function	Themes
Entrepreneurial activities	Innovations which have already developed entrepreneurial activities are more promising, but this aspect is not experienced as an essential function
	Innovations must improve the throughput, punctuality, customer services or freight tariffs (e.g. by reducing fuel consumption)
Knowledge development	Innovations with high levels of knowledge development are more promising, but this aspect is not experienced as an essential function
Knowledge diffusion	Knowledge diffusion is helpful but this aspect is not experienced as an essential function
Support from advocacy groups	Innovations with high levels of support from advocacy groups are more promising, but this aspect is not experienced to be essential
Guidance of the search	Innovations must not require exemptions from regulations
	Standardisation is helpful but not experienced as an essential function for the adoption of innovations
Market formation	Market formation can be helpful but is not experienced as an essential function for the adoption of innovations
Mobilising resources	Innovations must have low pay back periods (read: innovations must reduce the fuel costs)
	innovations with low investment costs are more promising, but this aspect is not experienced to be essential

It is remarkable how many of the essential functions are not experiences as an essential function in the container segment. The backgrounds for this are explained in the previous subchapters. Generally speaking, these functions are not experienced as an essential function because shipping companies in the container market are early adopters of innovations. [Mohr et al., 2010] explains that early adopters tolerate lower levels on these functions and are even willing to take part in the development of innovations (and the related essential functions).

5.3.4 Multi criteria analysis: which innovations meet the conclusive criteria for market adoption

Similar to the case study of the sand, stone and gravel market there are many innovations which do not yet meet the criteria for successful implementation in the container market (see Chapter 4). The main findings when analysing the innovations their performance on the criteria identified in the previous subchapter, are:

Table 5.11: The criteria analysis of the innovations' performance

Innovation	**Main performance on the criteria**
Improved fuel quality	Limited knowledge development
Diesel and lubrication oil additives	Limited knowledge development
Biofuels	Limited knowledge development, as well as limited entrepreneurial activities (availability) and it does not reduce fuel costs
LNG	Entrepreneurial activities for the segment are insufficient, as well as guidance of the search and the mobilisation of financial resources
CNG	Entrepreneurial activities are limited, as well as guidance of the search and the mobilisation of financial resources
GTL	Knowledge diffusion and knowledge development are limited
Full electric powering	limited entrepreneurial activities and guidance of the search, among other insufficiencies like financial resources
Wind energy and solar energy	Limited entrepreneurial activities (only auxiliary power) and other insufficiencies (like having long pay back periods)
Hydrogen fuel cells	Insufficient mobilisation of financial resources
Improved maintenance	Knowledge development is limited
New components	Insufficient mobilization of financial resources
Diesel-electric and part load efficiency	Knowledge development is still limited and it does not have a low pay back period due to the uncertain and limited fuel savings potential.
Exhaust gas recirculation	It increases fuel costs instead of lowering them
Waste heat recovery	Insufficient entrepreneurial activities for container ships, and does not have a low pay back period for container ships
Drastic changes to the ship design	Insufficient mobilization of financial resources
LED lighting	Does not reduce the freight tariffs, throughput, punctuality, or customer services
Friction-reducing coatings	Knowledge development is still limited
Propeller optimisation	Insufficient mobilization of financial resources

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Table 5.11 – *Continued from previous page*

Innovation	**Main performance on the criteria**
SCR catalysts and particle filters	Does not improve freight tariffs, throughput, punctuality or customer services
Advanced route planning	Meets all criteria
Fuel-efficient sailing techniques	Meets all criteria
On-board monitoring	Meets all criteria
Cold ironing	Does not improve freight tariffs, throughput, punctuality or customer services
Hubs and spokes	Meets all criteria
Hops	Meets all criteria
Fairway infrastructure information sharing	Meets all criteria
Planning integration with chain partners	Meets all criteria
Network cooperation	Meets all criteria

The innovations which meet all the criteria are the following:

- Advanced route planning
- Fuel-efficient sailing techniques
- On board monitoring
- Hubs and spokes
- Hops
- Fairway infrastructure information sharing
- Chain partner planning integration
- Network cooperation

These are all logistical and operational innovations. Additional research may confirm the good performance of some technical innovations and these innovations may soon be added to this list: high quality fuels, diesel and lubrication oil additives, LNG, improved maintenance and friction-reducing coatings.

The following section is the last part of the evaluation of the case study of the container market. It evaluates what is needed from the stakeholders to have aid in the fast and successful implementation of these innovations in the container market.

5.3.5 Evaluation: what is needed to improve the market adoption process

The adoption of the most promising innovations (advanced route planning, fuel-efficient sailing techniques, OBM, hubs & spokes, hops, faiway infrastructure information sharing, chain partner planning integration and network cooperation) can all together save about 30 to 50 % of the exhaust gas emissions in the container segment. This requires an investment of approximately 15.000 to 25.000 EUR per vessel, and the investment of time and effort to agree with other stakeholders on how to cooperate.

The main challenges in the adoption of the most promising innovations is shown in Table 5.15. This is based on the main barriers for these innovations, which are described in Chapter 4.

Table 5.12: What is needed in the container market to ensure the successful implementation of the most promising innovations

Innovation	**What is needed**
Advanced route planning	Incorporation of modern insights into planning software and encouraging captains to carry out the planning mindfully
Fuel-efficient sailing techniques and OBM	Showing and convincing captains that they can still improve their -already good- navigation techniques
Hubs & Spokes and hops	Creating communication between the stakeholders and setting up digital platforms
Fairway infrastructure information sharing	Creating a digital information stream
Chain partner planning integration	Creating communication between the stakeholders and setting up digital platforms
Various types of network cooperation	Creating communication between the stakeholders

5.3.5.1 Elaboration

This section elaborates on the evaluation of what is needed to ensure the succesful implementation of the most promising innovations in the container segment.

Chapter 5.2.5 analyses what is needed to assure the successful implementation of advanced route planning, fuel-efficient sailing techniques and on-board monitoring in the sand, stone and gravel market. The same approach that will lead to successful market adoption in the sand, stone and gravel market will ensure the innovation's adoption in the container segment as well.

Hubs & spokes and hops[10] have the potential to reduce the emissions by 40%. Planning integration between chain partners[11] on the other hand may reduce the emissions by 10%. To assure the successful implementation of these innovations in the container market, the communication between shipping companies and their operational relations must be strengthened. Open communication between these actors will ensure they know what to expect from each other and will give them insights in their similar interests. This can create common grounds from which they can start building their partnership in the creation of a hub or hop service, or for them to start integrating their planning.

The first step in this process of strengthening the communication between the stakeholders, is getting these actors together and getting them to talk to each other. Advocacy groups and regulating authorities play a role in motivating these actors to be open for these meetings. Knowledge institutions on the other hand, have extensive knowledge and valuable experience on how to frame these meetings so that the actors feel safe and comfortable enough to engage in a constructive discussion with the other actors. The IDVV gaming sessions with various stakeholders have for example already proven to be a catalyst in the creation of partnerships. Other methods to trigger the dialogue which is needed to adopt logistical innovations, may include simulation models and role playing workshops.

Fairway infrastructure information sharing[12] can save up to 10% of the emissions. The poor digital information sharing of the fairway infrastructure managers must be resolved for this innovation to be adopted. The simplest information sharing may be a start: providing time tables and sharing updates via a website. This may even be done on existing information sharing platforms since supply-side actors may act on this new information and offer the service of bundling and analysing these data and providing planning advice. Additionally, the popularity of smart-phones and information sharing applications like Twitter and Whatsapp among the crew of inland vessels will aid in this information sharing. That this innovation will take off once this information is shared digitally seems to be beyond any doubt. So what is needed to get infrastructure managers to share this information? This question puzzles the shipping companies in the container market, and many other stakeholders as well. The interviews reveal that a part of the answer may lie in the way that waterway infrastructure seems to be managed. The Ministry of infrastructure and environment is often accused of being too slow and bureaucratic. That the Ministry has recently taken budget cuts will presumably also not facilitate the development of digital information sharing.

The last innovation to be analysed is network cooperation[13] which also requires the same level of trust between partners. Rather than joining cooperations like single-ship captain-owner could do, other types of horizontal market cooperation between shipping companies are more relevant in this evaluation. Shipping companies can for example work together on bundling cargo so they can reduce the number of terminals they call at

[10] Hubs & spokes and hops are discussed in 4.5.1
[11] Planning integration is discussed in Chapter 4.5.3
[12] Fairway infrastructure information sharing is discussed in Chapter 4.5.2
[13] Various types of network cooperation are discussed in Chapter 4.5.4

within the port of Rotterdam. Research of [TNO et al., 2013] reveals that the call size per stop is quite small: between 40 and 50% of the stops within the port of Rotterdam are for up to 5 containers. Only 10 to 20 % of the stops are for 20 or more containers. Shipping companies could work together to bundle their calls and to reduce the number of stop with these small call sizes. This particular IDVV project had no succesfull follow-up, mainly because the relation between the cooperating shipping companies was not constructive. This showcases the need for good communication between the stakeholders, which is a must to create the required trust for these innovations. This can be done by facilitating shipping companies to meet their competitor-colleagues and guiding them in a constructive dialogue. Since these companies may have different approaches and even opposite interests, supporting them in the process of setting up these cooperations is essential. A mediating role may be taken up by regulating authorities, advocacy groups or knowledge institutions.

5.3.5.2 Other promising innovations

There are some innovations which *almost* meet the criteria for the most promising innovations, but they still require additional research. The next table shows what is primarily needed to ensure the successful adoption of these innovations in the container market.

Table 5.13: What is needed in the container market to ensure the successful implementation of other promising innovations

Innovation	**What is needed**
Improved fuel quality	Research to the effect on emissions
Fuel and lubrication oil additives	Research to the effect on emissions is n
Improved maintenance of drive chain components	Simulation and modelling based research
LNG	R & D to the effectiveness in reducing emissions and into different scenarios on the total cost of ownership
Friction-reducing coatings	Modelling and simulation based research

It must be noted that these are almost the same innovations as with the sand, stone and gavel market. The only difference is that diesel-electric drives are not in this list for the container market, and that LNG is included. An elaboration on what is needed to ensure these innovations' successful adoption is included in Appendix H.

5.3.6 Case-specific conclusion

This research concludes that the most promising innovations to improve the environmental performance of the container market are operational innovations and logistical innovations. The emissions could be lowered by up to 30 to 50 % and the investment required would be about 15.000 to 25.000 EUR per vessel (+ time and effort to create logistical partnerships between different actors in the container segment). Table 5.14 shows the potential and costs of each of the most promising innovations.

Table 5.14: The emission reduction potential and costs for the most promising innovations in the container market

Innovation	**Emission reduction potential**	**Costs**
Advanced route planning	less than 10%	less than 2000 EUR
Fuel-efficient sailing techniques and OBM	less than 10 %	less than 10,000 EUR
Hubs & spokes and hops	up to 40% per tonkm	various value cases
Fairway infrastructure information sharing	less than 10 % per tonkm	reduced fuel expenses for operators but costs for the creation of the IT system
Chain partner planning integration	less than 10% per tonkm	reduced fuel expenses for operators but costs for the creation of the IT system
various types of network cooperation	less than 20%	Administrative costs for the setting up of the agreements

Just as with the sand, stone and gravel market, it is remarkable that the technical innovations seem to receive most attention from the stakeholders, while these are the most promising innovations. The same discussion presented for the sand-stone and gravel market which urges stakeholders to not overlook operational innovations, also applies to the container market.

Even more so, the same recommendation is made for the logistical innovations as well. Fortunately, numerous examples of logistical innovations which are specific to the container market exist and can be used to highlight the potential of these innovations. The factsheet of [Sjoerdsma and Groen, nd] for example explains 8 different types of information sharing innovations specific to the container segment in inland shipping which can lead to more efficient operations. Another publication going into sustainable logistics is from [Smokers et al., 2014]. Logistical innovations in the container segment range from aggregating information from different sources to avoid unnecessary movements, to prioritising calls based on the vessels' environmental performance.

This research concludes that most stakeholders of the inland shipping industry acknowledge the potential of logistical innovations to improve the industry's environmental performance. The evaluation shows that logistical innovations, together with operational innovations, are most promising for a fast, cost and effort-effective adoption in the container market.

These logistical innovations are however not as noticeable as some of the technical innovations in the industry like for example LNG powered vessels. This may be explained as follows: the actors in the container segment are continuously improving their operations and are almost incessantly trying to work together better with their direct partner in the transport chain. The interviews show that these actors themselves perceive these efforts as a part of their core business and day-to-day operations. Therefore they do not consider their efforts to cooperate or to align their planning as an environmental innovation.

The main activities which are required to ensure the successful adoption of the most promising innovations, are shown in the following table.

Table 5.15: What is needed in the container market to ensure the successful implementation of the most promising innovations

Innovation	**What is needed**
Advanced route planning	Incorporation of modern insights into planning software and encouraging captains to carry out the planning mindfully
Fuel-efficient sailing techniques and OBM	Showing and convincing captains that they can still improve their -already good- navigation techniques
Hubs & Spokes and hops	Creating communication between the stakeholders and setting up digital platforms
Fairway infrastructure information sharing	Creating a digital information stream
Chain partner planning integration	Creating communication between the stakeholders and setting up digital platforms
Various types of network cooperation	Creating communication between the stakeholders

Just as with the sand, stone and gravel market, the recommendation to primarily focus on the most promising innovations does not mean that no efforts must be made in technological innovations. Due to the market segment's strong financial position and shipping companies their willingness to innovate, technical innovations have a higher likeliness of being adopted in this segment first.

Chapter 6

Conclusions, discussion and recommendations

This chapter concludes the presented research. The chapter conclusions at the end of each Chapter already answered the research questions of these chapters. In this Chapter these chapter conclusions are combined to show the final results and conclusions of the research. This chapter then focuses on the discussion of the results and on the recommendations that follow from this research.

6.1 Conclusions of this research

Inland waterway transport is currently characterised by overcapacity and a low economy. Many vessel operators are confronted with a financially challenging future. To reduce harmful emissions and greenhouse gases it is therefore important that the industry focuses its attention on the most promising environmental innovations. These are innovations that can be adopted by the industry in a cost, time and effort effective way.

Finding the most promising innovations is complex because the inland shipping industry is very diverse. The inland shipping industry for example transports many types of cargo, and there are numerous types of vessels. The size of these vessels varies greatly in size (depending on the size of the waterways they sail on) and includes both ships as coupled units. The fleet has some modern vessels from only a couple of years old, but the majority of vessels is far older, with small vessels averaging 70 years for example. The life span of diesel engines is also long, about 35 years, and because the strictness of emission limits has not evolved a lot in the past years, the emissions of this very diverse fleet are becoming higher than the emissions of other transport modalities.

Another reason why finding the most promising innovations is complex, is because an effort of all the stakeholders is required for the successful implementation of innovations. These stakeholders are also diverse and have different considerations when it comes to environmental innovations. Most stakeholders have internal drivers towards a reduction of fuel consumption, because this automatically translates to reduced fuel costs. In other words: the inland shipping industry is naturally focussed on reducing CO2 emissions. The stakeholders which are primarily focussed on reducing other emissions, like PM and NOx, are regulating authorities and ports. When it comes to adoption of an innovations, the stakeholders can have opposite interests. This makes it essential to keep in mind stakeholder considerations in the evaluation of environmental innovations.

The environmental innovations relevant to the inland shipping industry are numerous and diverse. This research identifies 28 technical, operational and logistical innovations. The technical innovations can be further categorised into changes in the energy source, drive chain, energy demand and exhaust gases. The variety in the characteristics of environmental innovations is large. Some innovations have a high emission reduction potential while others have a marginal effect on the emissions. Some innovations have high investment costs while others have low investment costs. Other points of divergence are the innovation' suitability for retrofits, their suitability for certain market segments, if they work from well-to-tank of from tank-to-propeller, if they save fuel or not, and which level of market adoption the innovations have reached.

In spite of the innovations their differences, there are some recurring aspects as well. The main drivers are in many cases that innovations require few operational changes, that they reduce the fuel consumption and thus fuel costs, and that they are broadly supported by different stakeholders. Some recurring barriers in the adoption of innovations are high investment costs, the lack of regulations, and the innovation's slow pace of 'natural' adoption because of the long service life of components (propeller, engine, etc).

This research evaluates for two case studies what the most promising innovations are for a fast, cost- and effort effective adoption. The selected case studies are quite different from each other: the container market and the sand, stone and gravel market have different owner-operators (captain-owners vs shipping companies) and work with different freight contracts (spot market vs long term contracts) for example.

In the segment of sand, stone and gravel, it are the operational innovations (advanced route planning, fuel-efficient sailing techniques, On Board Monitoring and cold ironing) and LED lighting which are the most promising innovations. These innovations do not require any additional R& D, have low investment costs, reduce the fuel consumption, have low pay back periods, and do not require captain-owners to cooperate with other actors in the industry. These innovations can save 20 to 30% of the emissions and require an investment of about 10,000 to 15,000 EUR per vessel.

In the container segment operational innovations and logistical innovations (hubs and spokes, hops, fairway infrastructure information sharing, chain partner planning integration and network cooperation) are the most promising for a fast, cost- and effort effective implementation. These innovations do not require any additional R& D, have short pay back periods, have broad support and direction by advocacy groups and they improve the throughput, punctuality, customer services or freight tariffs the shipping companies can offer. The adoption of these innovations can reduce the emissions by 30 to 50% and require an investment between 15,000 to 25,000 EUR per vessel.

To ensure the successful implementation of innovations, all the essential functions for market adoption must be provided [Suurs, 2009]. For most of the logistical innovations communication between the stakeholders must be created, for the operational innovations it is key to show owner-operators that they can still improve their navigation techniques.

6.2 Discussion and recommendations

This thesis research was conducted with the greatest care. No efforts were spared in in the design of the research, the gathering of data, the analysis of data and the evaluation of data. Still, like with any other research, there are many ways in which this research could have been performed differently. The author could easily write a 20 page report about this, but this would defeat the purpose of a discussion and recommendations. Therefore only 3 aspects which should not remain unaddressed are selected.

Qualitative, quantitative and mixed methods research

This is a qualitative research. Some researchers may have chosen a quantitative approach to find the most promising innovations for the inland shipping industry. Qualitative research was chosen because there is, in general, a lack of readily available and reliable data on the subject. The author would have needed to resort to approximated values (e.g. operational data, savings potential, costs, value of time, internalization of external costs) which would have most likely resulted in conclusions which are hard to validate and which have a low significance.

A mixed methods approach in which qualitative data (from the interviews) would have been quantitatively analysed was not chosen due to the labour intensive nature of coding interview recordings. Furthermore, at the time of designing the research procedure, it was uncertain if stakeholders would allow interview recordings to be made.

Interviews: method and selection of stakeholders

Guided interviews were conducted. The author chose this approach to safeguard there was enough space for respondents to elaborate on the subjects they were well-informed or well-opinionated over. However, providing this freedom during the interviews while staying 'on-topic' and making sure all the topics were covered, proved to be cognitively challenging and physically exhausting. The author urges other researchers who are inexperienced with semi-structured interviews to consider the following carefully: this fatiguing research method creates a maximum on the number of interviews that can be conducted.

The author performed 18 interviews with carefully selected stakeholders. The author acknowledges that more interviews would have provided more insights into the subject but due to the exhaustive nature of the interview method concessions had to be made. Some stakeholders which would have without a doubt revealed more information are ABC, Ahold, Friesland Campina, BLN, Vibia, EVO, DG Clima and DG Move.

Conscious omissions and research recommendations

Many aspects were consciously omitted from this research. The author suggest future research to these aspects. These include, but are not limited to:

- What are the differences between low-speed two-stroke diesel engines and high-speed four-stroke diesel engines with respect to emissions
- What is the effect of operational profiles on the effectiveness of innovtions and on their pay back period?
- Which indicators can be used to quickly assess a ship's operational profile: route, cargo, 'dagvaart' and 'continuvaart', ...
- What are all the reasons why engine suppliers are unwilling to invest in the development of engines for the inland shipping industry and what are the differences with engines for automotive, non-road mobile machinery, and maritime applications.
- Which conclusions can be drawn from the comparison of both case studies and how do these conclusions transfer to other market segments of the inland shipping industry, like e.g. ferries, tankers and tugs.
- Are there other markets with a highly fragmented nature similar to that or the inland shipping industry; and based on these markets their similarities and differences: is the inland shipping industry expected to evolve into a market with mainly shipping companies or should it be expected to stay characterised by single-ship captain-owners.


Dedico mi tesis a mi mamá y mi papi lindo. Les agradezco muchísimo enseñarnos cuales
cosas realmente importan: salud, familia, educación y librepensamiento.

Appendix A

Additional documentation about the stakeholder interviews

The guided interviews with various stakeholders of inland waterway transport, covered several subjects. The flow chart of the interviews and the questions the researcher was interested to find answers to, are shown in Figure A.1. The interviews did not strictly follow the sequence of these flow charts, but the researcher made sure to cover each subject on the flow charts. Figure A.2 shows the hand-out which was used during some of the interviews. Because of the elaborate nature of the overview this was not used when the respondents had experience with (or knowledge of, or opinions about) only some of the innovations. Note that a Dutch version of these figures was used for the majority of the interviews, an English version was used only for the interviews which were held in English.

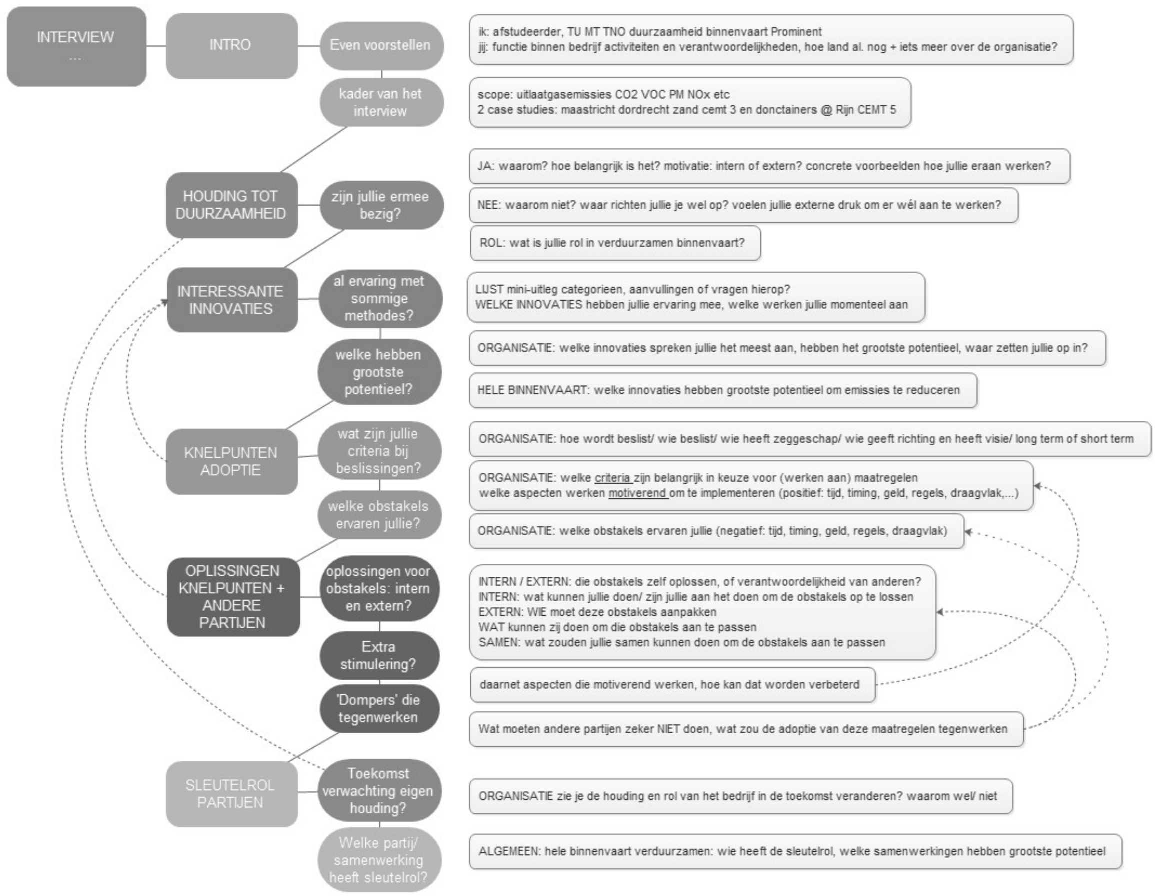

Figure A.1: The questions of the guided interviews in a flow chart

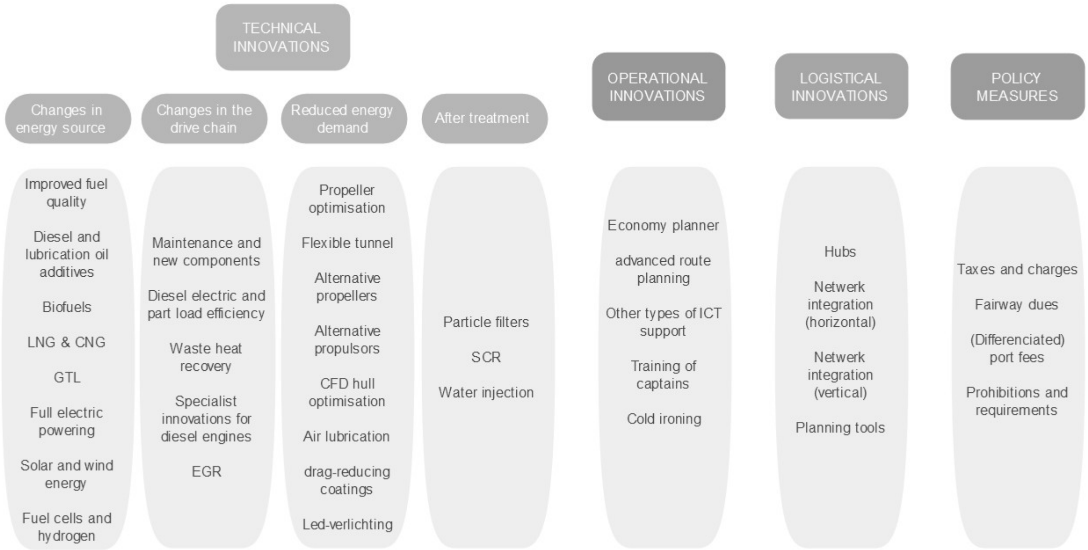

Figure A.2: The list of innovations which was used during some of the interviews

Appendix B

Quantitative analysis of metadata on inland waterway transport

Metadata of the inland waterway transport in the Netherlands from [CBS, 2013] have been analysed in this research. Some The next figures reveal some interesting information on the Dutch inland shipping industry. All the figures are based on the transported tonkm, rather than on the tons of transported cargoes or the number of voyages. The figures are focussed on presenting information about the overall industry as well as the two selected case studies in this research.

The first figure shows in which countries the cargoes are loaded and unloaded. The loading and unloading ports of the freight is shown in the next figure. The last figure gives a more detailed overview of the loading and unloading regions

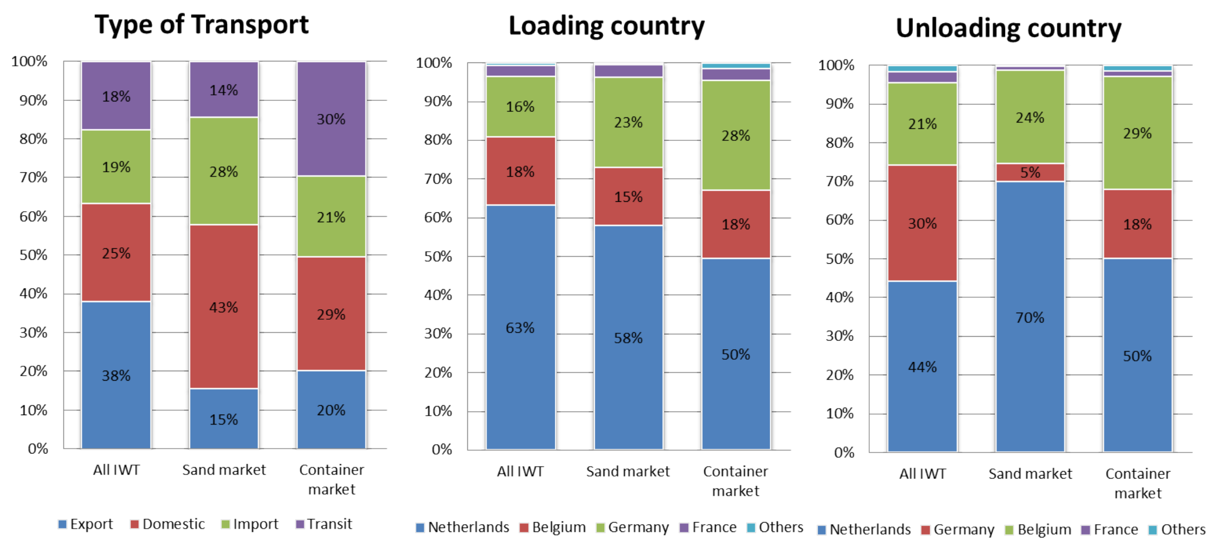

Figure B.1: Metadata on the overall loading and unloading countries

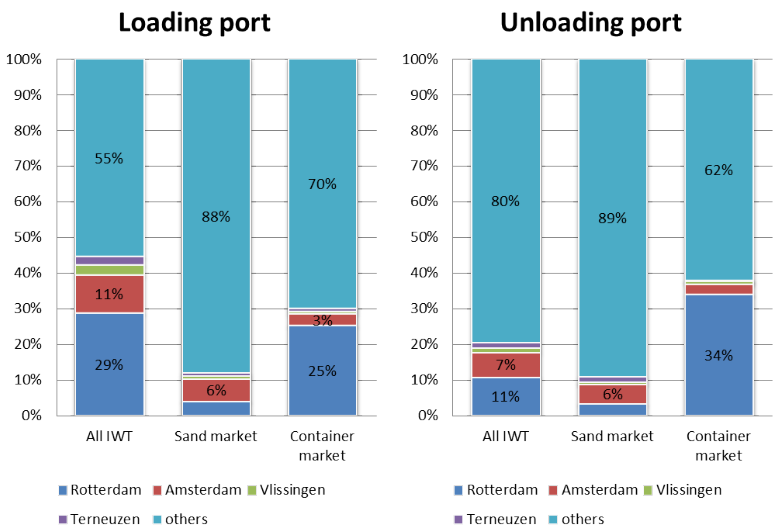

Figure B.2: Metadata on the loading and unloading ports of the cargoes

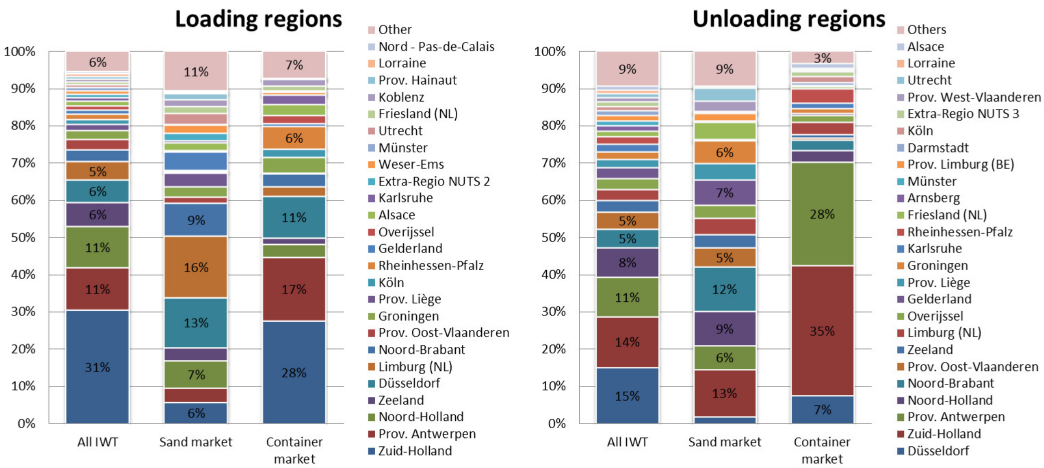

Figure B.3: Metadata on the detailed loading and unloading regions

Appendix C

Length of navigable waterways according to CEMT class and fairway characteristics

Figure 2.4 in Chapter 2.1.3 shows the length of navigable waterways in the Netherlands. The categories used in this figure are specified in Table C.1. An alternative way of showing the diversity of the Dutch inland waterways is to show the length of the waterways based on their size. Figure C.1 shows the length of the waterways according to their CEMT class. These classes are explained in Chapter REF.

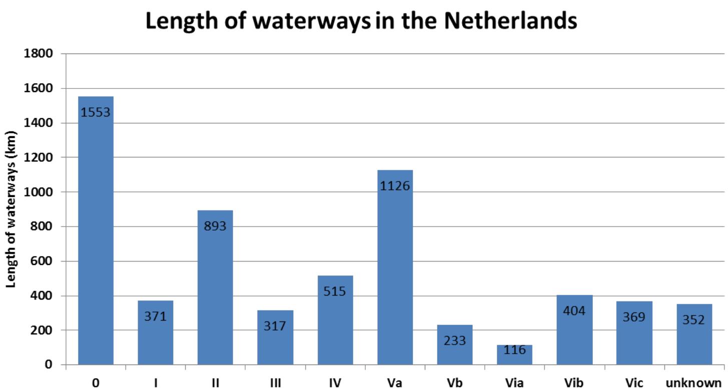

Figure C.1: The length of waterways in the Netherlands, based on CEMT class. Data from [CBS, 2014]

Table C.1: The definitions of the categories of inland waterways based on their character, as defined by [CBS, 2014]

English	Original Dutch category	Original Dutch definition
River	Rivier	Natuurlijke waterloop waarop scheepvaart mogelijk is.
Channelled River	Rivier, gekanaliseerd	Een rivier, waarbij door middel van stuwen en/of sluizen de waterstand wordt geregeld. Dergelijke stuwen en sluizen verdelen de rivier in zogenaamde panden. Naast de stuw bevindt zich dan de schutsluis ten behoeve van de scheepvaart.
Channel	Vaargeul	Geul van voldoende diepte als vaarwater. Is er sprake van meer dan één geul in een rivier, dan wordt dit type vaarweg vaargeul genoemd. Geulen in het deltagebied worden als vaargeul gekarakteriseerd. Een aantal vaarwegen in het bestand 'Vaarwegen in Nederland' (ViN) voor 2007 liggen anders dan in 2006 en 2008, terwijl de vaarwegvakken in het Nationaal Wegenbestand (NWB) onveranderd zijn. Hierdoor kunnen de lijnen in het NWB in 2007 niet verrijkt worden met gegevens uit het ViN en worden ingedeeld als onbekend. Deze situatie doet zich voornamelijk voor in de vaargeulen van het Lauwersmeer op de grens van Groningen en Friesland.
Canal	Kanaal	Een gegraven waterweg voor de scheepvaart.
Outport	Voorhaven	Het toeleidingsgedeelte vanaf een rivier of een open water naar een sluis.
Lake	Meer/ Plassengebied	Bevaarbaar meer of plas met al dan niet op diepte gebrachte of betonde geulen. Op meren en plassen zijn de vaarwegen bepaald door de uitmondingen van andere vaarwegen op het betreffende meer of plas zo logisch mogelijk met elkaar te verbinden. Daarbij is rekening gehouden met de eventuele aanwezigheid van op diepte gebrachte of betonde geulen. Voor het IJsselmeer resulteert dit in een complex netwerk van vaarwegen.
Fairway in port	Vaarwegen in havens	Alle vaarwegen in havens die een verbinding vormen tussen de doorgaande vaarwegen en de haven, en de vaarwegen door havens.
unknown	onbekend	-

Appendix D

Descriptions of the different types of inland vessels

The next table describes the different types of inland vessels which are listed in Table 2.3.

Table D.1: The descriptions of the different types of inland vessels

Type	**Descriptiom**
Vessel	Vessels are all the objects that are constructed to float with the primary purpose to carry cargo or people over water.
Ship	Ships are vessels that have a propulsion and steering system on board. All self-propelled vessels are ships.
Barge	Barges are vessels that do not have a propulsion system on board.
Coupled unit	Coupled units (also called convoys) exist of at least one ship and any number of barges. This research does not make the distinction between coupled units which are powered by a cargo-carrying ship, or a pushboat
Dry cargo vessel	Dry cargo vessels are vessels that are built to carry either bulk or non-bulk dry cargoes. Several dry cargo vessels are equipped to handle bulk as well as containers.
Tanker	Tankers are ships that are constructed to carry fluid cargoes Fluid cargoes can be either liquids or gases, that is why there are both liquid tankers and gas tankers.
Pushboat	Pushboats are ships that are built with the purpose to propel other vessels. These other vessels are often barges, and pushboats usually do not have the means to carry cargo.

Continued on next page

Table D.1 – *Continued from previous page*

Type	Description
Tank barge	Tank barges are barges which are designed to carry liquid or gaseous bulk cargoes.
Tug	Tugs are ships that are constructed to tow push other vessels.
Pontoon	Pontoons are technically not vessels because they are not constructed to carry cargo or people over water. Pontoons are flat-bottomed barges which are used to support other structures. They can also serve as a (temporary) bridge or as docking site.
Ferry	Ferries are ships that are produced to carry people and their vehicles at the same time.
Hopper barge	Hopper barges are barges which are constructed for dumping goods under the water surface. Hopper barges have cargo holds that can be opened on the bottom.
Floating equipment	Floating equipment is technically not a vessel because their primary purpose is not carrying cargo over water. Floating equipment has some other function (e.g. lifting objects) as its primary purpose. Carrying cargo over water can be is a secondary purpose of floating equipment.
Elevator barge	Elevator barges are barges with diagonal sides to allow them to be unloaded easier by elevators. Elevators are any type of equipment that hoists, scoops or sucks up the cargo.
Container vessel	Container vessels are dry cargo vessels which are optimized to carry containers.
Roro ship	Roro ships are ships that are constructed to carry rolling cargo.
Car carrier	Car carriers are ships that are constructed to carry vehicles over water. While most car carriers are roro ships, not all the vehicles may be loaded as rolling cargo.
Powder tanker	Powder tankers are ships that carry dry bulk cargo as if it were a liquid. They have tanks on board and can be loaded and unloaded with pumps, due to the liquid-like nature of the cargo.
Well barge	Well barges are barges that are constructed to carry dredged materials. These barges are built to drain off water from the cargo.
Push barge for heavy goods	Push barges for heavy goods are barges which are engineered to carry particularly heavy pieces of cargo. These barges are considerably stronger than other barges.

Continued on next page

Table D.1 – *Continued from previous page*

Type	**Description**
Lighter vessel	Lighter vessels are a specific type of floating equipment. Their primary purpose is to lift cargoes.
Lighter aboard ship (LASH)	LASH ships have at least one crane aboard that allows the ship to load and unload its cargo.
LNG Carrier	LNG carriers are tankers which are built to transport Liquefied Natural Gas.
LPG carrier	LPG carriers are tankers which are constructed to carry Liquefied Petrol Gas.
Oil-Bulk-Ore carrier (OBO)	Oil-bulk-ore carriers are ships that can carry three types of cargo (oil, dry bulk and ores) simultaneously.
Fishing vessel	Fishing vessels are vessels which are used for fishing operations. These operations include the transportation of fishing products.

Appendix E

CEMT and AVV classifications of inland vessels

The next figure shows the relation between the CEMT classification and the AVV classification of vessels.

I	M1	Spits	5.05	38.5	2.50	251-400	B= 5.01-5.10 en L>=38.01
II	M2	Kempenaar	6.60	50 of 55	2.50 of 2.60	401-650	B=5.11-6.70 en L>=38.01
III	M3	Hagenaar	7.20	55 of 67 of 70	2.60	651-800	B=6.71-7.30 en L>=38.01
	M4	Dortmund Eems (L < = 74 m)	8.20	67 of 73	2.60 of 2.70	801-1050	B=7.31-8.30 en L=38.01-74.00
	M5	Verl. Dortmund (L > 74 m)	8.20	80 of 85	2.60 of 2.70	1051-1250	B=7.31-8.30 en L>=74.01
IV	M6	Rijn-Herne Schip (L <= 86 m)	9.50	80 of 85	2.70 of 2.90	1251-1750	B=8.31-9.60 en L=38.01-86.00
	M7	Verl. Rijn-Herne (L > 86 m)	9.50	105	3.00	1751-2050	B=8.31-9.60 en L>=86.01
IVb							
Va	M8	Groot Rijnschip	11.40	110	3.30	>=2051	B>9.60 en L>=38.01

MARIN/DVS febr. 2010		Karakteristieke kenmerken van grote nieuwbouwschepen				
CEMT Klasse	AVV klasse	Type schip	L	B	D Gem.	T Gem.
Va	M8	Groot Rijnschip	110	11,40	3,50	3013
Va	M9	Verlengd Groot Rijnschip	135	11,40	3,50	3736
VIa	M10	-	110	13,50	4,20	4125
VIa	M11	-	135	14,20	3,70	5030
VIa	M12	Rijnmax Schip	135	17,00	3,80	6082
Dit overzicht is zeker niet compleet. Lees het document Scheepskarakteristieken van nieuwe grote schepen van MARIN voor complete overzichten. Lees ook Vlootontwikkeling Binnenvaart Schaalvergroting Binnenvaart						

Figure E.1: The CEMT and AVV classes of inland vessels. Images from [EICB, 2015b]

Appendix F

Extensive overview of the stakeholders of inland waterway transport

The bubble chart gives a visual overview of the stakeholders in the 7 categories which are introduces in Chapter 3.1. The figure shows how many stakeholders there are, and could easily be expanded to show more relations and to have more categories of stakeholders. The level of detail of this overview is chosen to be detailed enough to convey how many different stakeholders there are, while at the same time to be understandable without having to define the precise difference between the different categories. However, because some of the stakeholders are so important that they are mentioned throughout the thesis, a brief description of them is included in Table REF

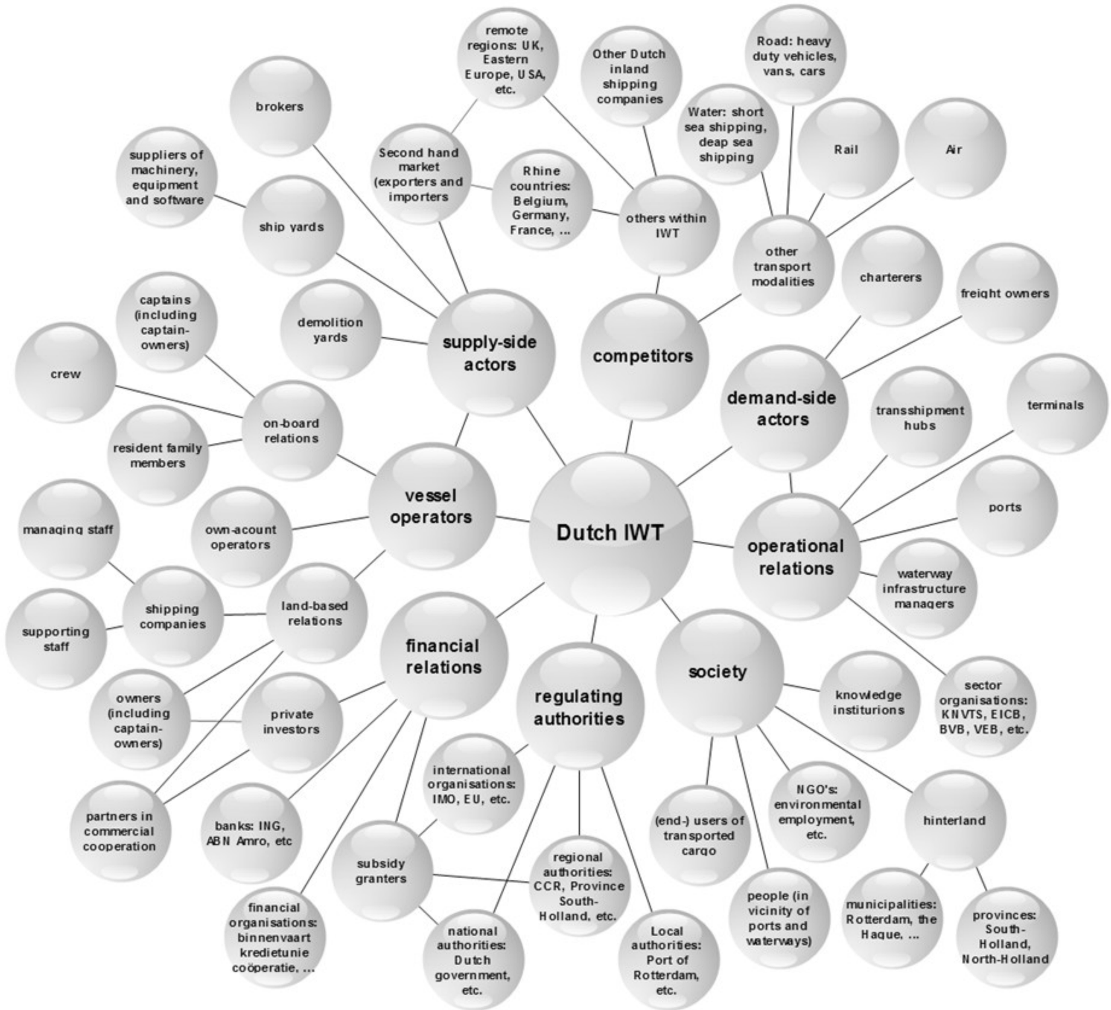

Figure F.1: An overview of the stakeholders of the Dutch inland waterway transport network

Appendix G

Literature on the environmental innovations relevant to inland waterway transport

The following table gives an overview of the most important reference material of Chapter 4: the studies 'Move-iT!' and 'IDVV Schone Schepen'. The table refers to the reports which have been analysed, and shows which categories of environmental innovations are considered in these studies. It must be noted that both these research programs categorise innovations differently and that the studies' emphasis lays on different innovations. This may be attributed to the character of this kind of publications: they are identifying innovations in the early stages of their development. It can be hard to evaluate which innovations are 'there to stay' and which ones are not.

Table G.1: The categories of environmental innovations in different publications

Move-iT!	**IDVV**
[Move-iT!, 2012], [Hekkenberg, 2013b], [Gille, 2013], [Thill and Hekkenberg, 2014]	[CE Delft et al., 2013a], [Winkel et al., 2013], [Gille et al., 2013], [Ecorys et al., 2013], [CE Delft et al., 2013b]
CCNR2 engine	LNG
Stage IIIB engine	CNG
CCR 4 engine	GTL
Particle filter (open)	Hydrogen
Particle filter (passive)	Biofuel
Particle filter (active regeneration)	Electricity
Exhaust Gas Recirculation	Wind energy
Selective Catalytic Reduction	Solar energy
Diesel-electric	Economy Planner

Continued on next page

Table G.1 – *Continued from previous page*

Move-iT!	**IDVV**
Hybrid incl. battery	PC Navingo eco
All battery	Training
Fuel cell	Cold ironing
Fuel cell + reformer	Waste heat recovery
Gas CNG	System integration
Gas LNG	Serial turbocharging
Dual fuel engine	Exhaust gas recirculation
Solar power	Engines for natural gas
Wind power	Gas turbines
Waste heat recovery	Fuel cells
2 stage TB + Miller Timing	Multiple engines for part load efficiency
Dual fuel engines + electric transmission	Diesel electric drive
SCR + DPF	SCR
LNG engine + electric transmission	Soot filters
2-stage TC + SCR + DPF	Water injection in cylinders
Bow thruster valves	Water in exhaust gas
Propeller nozzle, Schneekluth wake equalizing duct	Hydrogen injection engine
Propulsion system: better geometry, alternative blades	CFD for front and aft hull shape optimisation
Azimuthing thrusters	ACCESS air lubrication
Stator-rotor system	Filling empty spaces
Flexible tunnel	Ecospeed friction-reducing coatings
Down gradient/ wake panel/ dynamic streamlining	Catamaran ship
Alternative materials	Buoyancy increasing elements
Lengthening and widening	Adjustable tunnel
Air lubrication	Contra-rotating propeller
Dove tail	Propeller with bladed cap nut
Trapezes	Whale tail
	Ofoil
	Distributed propulsion
	Q barge
	Barge Truck
	E2 tug
	Mer-Green
	Shallow draught vessel

Appendix H

Elaboration: the succesful immplementation of selected innovations

These elaborations are based on the information presented in Chapter 4.

For **improved fuel quality** research is needed to show how large the variations are in the chemical composition of fuels of the same grade. Such research is being performed at TNO for automotive fuels by [Ligterink, 2016]. Even when these results confirm there are significant differences in the fuel compositon, similar research must still be done for marine gas oil and even more research must show what the effect of these emissions is on the exhaust gas emissions of engines. The innovation's potential to improve the environmental performance of inland waterway transport without requiring initial investment costs of captain-owners, and without requiring any changes to the operations of vessels, makes it a promising innovation. Stimulating the above mentioned research is therefore recommended. Regulating authorities could play a role in the stimulation of this research, especially because it is expected that suppliers and distributors of marine gas oil may not be enthusiastic to cooperate in this research. This is because they may fear performing bad compared to other fuels and they may not want to lose business because of this.

Similar research is needed to the effect of **fuel and lubrication oil additives**. Research to the effect these additives may have on the emissions must be designed in a way that it excludes the effect additives may have on the behaviour of the crew on inland vessels. It is suspected that some of the reported positive results may be caused by behavioural changes of the vessel operators instead of the additives. One could imagine that captain-owners who are willing to purchase additives to improve their environmental performance, are paying extra attention to their sailing and manoeuvring practices. Objective research with valid conclusions which excludes correlations between the behaviour of the crew and the actual engine performance will clarify if (a part of) the reported positive effect can be attributed to a placebo-like effect. If research shows that this is not the case and that additives can indeed reduce the exhaust gas emissions of inland vessels, this innovation is also ready for a fast, cost and effort effective implementation by the inland shipping industry.

The effect of **improved maintenance** of drive chain components may be done through computer modelling and simulations. This is because the author expects field-experiments may prove to be close to impossible due to the effects of a better maintenance have a long-term nature. It seems almost impossible to create a control group or baseline case to compare the results with, especially because the effect on the emissions is correlated to so many factors which would be practically impossible to control or to correct for. This makes it almost impossible to design valid field research and leaves simulation-based research as a method to investigate the effects of improved maintenance on the exhaust gas emissions of inland vessels.

The same approach of simulation-based research seems to be adequate way to research the potential of **diesel-electric drives**. Research for particular cases is required because the operational profile of vessels differs greatly. Engine matching and the design of the optimal power generation system is generally acknowledged to be case specific (e.g. [Stapersma and Klein Woud, 2008]). Only a couple of demonstrators of converted vessels which have realised a considerably higher fuel economy at an acceptable investment cost, can be enough to convince owner-operators to seriously consider this innovation. Clear communication on these demonstrators, their costs and their benefits must therefore reach the owner-operators in an unbiased way.

Finally, **friction-reducing coatings** also meet all but one of the criteria for the innovations which are most promising for the implementation by the sand, stone and gravel market. objective and valid research to the effects of different coatings and the effect of reduced intervals between treatments is needed. Just as with additives and maintenance, the long time span that would be required to research the fouling effects on the vessel's fuel consumption is the main obstacle to field research. Modelling and simulation-based research is therefore also necessary to aid in the successful adoption of this innovation.

LNG is included because, just like the other innovations in this list, it comes short only on R& D. The pay back period is expected to be relatively low because the price of LNG is expected to decrease in relation to that of MGO. Several of the stakeholders are convinced of its potential and have a clear directional idea about it. The Dutch state, the CCNR, the EU, several port authorities and also banks have a directional idea about LNG. The low voyage related costs would also mean shipping companies could accept lower freight tariffs, giving them a competitive advantage over others. Another reason why shipping companies in the container market believe they could have a competitive over others when sailing on LNG, is the growing interest of freight owners in the environmental performance of their transport.

The only box it cannot yet tick, is that the innovation does not require any additional R& D. Pilot projects are currently needed to develop knowledge on the conversion of existing vessels. It is still unclear which type of engine has the best overall results in terms of fuel efficiency, methane slip, and pollutants. Knowledge development which allow shipping companies to understand the financial effects of different economic scenarios that affect the price of LNG (and thus the total cost of ownership of their investment) is required. This information is crucial to enable shipping companies to make well-founded and resilient business decisions.

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