



Innovation in Inland Navigation: Failure and Success

The European case

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Inland navigation was for me an unavoidable choice of topic to pursue, when sailing with my father on board the MTS Arbon or as a child at sectoral organisation events, it was everywhere. Years later as a student at UFSIA and UIA where I studied political and social sciences as one of the last generation of “licentiaat” students, I decided to do my Master’s thesis on the Europeanization of inland navigation policy which triggered my fascination for and passion to continue with this topic. During my second Master’s thesis in Maritime Sciences, I was given the opportunity to compare inland navigation with Short Sea Shipping, under the supervision of Professor Dr. Dr. Evrard Claessens to whom I express my deepest thanks.

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Abstract

European inland navigation is generally regarded to be part of the solution to road congestion. It is also the transport mode with the lowest external costs. Therefore, a strong and competitive inland navigation can be a key element in achieving climate change objectives for the transport sector. In order to remain competitive and attractive, inland navigation needs to innovate in the midst of a rapidly changing globalized logistics chain. Innovation in inland navigation is both necessary to maintain the modal share or to grow in performance, and to keep the title of the most sustainable transport mode. Alternative fuels, innovative engines and propulsion, ship design, automation and digital business applications are just a few examples of possible innovations that could provide an answer that is attractive both for the investor (industrial-economics perspective) and for society (welfare-economics perspective). Private actors play a role in this; innovation is often a story of collaboration between public and private actors within a multi-layered network to create the best conditions for successful innovation.

This doctoral dissertation focuses on innovation in European inland navigation and takes the reader on a journey into a relatively uncharted world without avoiding relatively complex networks such as the (pan-)European institutional setting. The central research question is as follows: What are the factors that determine success or failure of innovation in inland navigation and what is the role of policy?

Four cases have been analysed in order to answer the research question. The cases concern the automated inland vessel, LNG as an alternative fuel for inland navigation, e-barge chartering instead of conventional chartering and the small barge convoy to reactivate small waterways.

After a detailed and updated institutional analysis of the European multi-level governance model for inland navigation policy, a combination of analytical methods is applied where meaningful and possible within a multiple case study framework. The system innovation approach allows for mostly qualitative analysis and shows if there are any patterns during the development phases of innovation and which conditions lead the innovation to success or failure. The (social) cost-benefit analysis framework was the main source of inspiration to develop a quantitative economic analysis that includes external costs and that fits the private cost structure of an inland vessel. Innovation can bring benefits for both private and public actors or for only one of them and has implications for both actors. Finally, the role of the various policy levels, tools and their impact are analysed. This study helps investors to decide if innovation is attractive and allows policy makers to judge whether and how innovation can be supported or not and by which policy level(s).

Innovation in inland navigation is understood here as a technological or organizational (including cultural as a separate sub-set) change to the vessel (or service) that either lowers the cost of the vessel (or service) or increases the quality of the vessel (or service) to the consumer. Sustainability is hereby considered as a quality improvement. In this study, the vessel owner is the principal consumer who decides whether a certain innovation is purchased or not.

The developed methodology can be repeated on other cases and includes a multidisciplinary approach with elements from welfare economy, system innovation and policy analysis that mutually reinforce each other and provide insight into this less-explored field of research in inland navigation innovation. The combined methods are useful for innovators, investors and other stakeholders in order to frame the challenges and contextualize the right circumstances or conditions to stimulate innovation.

Nederlandstalig abstract

De Europese binnenscheepvaart wordt algemeen beschouwd als een deel van de oplossing voor de congestie op de weg. Het is tevens de transportmodus met de laagste externe kosten. Door te investeren in deze transport modus, trachten diverse actoren volumes over te hevelen van de weg naar de vaarweg. Een sterke competitieve binnenvaart is daarbij een belangrijke schakel in het halen van de klimaatdoelstellingen voor de transportsector. Om competitief en aantrekkelijk te blijven moet de binnenvaart innoveren en dit in een snel veranderende geglobaliseerde logistieke keten. Innovatie is niet alleen nodig om het modaal aandeel te behouden of te doen groeien, het is ook nodig om de status als modus met de laagste externe kosten te handhaven. Alternatieve brandstoffen, innovatieve motoren en aandrijving, scheepsontwerp, automatisering en kosten-reducerende digitale business applicaties zijn maar enkele voorbeelden van mogelijke innovaties die een antwoord kunnen geven dat zowel interessant is voor de investeerder (industrieel-economisch perspectief) als voor de samenleving (welvaart-economisch perspectief). Niet alleen private investeerders spelen hierbij een rol. Innovatie is vaak een verhaal van samenwerking tussen private en publieke actoren binnen een meerlagig netwerk om de juiste omstandigheden te scheppen voor een succesvolle innovatie.

Deze doctorale dissertatie gaat dieper in op innovatie in de Europese binnenvaart en neemt de lezer mee in een relatief onbekende wereld en schuwt complexe netwerken niet zoals de (pan-) Europese institutionele setting. De centrale onderzoeksvraag luidt als volgt: Wat zijn de factoren die succes of falen bepalen voor binnenvaartinnovatie en wat is de rol van de overheid?

Vier gevalstudies werden geselecteerd uit een opgemaakte langere lijst en onderzocht om de onderzoeksvraag te beantwoorden. Het betreft het automatische onbemande binnenschip, LNG als alternatieve brandstof, elektronisch bevrachten van een binnenschip en het kleine duwkonvooi om de kleine waterwegen te reactiveren.

Een combinatie van analytische onderzoeksmethodes werd waar mogelijk en zinvol toegepast binnen een meervoudige gevalstudie en dit na een gedetailleerde en geactualiseerde institutionele analyse van het meerlagige bestuursmodel van het binnenvaartbeleid. De systeem-innovatieve benadering staat een kwalitatieve analyse toe die mogelijke patronen herkent in de verschillende ontwikkelingsfasen van de innovatie en welke condities leiden tot succes of falen. Het kader van de (sociale) kosten-batenanalyse bood inspiratie voor de ontwikkeling van een kwantitatieve economische analyse dat rekening houdt met externaliteiten en dat op maat is van een binnenvaartonderneming. Een innovatie brengt kosten en baten met zich mee voor zowel private als publieke actoren of voor slechts één van beiden en met telkens implicaties voor beiden. Tenslotte wordt ingezoomd op de rol van verschillende overheden en de mogelijke impact van hun instrumenten op binnenvaartinnovatie. De studie biedt een geactualiseerde institutionele setting van het huidige Europese binnenvaartbeleid en helpt te oordelen of en hoe een innovatie gesteund kan worden (of niet) en door welke beleidsniveaus.

Een binnenvaartinnovatie wordt hier begrepen als een technologische of organisatorische verandering aan het schip (of de dienstverlening) dat ofwel de kosten van dat schip (of dienstverlening) verlaagt, ofwel de kwaliteit ervan verhoogt naar de consument toe. Duurzaamheid wordt hierbij beschouwd als een niet onbelangrijke kwaliteitsverbetering. In dit onderzoek is hoofdzakelijk de scheepseigenaar de consument die beslist of een bepaalde innovatie gekocht wordt of niet.

De ontwikkelde methodologie kan herhaald worden op andere cases en omvat een multidisciplinaire benadering met elementen uit de welvaartseconomie, systeeminnovatie en beleidsanalyse die elkaar onderling versterken en inzicht geven in het minder verkende onderzoeksterrein van binnenvaart-innovatie. De gecombineerde methodes zijn nuttig voor innovators, investeerders en andere stakeholders om uitdagingen te kaderen en de juiste omstandigheden te contextualiseren.

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Used abbreviations

ABS	Automated Bunkering System
ACM	Automated Cargo Management
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterway
ADS	Automated Docking Systems
AER	Automated Engine Room
AGN	European Agreement on Main inland waterways of international importance
AIS	Automatic Identification System, standard in IWT is called inland AIS.
AV	Automated vessel
AWS	Automated Wheelhouse System
CAPEX	Capital expenditures
CBA	Cost-Benefit Analysis
CBA	Cost-Benefit Analysis
CBRB	Union Central Bureau for Rhine and inland navigation
CCNR	Central Commission for the navigation of the Rhine
CEF	Connecting Europe Facility
CESNI (/QP/PT/TI)	Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure: /Qualifications of personnel/Technical requirements/Information technology
CEVNI	Code européen des voies de navigation intérieures (waterway traffic codes of UNECE)
CIS	European Community Innovation Survey
CMNI	Convention on the contract for the carriage of goods by inland waterway
DC	Danube Commission
DG MOVE	Directorate General for Mobility and Energy of the European Commission
DPD	Differentiated port dues
DPF	diesel particulate filters
DWC	Differentiated waterway charge
e-BC	Electronic barge chartering
EBIS	European Barge Inspection Scheme
EBU	European Barge Union
EC	European Commission
ECDIS	Electronic Chart Display and Information System for Inland Navigation
ECSWA	Enhancement of Containerized freight flows over Small Waterways
EFIP	European Federation of Inland Ports
EIT	European Institute of Innovation and Technology
EK	External knowledge
ERI	Electronic Reporting International
ESO	European Skippers Organization
ESPO	European Sea Port Organization
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation vessels
ETF	European Transport Workers' Federation
EU	European Union
FPB	Freight push barge
FTE	Fulltime-equivalent
GAC	Green Award certificate
GHG	Greenhouse gases
HC	Hydrocarbon limits
IALA	International Association of Lighthouse Authorities
ICPD	International Commission for the Protection of the Danube
ICPR	International Commission for the Protection of the Rhine
IK	Internal knowledge
IKC&I	internal knowledge convergence and integration
IKSE-MKOL	International Commission for the protection of the Elbe
IMO	International Maritime Organisation
INE	Inland Navigation Europe
INEA	Innovation and Networks Executive Agency
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return

ISRBC	International Sava River Basin Commission
IVR	International Association for the representation of the mutual interests of the inland shipping and the insurance and for keeping the register of inland vessels in Europe
IWA	Inland Water Auxiliary engines: Support engines with a reference performance > 19kW for inland barges
IWP	Inland Waterway Propulsion: main engines with a reference performance of at least 19 kW for direct or indirect movement of barges only
IWT	Inland Waterway Transportation
LAESSI	Leit- und Assistenzsysteme zur Erhöhung der Sicherheit der Schifffahrt auf Inlandwasserstraßen
LNG	Liquefied Natural Gas
MC	Moselle Commission
MR	Mutual Recognition
MS	Member States
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
NOVIMAR	NOVel lwt and MARitime transport concepts
NPV	Net present value
NRMM	Non-Road Mobile Machinery
NtS	Notices to skippers
P&F	Port dues and fairway fees
PA	Policy analysis
PCT	International Patent Cooperation Treaty
PEINP (A)	Pan-European Inland Navigation Policy (Analysis)
PIANC	Permanent International Association of Navigation Congresses
PSB	Pallet Shuttle barge
RAINWAT	Regional Arrangement on the Radio-communication Service for Inland Waterways
RC	River Commission
RQ	Research Question
SBC	Small Barge Convoy
SCBA	Social Cost-Benefit Analysis
SCC	Shore Control Centre
SCR	Selective Catalyst Reduction
SIA	System Innovation Analysis
SIGNI	Signs and Signals on Inland Waterways
SPDB	Self-propelled dump barges
STS	Ship-to-ship
SWW	Small Waterways
TEN-T	Trans-European Networks for Transport
TPB	Tanker Push Barge
TPS	Terminal-to-ship
TRIMIS	Transport Research and Innovation Monitoring and Information System
TTP	Tank to propeller
TTS	Truck-to-ship bunkering
UNECE	United Nations Economic Commission for Europe
VO	Vessel owner
WIPO	World Intellectual Property Organization
WTP	Well-to-propeller
WTT	Well-to-tank

1. General Introduction

The Paris agreement stated that every industry must reduce its carbon footprint and emissions in order to reach the targets that were put forward to reduce the impact of climate change (UNFCCC, 2015). The transport sector still strongly depends on scarce fossil or conventional fuels. In the EU, the transport sector is responsible for almost a quarter of Europe's greenhouse gas emissions and is the main cause of urban air pollution with road transport as the largest emitter (more than 70%) (EC, 2014a). Inland navigation is responsible for 13% of the transport sector's greenhouse gas emissions and only has a 1.1% share in transport energy demand. There is still a broad unanimity in literature that inland waterway transport (IWT) has a strong sustainable performance with low emissions and related external costs (Van Essen et al., 2019). However while other transport modes are rapidly improving their environmental performance by decreasing emissions and fuel usage, IWT may well to lose its advantages if current emission levels do not change.

In addition to external environmental costs, Inland navigation is a part of the solution for the growing congestion on European roads within hinterland transportation by shifting volumes from road to waterway. To keep or improve its sustainable position and to further grow as a sector, innovation is needed. IWT is perceived in this regard as a sector that is lagging behind in the implementation of successful transport innovations compared to other modes. Although inland navigation features several innovations such as diesel engines, pushers, container vessels, radar, river information services and the introduction of alternative fuels, innovation in inland navigation is still a largely unexplored field of research.

The main challenge of this research is to develop an analytical method that combines elements from scientific literature on innovation, welfare-economics and political sciences in order to answer how innovation can be improved in IWT and what the role of policy is in this context.

Innovation is crucial for an economy to grow, both from an industrial-economics perspective, and also from a welfare-economics perspective. The latter looks at an innovation from a social point of view and pays more attention to the reduction of external costs related to congestion, environment, climate change, infrastructure and accidents. Innovation literature offers a vast set of typologies and methods to examine all forms of innovation. It is also a starting point for furthermore quantified research with tools such as a cost-benefit analysis.

Over the past decades inland navigation has experienced an institutional reform and with a growing geographical scope which no longer affects only the member states of the European Union but also involves the United Nations. That is why, in this research, the term pan-Europe is preferred. Another particularity is the existence of river commissions across Europe.

The next part of this introduction briefly describes European inland navigation and introduces some important concepts that be returned to in different Chapters of this dissertation. It offers the reader a basic insight into the inland waterway freight transport sector in Europe.

1.1. European inland waterway transport

The European Inland Waterway Transport (IWT) can be introduced in several ways: as a market whereby freight consisting out of dry, liquid or break bulk and containers, is loaded and unloaded by inland vessels of a wide variety of sizes and vessel types that sail from origin to destination for and often by an independent skipper/vessel owner or an employed vessel operator, under the instruction of a shipper (with usually a freight charterer in between). Alternatively, IWT can be understood as a transport modality within the hinterland freight transportation while comparing it to other transport

modalities (modal share expressed in volume or performance). For this, it is important to understand some basic transport economics concepts.

Europe has more than 40,000 km of navigable waterways, but only a limited number of Member States (MS) have significant freight volumes or traffic. Most European inland navigation is concentrated in the Rhine countries and Belgium, which also have a national or regional inland navigation policy. The waterways are used for recreational, military, floating stock, hotels, housing and even churches. Over the past decades, the professional fleet has not grown in the number of vessels but mostly in vessel size and capacity. There is little standardization in ship construction and most ships are rather unique. Freight can be transported on the inland waterways by barges with their own propulsion or by pushers or towers that are able to transport convoys of dumb barges. Convoys have a relatively small market share in Western Europe, but this share is much larger in Eastern Europe (e.g. Danube) and in the United States of America (e.g. Mississippi).

In order to set the scene for the importance of innovation in IWT, the following part of this thesis analyses the age of the fleet, looks at fleet capacity and trends, the size of the fleet, the waterway network and different vessel types, the modal share of IWT, the IWT market and takes a closer look at the external costs of inland navigation.

1.1.1. The age of the fleet

One of the reasons why people may perceive inland navigation as less innovative, is perhaps the relatively old age of the European fleet. This is not necessarily a good indicator for the degree of innovation because most of the vessels are kept in compliance with regulations and are frequently inspected, upgraded and renovated during mandatory dry dock visits. The relatively high average age of the active Rhine fleet, which suggests a relatively slow vessel replacement rate and the limited investment capability of the sector, are often identified as the main bottlenecks for innovations.

Figure 1 shows the age of the European freight fleet of self-propelled vessels, according to building year and with the distinction between dry or liquid bulk.

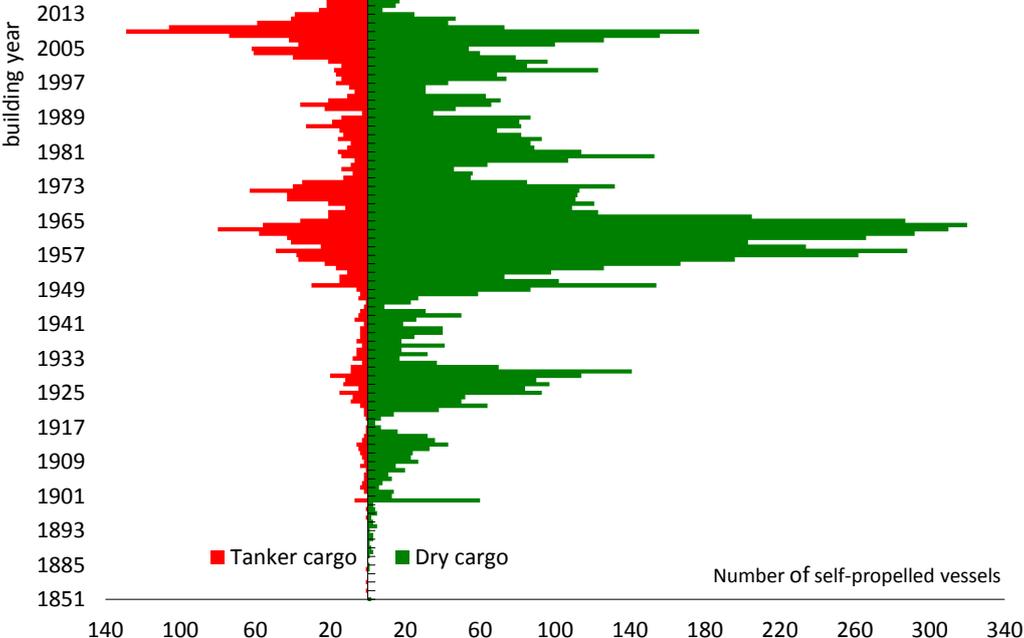


Figure 1: Age of the current European fleet

Source: IVR (2018), data based upon country registration in Austria, Belgium, Bulgaria, Cyprus, Czech Republic, France, Germany, Hungary, Italy, Luxembourg, Malta, the Netherlands, Panama¹, Poland, Portugal, Moldova, Romania, Serbia, Slovakia, Switzerland, Ukraine, UK

¹ A very small number of inland vessels in the European IWT fleet are registered in Panama and Cyprus.

1.1.2. Fleet capacity and trends

According to van Hassel, Vanelslander and Sys (2017; Wiegmans and Konings, 2017), current IWT markets are characterized by surplus capacities, which means that supply has become greater than demand. In both dry (since 2006) and liquid bulk (since 2002), supply has increased much more than demand². In their analysis van Hassel et al. take into account the old-for-new regulation (EEC/1102/89) and the demolition regulation (EEC/1101/89) that addressed the capacity problems and prepared the sector for the liberalization during the nineties, whereby Member States agreed to leave the tour-de-rôle systems³. Even though IWT is considered an environmentally sustainable mode, it is evolving into an economically unsustainable mode of transport with overcapacity as a major issue.

This overcapacity has a negative impact on freight rates for vessel owners and thus for their innovation investment possibilities. One suggested solution (van Hassel et al., 2017) could be state intervention with a reintroduction of the tour-de-rôle system with better regulation to avoid market abuses and a second option that refers to a voluntary, market-induced move of IWT companies towards a self-organized pool cooperation system with capacity control. Both options however have their own limitations and concerns.

Although, the capacity of the fleet appears to be increasing, the number of vessels appears to be decreasing, which means that the average size of the vessel is increasing as newly-built vessels tend to be larger in size. The following figure shows this situation for the dry cargo fleet in the Rhine countries and Belgium:

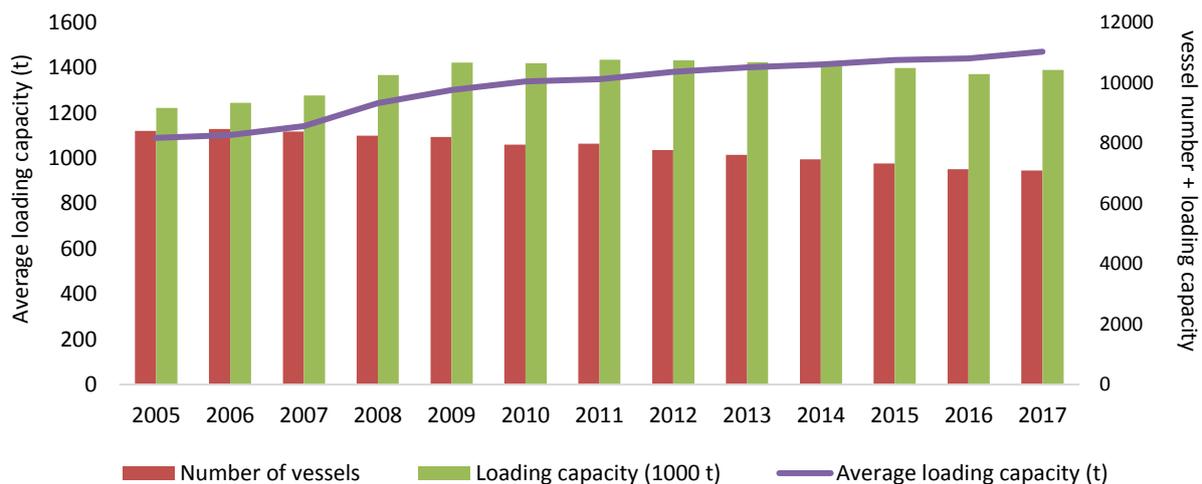


Figure 2: Evolution of the dry cargo fleet in Rhine countries and Belgium

Source: WSV, German authorities (2018), Market Observation (CCNR, 2018). CCNR analysis based on data from national administrations. Note: For Germany, data indicated for 2017 are from 2016.

1.1.3. The size of the fleet

Table 1 shows the total fleet as registered in 2017 for the pan-European fleet and collected by the IVR. Almost 14,000 freight vessels are active on the European waterways. The majority transports dry cargo and has a capacity of 13.7 million tonnages. The number of registered vessels differs between countries and follows the national performance of the sector. The table also shows that the average tonnage of

² The dry bulk market analysis (van Hassel, Vanelslander and Sys, 2017) used data from 1980 to 2017 for North-West Europe. Data concerning dry bulk push barges was excluded. The liquid bulk market was analysed with data between 1998 and 2014.

³ The old-for-new regulation (EEC/1102/89) only allowed new capacity when the same amount of tonnes was removed from the market, to support demolition with a demolition-to-newbuilding ratio. The tour-de-rôle systems or Festfrachten guaranteed minimum prices but without capacity control mechanisms and without free choice on the demand side of choosing a vessel. The Rhine was excluded from rotation systems because of the Mannheim convention (Beelen, 2011).

the inland tankers is much higher than in dry cargo. This is due to the trend of building larger ships and the recent renewal of the tanker fleet because of the double-hull requirements⁴.

	Total vessels (freight)	Dry cargo	Tonnage (1000t)	Average tonnage (t)	Tanker cargo	Tonnage (1000t)	Average tonnage (t)	Push & tug
Belgium	1,178	935	1,495	1,599	158	352	2,228	85
Bulgaria	266	194	290	1,496	19	25	1,333	53
Croatia	170	103	72	704	27	31	1,140	40
France	1,130	948	999	1,054	51	98	1,922	131
Germany	2,419	1,585	1,818	1,147	418	744	1,780	416
Hungary	380	319	391	1,225	3	4	1,228	58
Luxemburg	35	7	5	714	18	41	2,278	10
Moldova	50	34	41	1,193	5	4	800	11
Netherlands	5,107	3,559	5,945	1,670	824	1,788	2,170	724
Romania	1,574	1,191	1,523	1,278	97	85	880	286
Serbia	780	359	440	1,225	262	36	136	159
Slovakia	159	117	171	1,460	10	14	1,364	32
Switzerland	74	13	23	1,769	51	139	2,725	10
Ukraine	370	291	452	1,552	13	18	1,402	66
Total	13,692	9,655	13,663	1,415	1,956	3,379	1,728	2,081

Table 1: Potential customers in the Danube and Rhine fleet (freight vessels, liquid/dry bulk, pushers and tugs)
Source: Market Observation CCNR, 2018, National offices, Danube Commission (Rhine countries data year 2016; Danube countries data year 2015, Push&Tug for France is based on IVR data)

1.1.4. The waterway network and vessel types

The CEMT⁵ classification is used to categorize vessels and waterways. It was established in 1992 by the predecessor of the International Transport Forum and divided the European waterways into six categories taking depth, width, lock size and bridge gauge in account. Table 2 shows a basic overview of the classes of vessels according to their dimensions. This classification corresponds to the classification of waterways. A vessel of class III cannot navigate on class I and II but can navigate on all other classes.

Ship type	Tonnage	Length (m)	Width (m)	Depth (m)	Waterway Class	Category
Spits	250-400	39	5.05	2.2	II	Small
Kempenaar	400-650	55	6.60	2.5	II	Small
New type of Kempenaar	400-600	63	7.20	2.5	II	Medium
Canal du Nord type	800	60	5.75	3.2	III	Medium
Dortmund-Ems-Canal	968	67-81	8.20	2.5	III	Medium
Rhine-Herne-Canal	1,378	80-85	9.50	2.5	IV	Medium
Large Rhine vessel	2,160	95-111	11.4	2.7-3.5	V	Large
Large container vessel	470 TEU	135	17.0	3.0	VI	Large

Table 2: Classification of vessels in IWT
Source: Promotie Binnenvaart Vlaanderen, (cited from van Hassel, 2011a)

⁴ The UNECE Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN) has pushed out single hulls which explains the latest building wave in the tanker segment.

⁵ Conférence Européenne des Ministres de Transport

The inland waterways seem to require relatively low expenditures on inland waterway infrastructure (including maintenance). Expenditures on EU-28 level, furthermore show a decreasing trend. Most investments are in the Rhine riparian states⁶ and Belgium. Figure 3 shows the total investment and maintenance costs in the inland waterways (also including investments that are not only for freight transport) (ITF 2018)⁷.

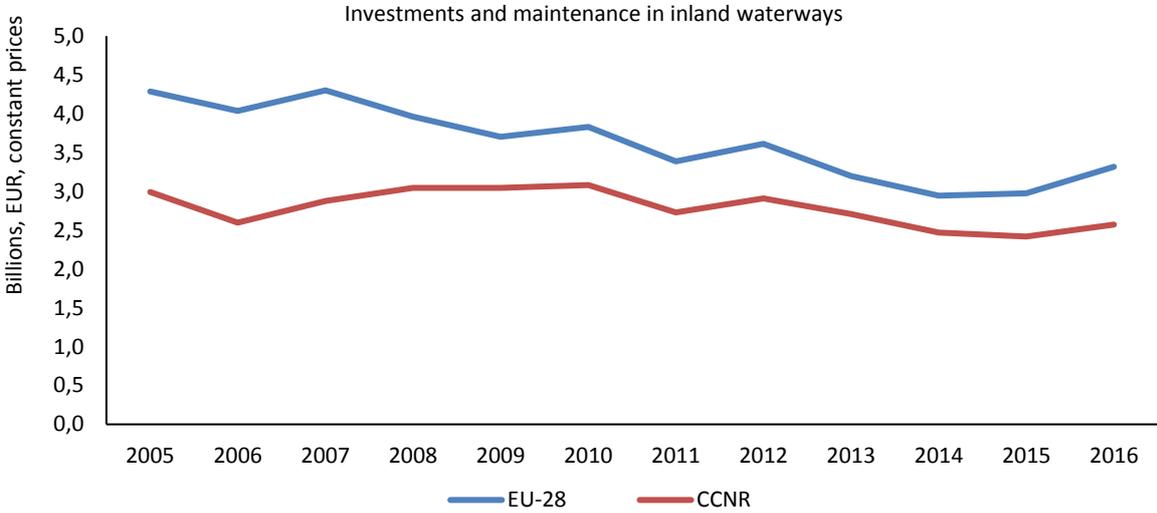


Figure 3: Investments and maintenance costs in inland waterways in Europe-28 and CCNR member states
 Source: OECD ITF (2018), constant prices of 2005

In constant prices (based on prices of 2005), the average annual IWT investment costs by all European Union countries, based on the period from 1995 to 2016, was EUR 2.7 billion. The maintenance cost was estimated in 2016 at EUR 880 million for the EU-28 (constant prices of 2005). This amount is significantly lower than maintenance costs and investments in other modes.

In addition to physical infrastructure, investments have been made in the implementation of digital infrastructure during the past decade. A number of mostly policy-lead and public-funded innovations, pilots and R&D can be identified concerning this kind of river information services. Most of the class IV waterways infrastructure, allows for track&trace with the automatic identification system (Inland AIS), electronic navigational chart reading with inland ECDIS viewers (Inland Electronic Chart and Display Information System) and even for notices to skippers which are digitally disseminated amongst skippers. Cross-border exchange of data in relation to electronic reporting, is, however, still an issue at the European level. Some EU Member States still find it difficult to exchange relevant data with each other and skippers are frequently asked to report already reported data in other Member States when crossing a border. The digital infrastructure is monitored by public actors through RIS centres which allows traffic management across the EU.

1.1.5. The IWT modal share

The competitiveness of IWT is often compared to other modes such as road and rail. This market share is expressed as the modal share which gives an indication of performance (in ton kilometres) or volume (in tonnes).

Figure 4 shows the modal split of the traditional hinterland modes of transport in the EU-28 as a percentage of the total performance (ton-kilometre):

⁶ These are Germany, France, Switzerland and the Netherlands

⁷ The investments include recreational navigation, environmental water policy related to flooding and reservoirs for locks and (drinking) water supply.

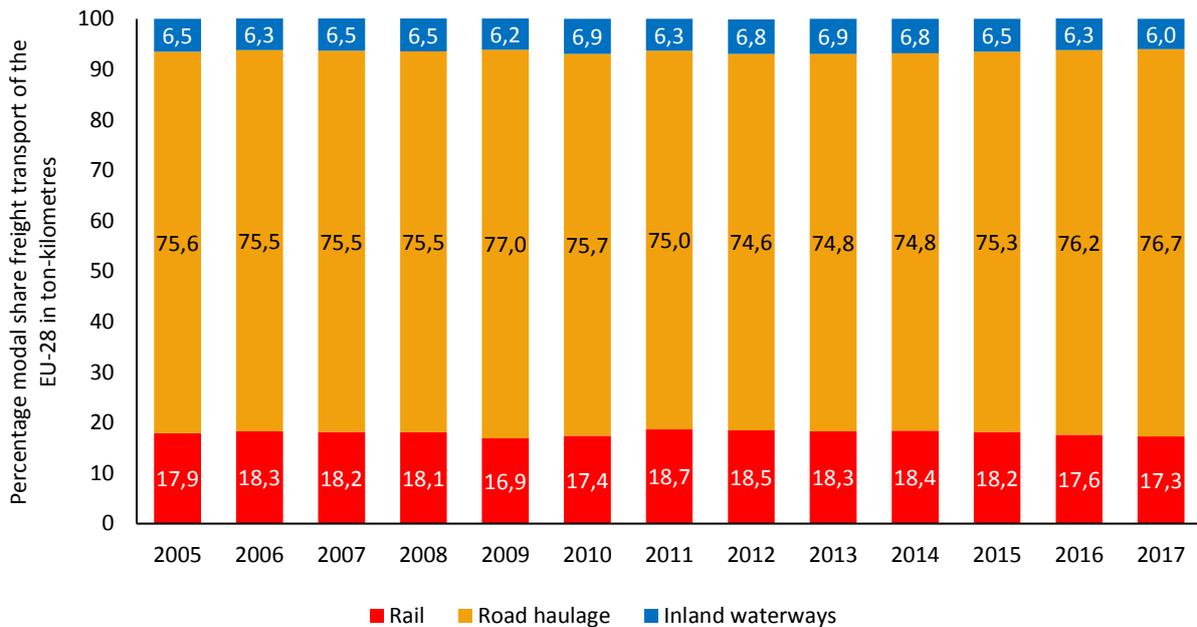


Figure 4: Modal split of freight transport in the EU-28 in percentage of total performance (tkm)
Source: based on Eurostat, 2019

The modal share of the sector at EU level has hardly changed and is consolidated at around 6%. According to Sys and Vanelslander (2011)⁸, this is partially explained by low price change sensitivity by the dry bulk market in particular. This price inelasticity occurs in addition to changes in other competing modes and is one of the reasons why the share has not increased despite stated policy objectives of several EU and national policies so far.⁹ Furthermore, not all EU Member States have significant and navigable waterways that allow professional freight transport or have invested in these waterways sufficiently.

IWT modal share clearly differs between Member States. The Netherlands is the leading IWT Member State in the EU by far (according to modal share¹⁰), followed by Romania, Bulgaria and Belgium which all depend on IWT for more than a tenth of their national total freight transport. Most Member States show a decreasing IWT modal share (Austria, Bulgaria, Germany, Luxembourg and Slovakia). In France and Hungary, the share remains consolidated within the examined time frame. IWT shows growth in modal share in Belgium, Croatia, the Netherlands and Romania. The modal share does not show the performance or volume of the transport mode. It could be the case that IWT is growing in tkm or in volume (expressed in tons) but has a lower or decreasing modal share while railways and/or road haulage increase stronger or vice versa.

The figures in Table 3 show the modal split evolution in Member States of the EU-28 with significant IWT (>1%). Only 11 Member States are considered to have a significant IWT activity.

⁸ Sys, C., Vanelslander T. (eds.) (2011), Future Challenges for Inland Navigation: A Scientific Appraisal of the Consequences of Possible Strategic and Economic Developments up to 2030.

⁹ The EU-data is at an aggregated level which does not imply that on smaller trajectories a modal shift or an increasing modal share does not occur. More detailed and less aggregated data could reveal other findings.

¹⁰ Germany has a higher IWT performance but the percentage modal share is smaller than the Netherlands.

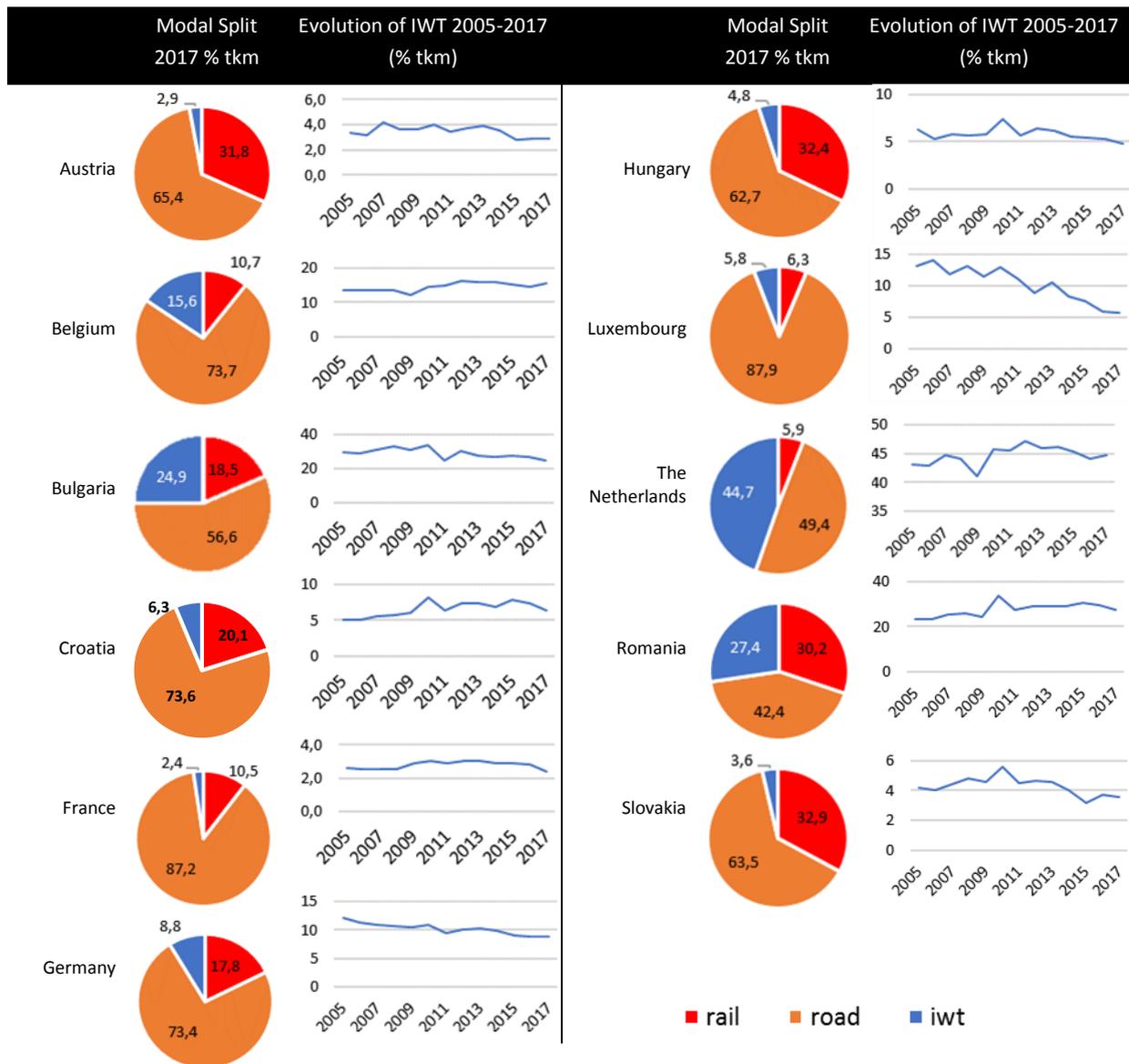


Table 3: Modal split in EU - MS with significant IWT and modal share evolution (% tkm)
Source: based on Eurostat, 2019¹¹

1.1.6. The IWT market

On the demand side, the three most important actors are shippers (freight owners), freight forwarders and terminal operators that need a transport service. On the supply side, there are several actors such as vessel owners/operators and freight charterers that are usually specialized in dry or liquid bulk, or containers. The market structure of IWT shows a relatively high number of SMEs with only one vessel in the Rhine Countries and Belgium, but there are significant regional differences. Quispel et al. (2015) uses Eurostat-data to show the number of IWT enterprises with only one vessel for the entire IWT market. In the Rhine countries, between 45% (the Netherlands and France) and 60% (Belgium) of the fleet are such enterprises, while for other countries, the number is significantly lower. In Croatia and Romania there are no single-vessel owners; in Austria less than 4% has one vessel; Switzerland, Czech Republic, Slovakia, Bulgaria and Poland have less than 20% of such enterprises.

¹¹ Poland, Italy, Portugal and Czech Republic are excluded in the latter overview because of the very low modal share of IWT (below 0.1%).

Owning only one vessel within one enterprise without any other activities, makes the business model vulnerable to market changes and lowers the ability to invest in innovation. The relatively high number of SMEs with one vessel in the most significant IWT countries, does not resemble the market power. For the latter, the organization of the market in relation to freight capacity becomes important. This organization is divided into a primary and secondary market as presented by Figure 5.



Figure 5: Schematic overview of the relation between shippers, freight charterers, VOs and vessel number
 Source: based on Quispel et al. (2015). Numbers differ from IVR dataset used elsewhere in this research (different year)

The conventional or traditional way to charter vessels is through a relatively complex system of intermediaries between the customer (sender of goods or shipper) and the vessel owner (VO). One of these intermediaries is the charterer. This actor usually has several ships under contract. The charterer looks for vessels on the market that can transport a volume of freight from a shipper from origin to destination. The rationale behind this process is that the charterer is more available and accessible to customers and can offer more flexibility and critical mass of vessel volume than one or two single vessels or VOs. From a shore office, the charterer allocates the available volumes according to demand and often takes care of some overhead costs (part of administration, customer communication, etc.).

If a contracted vessel is empty and close enough to the origin of the freight, the vessel will be called by the charterer and offered a freight rate. This freight rate is based on the negotiated price between the charterer and the customer and includes a charterers' provision that in most cases lies between 5 or 10 percentage of the freight rate (in Belgium maximum 10%). If the VO does not agree with the price, the freight will go to the next vessel that is linked to the charterer. If no other vessel is available (usually not the case), prices must be renegotiated or the shipper addresses another charterer. The system is not always transparent and the VO, in many cases, does not know what the full price is of the transport paid by the shipper.

Figure 6 shows the market where shippers and charterers (agent) meet and the market where charterers and VO (vessel owner) meet. The primary market is where a price (p) is negotiated between approximately 50 independent shippers and more than 200 charterers. The secondary market is where the VO negotiates a price (p') with the charterer that also implies a charterers' provision (van Hassel, 2013).

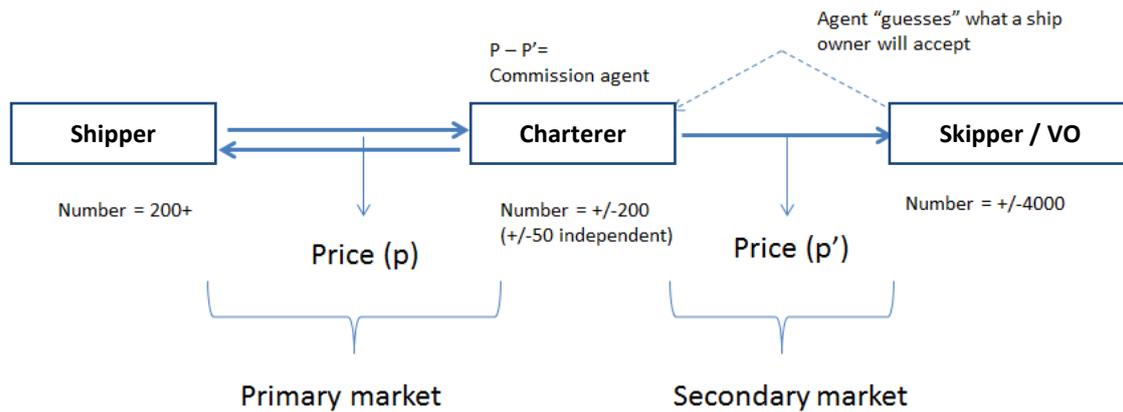


Figure 6: Two separate markets in the dry bulk segment of the inland navigation
 Source: Based on van Dijk et al. (2012) and van Hassel (2013:11)

The relation between a contracted VO and a charterer can be quite ambiguous. There are relatively large charterers with some market power in several segments of the sector which can offer more service to VO than smaller charterers. The degree of flexibility (changing from contracts), transparency (provision disclosed or not), the number of offered trips, freight rates and extra services differ between charterers, and influence the choice of the VO to prefer a certain charterer. In times of high demand and low supply, the VO has more bargaining power than the charterer. In times of low demand and high supply, the charterer has more bargaining power. A charterer can be a business partner of the VO or even a co-investor in a new vessel. Sometimes, in times when the VO has liquidity problems, the charterer can offer relatively cheap credit, which will help the VO in the short run but will make the VO more dependent on the charterer.

The personal business relationship between the VO and the charterer is often more important than the economic rationale behind it. As in all, social relations and the level of mutual trust is an important determinant. Trust can be jeopardized by irregularities such as:

- from the perspective of the charterer: frequent too late delivery of freight by the VO, unsafe behaviour such as insufficient maintenance and repair of the vessel, frequently not agreeing with offered freight rates, etc.;
- from the perspective of the VO: undisclosed provision of the charterer and negotiated gross freight rate, insufficiently high offered freight rates to cover operational costs, long waiting time between trips, waiting time to receive demurrage or detention fee.¹²

The ambiguous relationship between charterers and VOs is one of the reasons why the *European Barge Union* (representing charterers) and the *European Skippers Organisation* (representing VOs) took a relatively long time to cooperate with each other as representatives of the sector with common goals towards European policy makers and others.

In addition to the market of contractual VOs, there is the spot market. In this market segment, especially when dealing with dry bulk and project cargo, the VO tries to work without fixed time contracts with charterers or directly with shippers. In times of relatively high rates, the margins make it attractive to participate in the spot market, but in times of low demand, freight prices could work out lower than under fixed contracts. This means that participants in this market are more exposed to

¹² Demurrage and detention (D&D) can occur when the loading and unloading times are not respected and the VO did not cause this. The damage that the VO incurs because of D&D is usually paid by the charterer that receives this from the customer. This arrangement differs between countries but can lead to discontent if the reimbursement takes a long time. Questions can be asked as to whether the charterer has sufficient incentives to pursue proper payments from the customer to cover the D&D of the VO within a reasonable period of time.

volatility than when they are operating under a fixed contract. The possibility of navigating truly independently is the main driver for most participating VOs to be active on the spot market despite the higher risks.

According to a survey in the framework of Platina II¹³ in 2014, an average of 60% of VOs active in dry bulk was free from charterer and active on the spot market. One possible reason for this relatively high share is that, because of overcapacity, there are almost always enough available ships to charter. This makes it less necessary for charterers to conclude long-term contracts with VOs to guarantee enough transport capacity.

Figure 7 shows the operating mode of inland vessel owners. Especially in dry bulk, the spot market has a significant share. This share is also dynamic and follows market evolution. When freight rates are considered relatively high, the spot market becomes more attractive, if prices are relatively low, fixed contracts are more attractive.

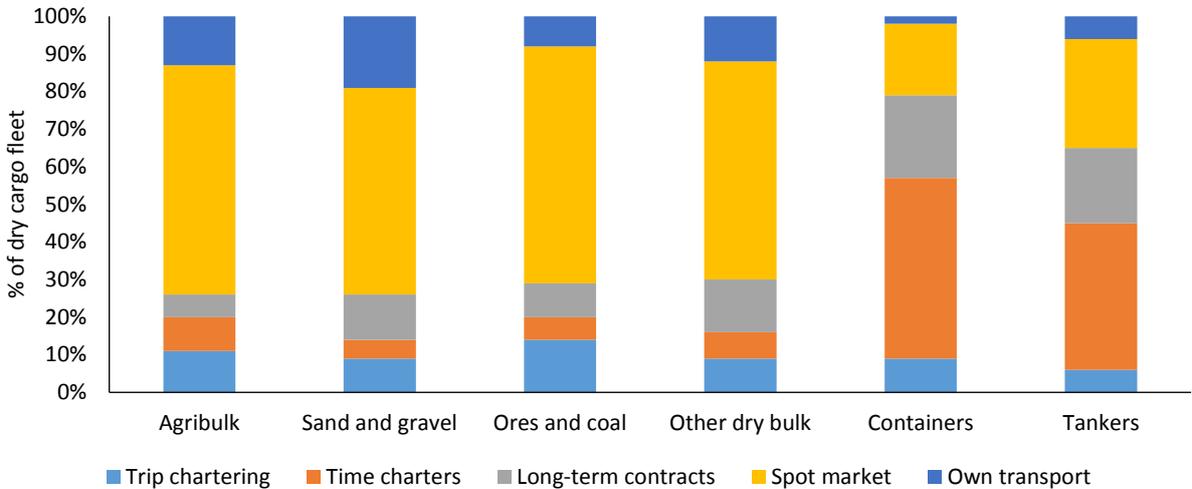


Figure 7: Operating mode for inland shipping dry cargo companies in Rhine countries and Belgium
 Source: Platina II (2014) as cited in and based on 391 respondents

The structure of the tanker market differs from that of the dry cargo market, because of the European Barge Inspection Scheme (EBIS) which comprises between 90 and 95% of the tanker market in IWT. This private initiative makes it more difficult to switch freight charterer which, although intended to ensure safety, consolidates the market dominance of a limited number of freight charterers and larger players.

In the Western-European fleet alone a high number of VOs are active. In the Danube basin, most vessels are owned by former state companies and these companies are still relatively large in size. The charter system differs between the Danube and the Rhine: whereas charterers offer an intermediary branch in Western Europe, in the Danube basin, customers usually call the owner directly, which usually has multiple vessels, directly.

On the IWT market skippers are paid by a negotiated freight rate which takes into account the volume of the freight that needs to be transported, together with the distance and the time needed. It also has a special extra charge when water depth is low, and vessels are not able to be fully loaded. Not much data has been found concerning the freight rate and every segment has their own freight rate indexes usually based on averages (e.g. PJK international for tankers). The scarce available freight rate data shows that the freight rate on the Rhine is linked to the variation of the water depth.

¹³ Platina II was a European Coordination Action which supported the implementation of the NAIADES II policy package "Towards quality inland waterway transport". The action ended in 2016.(EC, 2013b and 2014c) More information at <http://www.inlandnavigation.eu/news/policy/platina-2-has-ended/> and https://ec.europa.eu/transport/modes/inland/promotion/naiades2_en

Figure 8 shows the index of the gasoil freight rate for tankers as mentioned in the Market Observation between January 2002 and May 2017 for the Rhine fleet compared with the water level that causes a seasonal effect on the market. Low water depth periods cause a temporary decrease in supply and the mechanism of low water surplus, increases revenue of those who can sail in these conditions.

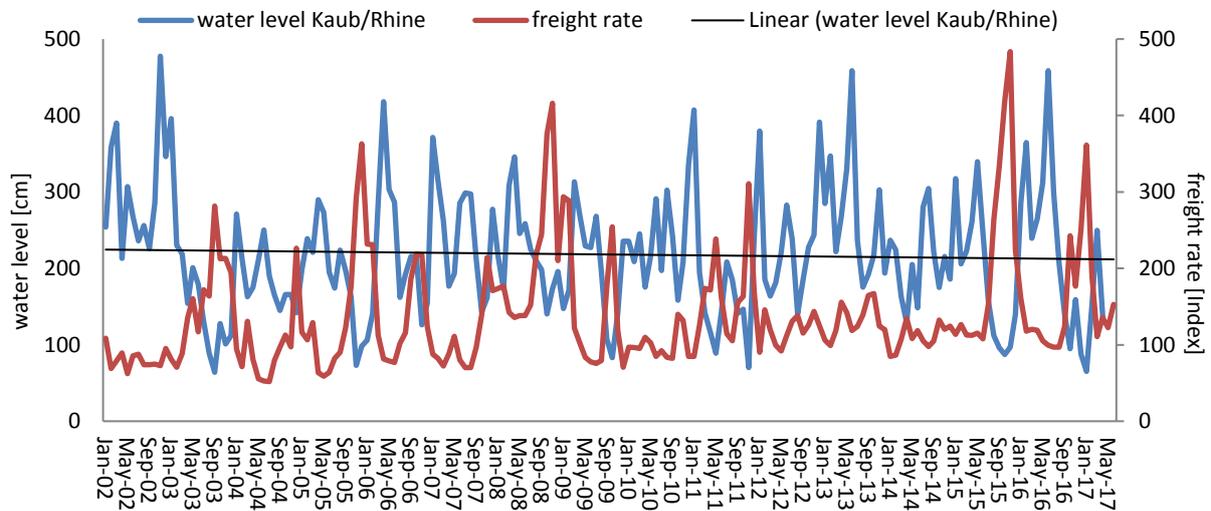


Figure 8: Freight rates of transporting gasoil and water levels

Source: Market Observation reports between January 2002 and May 2017, CCNR (2018) and PJK International (2002-2017)

Finally, all transport modes including IWT, are often examined in literature according their external costs. These costs not only show the environmental performance of IWT compared to other modes, but they also relate to accidents and congestion. These costs are introduced in the following part and must be interpreted with the necessary caution.

1.1.7. External costs in freight transport

External costs are costs that are not being paid by transportation users, but by society. External costs comprise the negative effects of transport such as climate change, energy use, emissions, accidents, noise, congestion and infrastructure¹⁴ (Ricardo-AEA, 2014:11; EC, 2014e). During the past decades, researchers have tried to valorise these costs for all transport modes.

External costs literature comprises a vast literature of decades of research and are commonly used to monetize the social impact of an investment or in this case an innovation. In this research the calculation of the external costs caused by the innovation, can be compared with a situation without the innovation. If there is an improvement, (e.g. if the innovation decreases external costs), there are potential social benefits. This will be further explained and applied during the methodological framework and the case studies.

However caution is needed when interpreting external cost values. There is no scientific unanimity concerning the monetarized values of external costs and the methodology behind them can be different according the source, geographical context and ways of measurement. What most consulted sources do find, despite certain limitations¹⁵, is that the external costs of IWT are the lowest of them all, of all freight transport modes. Figure 9 shows the different external costs for each transport mode and that only 0.3% is attributable to inland navigation.

¹⁴ By van Essen (2019) infrastructure costs are called habit damage costs.

¹⁵ Limitations such as the fact that average values are often assumed to be equal to marginal values for IWT (e.g. van Essen, 2019). Second, hardly any data for accident costs in IWT allow a basis for proper calculation of external costs. Emissions and greenhouse gases (GHG) are not measured at vessel exhaust in both stationary and operational mode. Finally, congestion is hardly measured at terminals, bridges, locks and other locations, despite the presence of digital tools on the side of the waterway manager and port authorities.

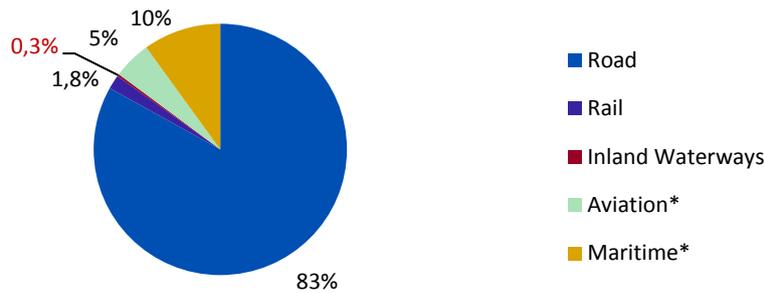


Figure 9: Percentage share of European IWT in external costs per tkm
Source: van Essen et al. (2019)

Although there are different ways to calculate external costs, most literature shows similar findings concerning IWT. Another caution relates to different views on how to look at external costs in IWT. When viewed in absolute values, a vessel has more emissions and higher fuel consumption than a truck. However when the transported freight and trip distance are taken into account (expressed by ton-kilometres), the inland vessel is, in most cases, more sustainable. However because of the low replacement rate of vessels and engines, it takes longer to replace existing vessels with engines that are more ecological or sustainable. The replacement rate of trucks is much shorter and follows the shorter depreciation or lifespan. Meanwhile railways are becoming more electrified. To maintain the position of the most sustainable mode of all hinterland freight modes, IWT has a strong need for innovation. Diffusion of alternative fuels, after-treatment systems or ecological sailing does not seem to be strong in IWT.

Furthermore, only limited evidence seems to suggest that the implementation of all sorts of digital infrastructure (e.g. developments of river information services) led to more efficient sailing with less fuel consumption. In this regard, limited evidence is suggested by the study Voortvarend Besparen (Full Sail Ahead with Savings), which tested the fuel use of two groups of vessel operators (Ecorys, 2011)¹⁶ with a total number of respondents of 280 vessels. The first group used one or more technical means to save fuel, such as a fuel consumption meter, speed advisor device (Tempomaat) and other instruments (such as AIS, Inland ECDIS and a digital depth meter). The second group used nothing or only one technical device. The conducted independent samples T-test analysis showed that between 2007 and 2010, the fuel consumption of the first group was significantly lower than that of the second group. The first group had a reduction of 8% while the second group showed a reduction of only 4.4%. The variance of both groups was tested with a Levene's test, which showed a p value of 0.038 smaller than 0.05¹⁷. Although larger vessels (>3000 ton) were overrepresented in the sample compared to the population, a total reduction of 6.7% in fuel consumption was shown for both groups. The ad random sample was claimed to be reliable enough to generalise for the entire (Dutch) population. The outcome of this study presents limited evidence that fuel consumption can be decreased by using digital tools for navigation and trip planning by between 0 and 3.6% but is too limited to generalise for the entire European IWT.

Some sources claim that the implementation of digital infrastructure leads to fuel saving and emission reduction by more energy efficient navigation in addition to engine modernisation (CCNR, 2012; ECORYS, 2012)¹⁸. It is claimed that optimizing speed with more information saves up to 10% of fuel and emissions. In free-flowing rivers with dynamic hydrography, a reduction could be made of 5% by

¹⁶ https://www.cbrb.nl/nieuws/documenten/doc_download/268-rapport-eindmonitor-voortvarend-besparen

¹⁷ A value lower than 0.05 shows that there is a difference between the variances in the population and the differences between the samples are unlikely to have occurred based on random sampling from a homogenic population (Levene, 1960).

¹⁸ CCNR (2012), CCNR report on the possibilities for reducing fuel consumption and CO2 emissions for inland navigation, Strasbourg. Ecorys (2012), Price elasticities in inland waterway transport: desk research, PLATINA WP6, Rotterdam as cited from Kurcsera and Kaufmann (2015)

choosing the most suitable track, especially upstream.¹⁹ Maierbrugger et al. (2015)²⁰ mention accurate waterway information as an enabler for energy-efficient sailing by optimising the sailing speed according to navigation conditions. This is claimed to have an estimated potential of 3 to 25.4% reduction of energy consumption (DST, 2011; as cited in Maierbrugger et al., 2015). With the use of more digital tools, this efficiency could be further improved. Another finding in this study is that several vessels have engines that seem to produce more power than needed for their vessel profile. It is claimed that refitting engines could lead to less fuel consumption and therefore fewer emissions, but reliable and complete data on used engines in the IWT fleet is still largely missing. Furthermore, the emissions can be reduced by on-shore electrification which allows operators to turn off the engine and to receive shore-power for domestic use on-board. These on-shore electrification stations are used in several areas in the Flemish region such as the Port of Antwerp.²¹

Finally, the usage of cleaner diesel (EN590) has decreased the emission of sulphur quite significantly and is currently the main used fuel for IWT. Transitions such as the shift from heavy fuels towards this kind of diesel also needs to be taken into account in updating external cost calculations. Similar transitions can be found in other transport modes such as road haulage related to the implementation of stricter emission standards. External costs are further explained in the literature review and are calculated for the selected cases where possible.

Now that the most important concepts in IWT have been introduced, together with the limited diffusion of innovations, it becomes possible to formulate the research question, scope and the outline of the dissertation in the following part.

1.2. Research question

European IWT shows a relatively old fleet with a consolidated modal share that does not indicate more growth towards other modes of transport. It has a diversity of vessels in different sizes and freight capacity and shows an important trend towards larger ships that are not able to sail on smaller waterways. Vessels and engines show a slower replacement rate than in other modes. Innovation seems rather limited and although IWT has the reputation of being the most sustainable mode in Europe, other transport modes are developing faster, and IWT is generally perceived as a transport with a low innovation spread. Is that perception true and if so, why is it that innovations are rare in IWT and can policy do something about this? The latter questions are rephrased into the following research question (RQ):

What are the factors that determine innovation success or failure in inland navigation and what is the role of policy?

The research question leads to the following sub-questions:

- What is innovation in IWT and what are the main trends?
- How can IWT innovation be analysed or measured?
- When is IWT innovation successful or a failure? What are the conditions that lead to failure or to success?
- Who are the relevant actors in IWT innovation?
- What is IWT innovation policy, how is it organized and which role does IWT innovation policy play?
- Which innovation policy measures are applicable to IWT?

¹⁹ “Main objective of Sub-Activity 2.3 in IRIS III was to investigate the potential role of River Information Services (RIS) and its information content for supporting fuel saving efforts on board of vessels (Kurcsera and Kaufmann, 2015).”

²⁰ Maierbrugger G., Schweighofer J., Kelderman B., Holtmann B., Verbeek R., Rafael R., Gille J., de Swart L., Quispel M., (2015), D 1.2 List of best available greening technologies and concepts, SWP 1.2, Via Donau, 74p. http://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_11_Prominent_D-1.2.-best-available-technologies_final.pdf

²¹ https://www.portofantwerp.com/sites/portofantwerp/files/Plooi kaart%20binnenvaart_2018.pdf

Two main objectives can be identified which offer building stones for the analyses:

- Identifying and analyzing innovation barriers in inland navigation
- Identifying and analyzing IWT policy that stimulates innovation in inland navigation.

The following parts show the chosen research scope and the outline of the thesis.

1.3. Research scope

The inland navigation in (pan-)Europe is the main topic of interest in this research. Most data and literature concerning IWT addresses issues which are situated in the 11 EU Member States with a significant inland navigation activity and a modal share that is larger than 1%.

Closer analysis shows that the Rhine and its tributaries have the most inland navigation activity of all Europe which was, in 2018, more than 84% of the total EU IWT performance plus Switzerland (CCNR, 2019). It is obvious that the largest market activity lies within this geographical scope and that it is safe to assume that most innovations are developed within the Rhine market. IWT policy however can have a much larger scope with non-EU Member States and the Danube countries.

1.4. Outline of the thesis

Figure 10 schematically shows the explained research outline. The research questions (RQ) are refined and broken down into sub-questions before they are answered by applying the methodology to the selected cases after the examination of the literature review and the conducted in-depth interviews.

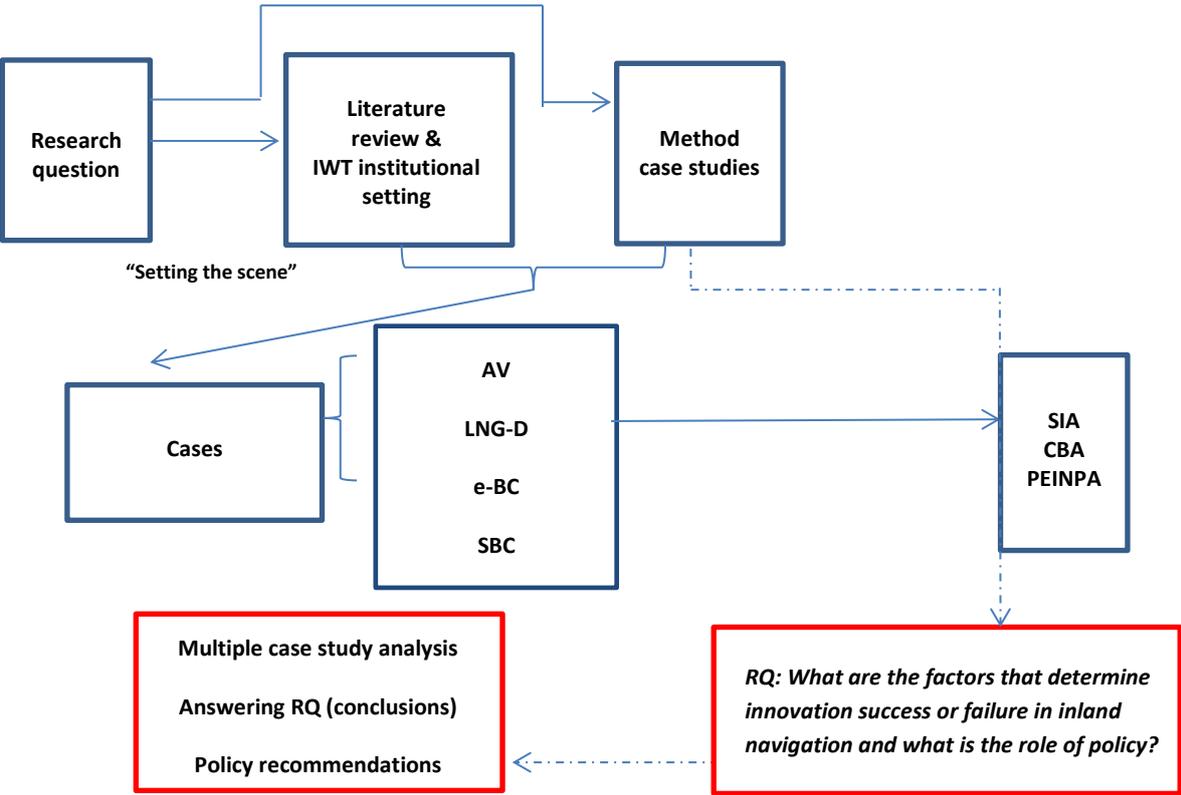


Figure 10: Research design schematic

After this introduction, the dissertation starts with a literature review. The purpose of the literature review is to identify gaps within the current state of the art. It provides building blocks for the research and shows what is known according to the consulted literature. First, a narrow review of IWT innovation in Europe and current trends are given. This includes several relevant research projects in IWT which are briefly explored. This is followed by a broader literature review concerning innovation in general, together with a review of used methodologies and typologies which helps to analyse innovations. The third sub-section helps to understand innovation policy with theories of the policy cycle, new institutional economics, European integration, multilevel and multi-layered policy, and key concepts such as subsidiarity and proportionality. This sub-section provides a better understanding of the current institutional setting of the European IWT which is essential to understand Chapter 3. This Chapter sets the scene for the development of the policy analysis tool for IWT innovation policy. The next sub-section in the literature review deals with social cost-benefit analysis literature and provides insight into how to perform this analysis on innovations where possible. The following sub-section reviews literature concerning case studies which also includes typologies and raises issues such as generalisation, sample sizes and theory testing, elaboration and building. More specific case-based literature (if any) is added at the beginning of each case study.

Chapter 4 explains the methodological framework which starts with the selection of the cases. Through a more pragmatic method, relevant cases are selected from a considered long list of IWT innovations. This Chapter also explains the role of the conducted in-depth interviews and the combined methodologies such as the system of innovation analysis (SIA), the cost-benefit analysis (CBA) and the developed pan-European inland Navigation Policy Analysis (PEINPA). The SIA applies an innovation typology that categorizes the innovations as being technological, managerial, organizational and/or cultural (as explained in the literature review). It examines whether infrastructure is needed, if there are enough factors available such as financial support, know-how and capabilities. Furthermore, the SIA explores whether regulation needs to be adjusted and even if there are interaction conditions (such as cultural factors) that could oppose the innovation. This analysis is qualitative and divides the innovation into three periods (initiation, development and implementation). During these periods the network of innovation actors such as VOs, charterers, industry with own vessels, shippers/ forwarders, third parties' lobbyists, manufacturers, consultants, sector organizations, knowledge institutes, public funding, standardization bodies and verification agencies are linked with the identified failure and success factors using a matrix approach. The result of the SIA indicates if failure factors are present that could prevent market uptake of the innovation which builds further on authors such as Roumboutsos et al. (2011 and 2013), Arduino et al. (2013), Aronietis (2013), Edquist et al. (2001 and 2006) and Garcia et al. (2002).

The developed cost-benefit analysis (CBA) includes components from social cost-benefit analysis (SCBA) such as external costs. The developed CBA helps to explore whether there is a positive business case for private investors and what the external costs are for society. This analysis quantifies the costs and benefits of the innovation from the perspective of the user (in this approach from the perspective of the vessel-owner) and not of the innovation producer. It takes into account external costs which are generated by a vessel model. These results advise investors and/or policy makers to pursue the investment or not at all within the limitations of this research. The approach follows the insights of Dupuis (1844), Blauwens (1986 and 1988), De Borger (2015), van Hassel (2011a & b) and Aronietis (2013) in taking into account externalities where possible.

The vessel models which were developed for the CBA are applied on the two main case studies. One vessel model carries liquid bulk and is designed with a dual fuel engine (LNG and diesel) or as coined in this research, the LNG-D. The other model carries dry bulk and is equipped and designed to sail unmanned and automatically (AV). These elaborated vessel models are applied to real world examples of inland navigation vessels. The models enable an analysis of the out-of-pocket costs for the private vessel-owner and gives insight into how much external costs the innovation reduces or generates.

The external costs are linked to the business case to calculate the potential social benefit of the investment on the level of the enterprise. The costs and benefits (both private and external) are calculated according to the annual performance of the vessel and explained assumptions.

The focus of the PEINPA tries to answer what the role of current pan-European IWT innovation policy is and how it can support or resist the innovation. The PEINPA is performed through a lens of transaction cost theory whereby the perspectives of both the end-user of the innovation and the policy makers are analysed. The PEINPA links the innovation case with the pan-European policy framework as developed and analysed in Chapter 3.

Each of the selected cases has its own Chapter. Every case analysis within this small-sample case study starts with a case-specific introduction that categorises the innovation according to existing typologies from literature and according to phases of development. After the SIA, it is decided if the case can be further analysed using the CBA and the PEINPA depending on cost data restraints, policy relevance or feasibility within the given time frame of this research.

At the end of all the individual case analyses, Chapter 8 analyses and compares the findings of each case. After the cross-case analysis, a general conclusion is drawn in a final Chapter which includes an invitation for further research and several policy recommendations.

2. Literature review

This chapter reviews innovation in IWT, theories of innovation and policy, the selected methodologies and literature concerning case studies and ends with more case-related literature of the main developed cases within this research. The main objective of the literature review is to find out if answers can be given to parts of the research question and to identify any empirical insights, gaps or missing pieces which this research addresses or which invites further research.

The first part reviews studies concerning IWT innovations and if there is a possibility how to measure this kind of innovations. A second part dives deeper in how to understand innovation in general. How to define it and if literature provides typologies that can be useful to categorize or analyse innovations. A third part is more related to the second part of the RQ and reviews how innovation policy can be understood. In order to answer partially the research question concerning the role of policy and to aid in the development of a proper institutional analysis of inland navigation policy, literature such as the policy cycle, theories of multi-level policy, European integration and New Institutional Economics is reviewed.

Fourthly, literature is given concerning social cost-benefit analysis. This part describes the origin of this analytical tool, the different related perspectives and explains possible costs and benefits which gives a framework for the development of a more quantitative analysis. A fifth part of the literature review explores how case studies can be performed and which issues are to be taken into account such as generalisation. A final part concerns literature that is more case-related. More specifically, it explains concepts and findings in existing literature related to the automated vessel and the LNG case. For the other cases case-related literature (if any) is integrated at the beginning of the case study.

2.1. IWT innovation literature

Most identified literature related to inland navigation innovation aims at researching cases and projects whereby a diverse arsenal of research methods can be applied. For infrastructure, literature can be found concerning locks and bridges, inland terminals, fairway maintenance, traffic management centres and even digital infrastructure such as River Information Services (RIS). In the framework of the Rhine-Alpine and Rhine-Danube corridors, several studies are done to support the corridor approach of the European Commission, which coordinates efforts with the river commissions (such as the CCNR and DC).

The European Commission launched an online tool to help analyse the effectiveness of innovation research in transport which is called the Transport Research and Innovation Monitoring and Information System (TRIMIS). It gives an overview of research trends and innovation capacities in Europe in different areas such as cooperative, connected and automated transport; transport electrification; vehicle design and manufacturing; low-emission alternative energy for transport; network and traffic management systems; smart mobility and services; and of course, infrastructure²².

The past few years, several research projects were funded in the framework of the Horizon 2020 and the Connecting Europe Facility (CEF) programs. Horizon 2020 is a public funding instrument of the European Union, which runs from 2014 until 2020 with an EUR 80 billion budget with the aim to increase the EU's global competitiveness with a strong emphasis on research and innovation. It is a follow up of the Framework Programs for Research and Technical Development and the European Institute of Innovation and Technology (EIT).

The Horizon 2020 program "Smart, Green and Integrated Transport" has given public funding to IWT research such as NOVel Iwt and MARitime transport concepts (NOVIMAR) which *aims to adjust*

²² European Commission (2017a), Transport Research and Innovation Monitoring and Information System https://ec.europa.eu/transport/themes/research/news/2017-09-19-trimis_en

*inland/short-sea shipping such that it can make optimal use of the waterborne system of waterways, vessels and ports/terminals.*²³ To achieve this, NOVIMAR introduces the waterborne version of ‘platooning’, the Vessel Train, which is in essence a number of unmanned follower ships with own sailing/manoeuvring capabilities and led by a manned leader ship.

Another Horizon 2020 program is the “Promoting Innovation in the Inland Waterways Transport Sector” (Prominent) which focuses on alternative fuels and the market uptake of innovation in this area. The project and its results are further explained in the LNG case within this research. Since 2014, more than fifty projects were co-funded by the CEF for the inland navigation sector (INEA, 2018)²⁴. According to the non-exhaustive list of the website of INEA, it is possible to have a first insight on public funded IWT innovation and support for infrastructure (Table 4).

CEF transport projects	2014	2015	2016	2017	total 2014-2017
Total transport projects	263	189	157	85	694
Belgium	26	13	18	3	60
The Netherlands	25	14	15	12	66
France	46	23	21	11	101
Germany	49	20	21	10	100
Luxembourg	5	2	0	0	7
% Rhine and Moselle countries	57%	38%	48%	42%	48%
Identified IWT projects	25	15	6	5	51
IWT innovation (other than RIS)	1 (Watertruck +)	1 (LNG)	0	2 (Electrical)	4
IWT infrastructure (other than RIS)	19	8	5	3	35
IWT RIS	3	6	1	0	10
IWT % of total CEF transport projects	10%	8%	4%	6%	7%
IWT infrastructure of total IWT projects	76%	53%	83%	60%	69%
INFRA+RIS on total IWT projects	88%	93%	100%	60%	88%

Table 4: Overview of CEF research projects since 2014 in EUR million (percentages if indicated with %)
Source: based on INEA (2018)

The number of projects for IWT do not reveal the size of the funding or the quality of the studies. However the bulk of funding for European transport goes to other modes such as road haulage and railways. Besides infrastructural IWT projects (digital such as RIS and physical), other recently funded innovations include four CEF projects for inland navigation: Watertruck+ which concerns the development of small barge convoy; Breakthrough LNG deployment in Inland Waterway Transport; and two recent projects concerning the building of an electrical inland navigation vessel (Port-liner)²⁵.

Most public funded projects that were identified concerning inland navigation are aimed at infrastructure, alternative fuels such as LNG and digitalization such as RIS. Next to European projects, most literature concerning IWT, relates to market functioning, technologies and sustainability. A recent overview of research in IWT is given by Wiegmans et al. (2017). The main part examines the economic performance of IWT within the logistics environment and identifies major drivers to improve competitiveness.

Hekkenberg and Liu (2017) identify that innovations in IWT are mainly directed at reducing fuel consumption (e.g. improved ship design or the usage of LNG), maximization of scale (e.g. larger ships) or entering niche markets (e.g. palletized goods, crane geared container vessels and special project

²³ As quoted from <https://trimis.ec.europa.eu/project/novel-iwt-and-maritime-transport-concepts#tab-outline>

²⁴ INEA (2018), INNOVATION AND NETWORKS EXECUTIVE AGENCY, Connecting Europe Facility, Inland Navigation, <https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport/projects-by-transport-mode/inland-waterways>

²⁵ The Port-liner projects showed a the lack of material (mostly kept confidential), although the innovators were interviewed.

cargo). They also indicate that there is a data problem concerning the relationship between the influence of water depth on the vessel’s resistance and on the optimal shape of the vessel. Projects such as Top Ships, which uses systematic Computational Fluid Dynamics calculations of different hull forms at different water depths (Rotteveel and Hekkenberg, 2015), or CoVadem, which designed a tool to measure real-time waterway depth and which could help in providing the necessary data to further optimize the hull design of a vessel.

Another interesting contribution is van Dorsser (2015), who identifies very long-term trends in IWT infrastructure, such as intermodal transport networks and the future 3D printer impact that implies a reduction of transport in combination with recyclable or locally produced bio-based materials. His central research question was to find out how the Dutch infrastructure policy *could develop a workable method for taking the very long-term development of the Dutch Inland Waterway Transport (IWT) system into account in the evaluation of integrated infrastructure development strategies with a very long-term impact*. He concluded that a different paradigm on economic growth and future discounting should be applied for very long-term trends in IWT infrastructure. However the technical consequences of van Dorsser are outside the scope of this research which focuses on current innovations and trends. Several important findings of van Dorsser can be mentioned. Firstly, there is no universal design standard for IWT systems because of the strong variety of waterways in dimension and service level. Secondly, there is a need for sufficient economies of scale regarding new infrastructure investments. Sufficient users are required and the investments should take in account the competition with other modes. And finally, van Dorsser also analyses briefly IWT policy and identifies policies concerning several topics such as: access to the waterways; traffic rules for inland navigation; technical vessel requirements; minimal crew standards; transport of hazardous goods; emission levels; and taxation.

An important question remains which was not found in the consulted literature and which refers to the possibility to measure innovation in the inland navigation. A commonly and generally used method in innovation literature is to look at patents. The World Intellectual Property Organization (WIPO) provides a wide variety of statistical databases related to the International Patent Cooperation Treaty (PCT) with publications that gather intellectual property patent data from national patent offices. This data-set allows to narrow down in order to obtain more detailed data through the online International Patent Classification system of WIPO. The used code is B63 Ships or other waterborne vessels which includes marine propulsion or steering. Class B63G which relates to military navy patents is removed from the data as presented by following figure:

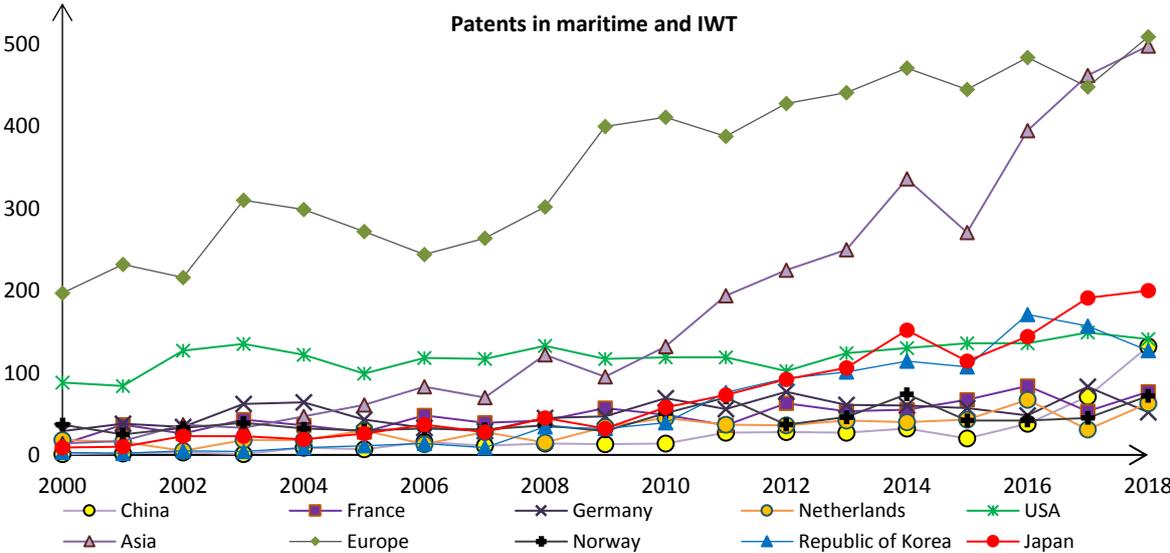


Figure 11: International patents in maritime and IWT
 Source: WIPO Statistics Database, 2019

European patent offices have collected the most patents for maritime and IWT, but Asia is reaching a similar level since 2017. The highest patents in Europe are from France, Germany, Norway and the Netherlands. Of course, patents are primarily linked with inventions and not with innovations. Patents do not say how inventions will perform on the market (Vertesy and Deiss, 2016). Other authors therefore suggest using the European Community Innovation Survey (CIS) data (Kleinknecht et al., 2012; in Andersson et al., 2012) that asks firms if their products or processes remain unchanged, are improved or entirely new. The CIS is made available on Eurostat for several years but does not make a distinction between maritime and IWT. Finally, not all Member States collect the required data (e.g. Austria, Belgium and the Netherlands are missing in CIS 2016 for water transport).

The following figure shows the number of enterprises in Europe that introduced innovation according to the specific innovation type based on available CIS data of 2016:

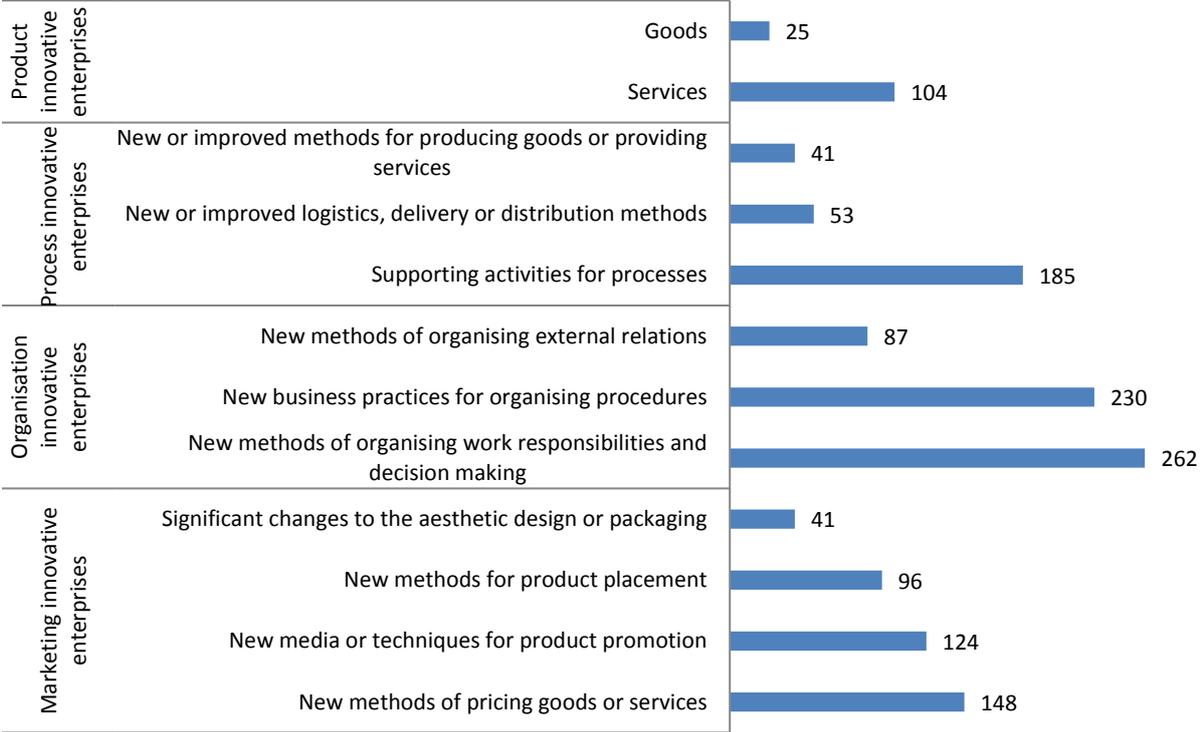


Figure 12: Number of innovative water transport enterprises that introduced specific types of the innovation
 Source: CIS 2016, Eurostat 2019: NACE Rev. 2 activity and size class [inn_cis10_spec]

In Europe, innovative enterprises in water transport were mainly focused on new organisational methods of organising work responsibilities and decision making, next to business practices for organising procedures and supporting activities for processes. Finally, more innovations were concentrated on innovative services than on goods. Because of adjusted methodologies between the different published CIS, time-series analysis would not be accurate because of too many differences.

Although both the CIS and the PTC do not allow innovation and patents to be divided between maritime and IWT, it is perfectly possible that most innovations in the category of water transport have a cross-sectoral nature. Such innovations that are developed for maritime vessels, find their way to IWT with any minor adjustments and vice versa. The LNG engine, the automated vessel devices such as automated mooring or even scanners, digital market places or e-barge chartering, etc. do not seem impossible to diffuse in both transport sectors. Without diving further in the technicalities and other available data-sets of the CIS and the PTC, the main lesson for now is that the innovations can indeed be measured on a European, national and regional level and that there is innovation activity on the level of the water transport firm although the number of innovations and innovative enterprises can be considered to be relatively low.

The following sub-section reviews innovation from a broader perspective than only European IWT. It looks for definitions and methods how to analyse innovations. It identifies recent developments, typologies and explains the used systems of innovation approach.

2.2. Innovation literature from a broader perspective

In literature, there is no clear-cut definition for innovation. First, an important distinction must be made between innovation and invention. An invention could result into an innovation but not necessarily, or in other words: *Innovation is possible without anything we should identify as invention, and invention does not necessarily induce innovation, but produces of itself no economically relevant effect at all* (Schumpeter, 1939). Others also make a clear distinction between invention and innovation:

Author(-s)	Innovation	Invention
Freeman, 1982	Innovation is the introduction of change via something new	Invention is the creation of a new device or process
Senge, 1990	'idea' becomes an innovation only when it can be replicated on a meaningful scale at practical costs	idea has been 'invented' when it is proven to work in the laboratory
Rouse, 1992	Innovation is the introduction of change via something new	Invention is the creation of a new device or process
O'Sullivan and Dooley 2009	Innovation is more than the creation of something novel. Innovation also includes the exploitation for benefit by adding value to customers. Invention is often measured as the ability to patent an idea	Invention need not fulfil any useful customer need and need not include the exploitation of the concept in the marketplace

Table 5: Innovation and invention concepts in scientific literature
Source: Kotsemir, M., Abroskin A., 2013

The first studies on innovation are generally linked to Joseph Alois Schumpeter (1883-1950) who described innovation as an historic and irreversible change in the way of doing things (Arduino et al., 2013; Smith, 1998; Sundbo, 1998). His most important work was the *Theorie der Wirtschaftlichen Entwicklung* (1912). He views the economic system as an evolutionary process as does Karl Marx. Unlike Marx, he does not find the main driver in the class struggle, but in the perennial gale of creative destruction with a special attention for the innovation entrepreneur (Schumpeter, 1942; Hospers, 2005). Creative destruction as meant by Schumpeter relates to the attacks of innovation upon an old economic structure at several moments in time until the old is destroyed and replaced by the creation of a new economic structure. In the process of creative destruction there is no optimal structure, but instead continuous structural change: innovations destroy the existing market structure and replace it with a new one.

In his book *Business Cycles, A theoretical, historical and Statistical Analysis of the Capitalist Process* (1939), Schumpeter defines innovation as a new production function that combines production factors in a new way which replaces or 'destroys' the old production function. Schumpeter even goes further by stating that a change in the total costs of production to an individual firm refers to innovation if other factors stay stable (p.85). *The old total or marginal cost curve is destroyed and a new one put in its place, each time there is an innovation.* Schumpeter makes a distinction between product innovation, being the introduction of a new good or a new quality of a good (1911:66; Edquist et al., 2001:10-11) and process innovation, which is the introduction of a new method of production or a new way of handling a commodity commercially. The changing of the production function by the innovation which can lead to new markets emerge, is a continuous process which Schumpeter and followers refer to as business cycles. These cycles can be schematically presented as Kondratieff waves.

Each successful innovation that destroys the old production function will eventually be destroyed and replaced by a next one.

Innovation is according to Edquist and many others a differentiated concept of innovation which encompasses both product and process innovations as well as subcategories of these types of innovation. Whereas, product innovation is divided in material goods and intangible services, and whereas process innovation relates to technological and organizational innovations (Utterback and Abernathy, 1975 in Edquist et al., 2001). It is broadly accepted that innovation is a driver for economic growth, but *mainstream economic theory has traditionally a primary focus on short-run problems of optimal resource allocation within a static framework, from which technological change has usually been excluded* (Rosenberg, 1986; Edquist et al., 2001:4).

According to the Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data (OECD, 2005:45-61) *an innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations*. It can be product innovation which is *a good or service that is new or significantly improved and which includes significant improvements in technical specifications, components and materials, software in the product, user friendliness or other functional characteristics*. Process innovation is defined as *a new or significantly improved production or delivery method which includes significant changes in techniques, equipment and/or software*. The Oslo Manual defines two more basic types of innovation such as marketing and organizational innovation whereas marketing innovation relates to *a new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing* and organizational innovation refers to *a new organizational method in business practices, workplace organization or external relations* (OECD, 2005).

According to the European Commission, innovation can be described as a change that speeds up and improves the way we conceive develop, produce and access new products, industrial processes and services. With improving changes, the European Commission refers to more jobs, improvement of people's lives and to the building of greener and better societies (European Commission, 2010). The sustainability aspect in this definition shows the priority of the policy maker and goes further than earlier definitions. Another definition comes from the InnoSuTra project that applies innovation research upon transportation (Arduino et al., 2013) and tries to summarize the variety of definitions and distinctions as follows: "An innovation is a technological or organizational (including cultural as a separate sub-set) change to the product (or service) or production process that either lowers the cost of product (or service) or production process or increases the quality of the product (or service) to the consumer." The definition of Arduino et al. (2013) can be added with the word sustainability but not necessarily. It depends how one defines the word quality to include sustainability or not. Another remark is that "the consumer" at the end of the definition, does not represent society at large. A better service or a higher quality could perfectly be only for the benefit of few. Furthermore, if CBA shows a less convincing result for the private innovator, although quality increases of the product to the consumer, it is not said that the innovator will continue. Moreover, the role of policy is not entailed in the definition in the debatable assumption that policy support is crucial for the innovation to succeed (crucial in the broad sense = to allow is already a support).

According to Kodama (2015) Innovation refers to a development processes involving multiple actors and stakeholders inside and outside of companies who collaborate for the purpose of the innovation of for their own benefit. It is important to know who the beneficiaries of the innovation are within the innovation network. However even more important, is to know who loses from an innovation and where resistance or lack of support can be expected.

For inland navigation specific, in most identified innovations the sustainability requirement is quite important. Inland navigation is often advocated as being the most sustainable transport mode for hinterland freight. As a consequence, and in general, innovation that stimulates growth of this mode

entails social benefits. Furthermore, the consumer in this research is the vessel owner that buys the improved product or service. The innovation can be on-board on the vessel (e.g. innovation in engines, navigation, ship design), on-shore (shore control centres, automated on-shore mooring devices) and even online (e-barge chartering, river information services). The definition of Arduino et al. (2013) can then be adjusted as follows for IWT innovation specific in relationship with the selected cases:

An IWT innovation is a technological or organizational (including cultural as a separate sub-set) change to the vessel (or service) that either lowers the cost of the vessel (or service) or increases the quality of the vessel (or service) to the consumer.

The literature review offered so far, a workable definition for the purposes of this research, but several sub-questions remain. Who does the innovation? Are there any classifications or typologies available that could help to understand the different types of innovations? Which ones can be applied on this research? And what is a successful innovation? These questions are addressed in the following sub-sections.

2.2.1. Typologies of innovation

Coccia (2006), Garcia and Calantone (2002; in Aronietis 2013) give an overview of several types or taxonomies of innovation according different perspectives which already makes clear that there is a vast literature of numerous typologies. Innovations can be “incremental”, “modular”, “systematic” or “radical”. Incremental innovations are innovations that are adaptive while refining and improving existing conditions, but other definitions exist and what some authors may call incremental, is a radical innovation for another. Radical innovations are defined by Damanpour and Aravind (2011) as disruptive innovations that discontinue leading practices, processes or products, as game changers while leaving the status quo behind. An innovation can be systemic which integrates multiple independent innovations that work together to improve the overall system performance. It can be modular which refers to a significant change in concept within a component of an existing process, product or service, but with a low impact (Sys, Vanelslander and Carlan, 2016; Acciaro et al., 2018).

Pavitt (1984) identifies four sectorial types of innovation which describes the behaviour of the innovating firm while predicting their actions into a framework for policy analysis (Coccia, 2006). He identified the following:

1. Supplier dominated firms: traditional industries such as clothing
2. Specialized suppliers: capital goods and equipment such as engine-manufacture
3. Science-based firms: in-house R&D laboratories
4. Scale-intensive firms: mass production industry

Later, Pavitt added information-intensive firms (1989; 2006, Coccia) but according to Archibugi (2001; Coccia, 2006) these type of firms belong to the second category as most of them are specialized suppliers. Other distinctions have been made (1987, Freeman, Soete; Coccia, 2006) to categorize various types of innovation which stress more on the nature of the innovation path. The first type relates to incremental innovations which occur continuously in any industry or service at a varying rate over different periods and different industries. The second type are radical innovations which are discontinuous events and are important for the emergence of new markets. A third one follows Keirstead (1948; Coccia, 2006) which combined the first two types as inter-related technically and economically ‘constellations’ of innovations as new technological systems. The latter type are changes of the techno-economic paradigm or technological revolutions such as the steam engine and electric power. This kind of innovations affect the input cost structure and the conditions of production and distribution for almost every branch of the economy (Freeman et al., 1982; Coccia, 2006) which allows to identify a type of innovation that comprises the former three types.

Innovation can be divided according to the forces behind driving the innovation. Innovation can be pulled by the market or pushed by technology (Darroch, Jardine, 2002; Coccia, 2006). The latter refers to new technologies or new combinations of existing technologies.

Utterback et al. (1998) classifies innovations according to technological, market and administrative or organizational features, whereas technological refers to the knowledge of components, methods, processes and techniques that are needed to produce a service or product.

Adding to the different typologies in literature, Coccia (2005) combines the existing classification with a seismic scale of innovation intensity dividing innovation impact in seven possible innovation degrees divided in three impact sets (low, medium and high). According to this 'seismic' approach an innovation of the seventh degree on the scale of innovation intensity refers to changes of techno-economic paradigms or systems.

Innovation can be open or closed referring to the degree of sharing of information versus closed secret innovation information kept in the innovating firm. With the development of a data driven economy, open innovation has gained a strong increase in scholarly attention according to Bogers et al. (2017) which lead to important insights into how companies use inflows of knowledge to accelerate internal innovation and outflows of knowledge to expand the markets for external use of innovation. Open innovation is 'a distributed innovation process based on purposively managed knowledge flows across organizational boundaries (Chesbrough & Bogers, 2017).'

Kodama (2015) describes a closed innovation as an innovation that is constrained within a company (pattern A) and observed a more hybrid innovation (pattern B) which is a mixture between closed and open types of innovation (Figure 13). Innovation networks stimulate the integration of knowledge through internal and external collaboration and include also the preferences of the customer (Kodama, 2015) as shown by following figure.

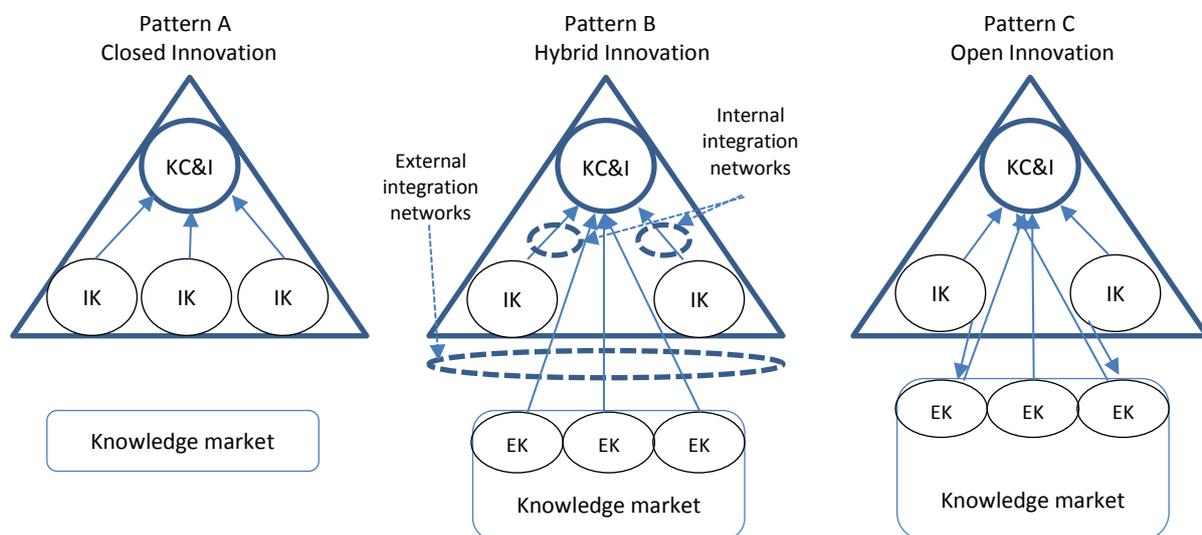


Figure 13: Open, hybrid and closed innovation typology
Source: Kodama M. (2015)

Pattern A (closed innovation) has a focus on internal knowledge (IK) convergence and integration (KC&I). The knowledge relevant to the innovation is integrated in internal networks within the company and is kept closed for the outside world. Pattern B (hybrid innovation) shows a mixture between internal knowledge and external knowledge (EK) but the knowledge integration networks are kept separated internally and externally. Pattern C (open innovation) focuses on external knowledge convergence and integration and shows an exchange of knowledge between the innovator and the knowledge market actors. Kodama (2015) places external knowledge on a knowledge market which indeed has the characteristics of a market. Most companies and other actors that are found on this

market are knowledge institutions, consultants or other experts that help to develop the innovation. These actors can be both private or public.

Three phases of innovation deployment can be identified in the innovation process: initiation, development and implementation. The initiation period includes a gestation period that shows that a change is required, some kind of shock (e.g. product failure, decrease in market share or changed management) which triggers the need for a change and which sparks the innovation (Arduino et al. 2011) and it includes resources that are inputs for the initiation processes.

The development period as described by the Minnesota Innovation Research Program (Arduino et al., 2011), includes seven factors which are: proliferation, setbacks, shifting performance criteria, fluid participation of personnel, top management involvement, altering relationships and cooperation concerning suitable infrastructure. The proliferation of the innovation follows a highly uncertain path and is used as a strategic choice to divide the risk over different paths to find out the most successful one. Setbacks are common in this period which could lead to changes in development. Performance criteria can be different at start of the development period and depend on budget or different views. As the end of the development period comes closer, resources could be depleted, and criteria altered to diverge what was envisioned and the practical feasible outcome of the innovation development.

The fluid participation of personnel refers to personnel changes, dynamic human emotions and individual career planning. Emotions will differ during the development period if the innovation succeeds or fails which has an influence on the development of the innovation. Involved managers can take on the role of sponsors, mentors, critics, institutional leaders, pragmatics and shift between these roles which also influences the development. Relationships between innovation actors change during this period as more actors are getting involved. Cooperative relationships can become competitive and simple relationships can become more complex with an influence on resources. A latter factor is the cooperation to obtain a suitable infrastructure. The innovator often needs infrastructure to be developed such as institutional arrangements or means of manufacturing, production and distribution.

The implementation period starts when the innovation is adopted by early adopters. Old processes or products are replaced or integrated with the innovation. This adoption process is an important measurement of the success of the innovation in this period which will indicate if the innovation will become implemented and institutionalized, if it will become common practice or if it is not adopted and resources are depleted to complete or redesign the innovation (Arduino et al. 2011).

The type of innovation depends on the sort of change an innovation introduces and is grouped as:

- A purely technological innovation;
- Managerial, organisational and cultural innovation;
- Technology, managerial, organisational, cultural innovation;
- Policy initiatives (introducing various types of innovation).

According to Fontan et al. (2004) and Damanpour et al. (2011) mostly technological products and processes are the main focus of innovation literature. Managerial innovation was first used by Kimberly (1981; Britt, D. 1985) and defined as *any program, product or technique which represents a significant departure from the state of the art at the time it first appears, and which affects the nature, location, quantity or quality of information that is available in the decision-making process*. Another definition comes from Birkinshaw et al. (2008) as *the invention and implementation of a management practice, process, structure or technique that is new to the state of the art and is intended to further organisational goals*. The definition of Birkinshaw uses the word "invention" which was rejected earlier in this Chapter but which is still used interchangeable by authors such as Birkinshaw et al. Walker, Damanpour, and Devece (2011) define managerial innovation or what they call management innovation as *new approaches to devise strategy and structure in the organization, modify the organization's management processes, and motivate and reward its employees*. This definition introduces employees and the reward system on the level of an enterprise.

Furthermore, following Giuliano, et al. (2016), the following situations can be identified:

- An internal decision made by the company for its own profit or efficiency motives;
- An internal decision influenced by external forces that created incentives or disincentives for the company; or
- A response to a significant level of public funding.

Companies who decide internally to go for innovation without any external incentives or disincentives can base their strategy upon research and development or on other internal reasons. A second situation is where external forces influence the decision to innovate as a possible response to competition behaviour or to new market information.

There is a vast literature concerning innovation and that there is no consensus on the use of typologies. The past decades a new approach emerged to explain innovations as a system. The related literature is reviewed in the following part.

2.2.2. Systems of innovation approach

The systems of innovation approach (SIA) takes in account principles of change and focusses upon innovation as being a collective learning and selection process, inherited from evolutionary economics (Nelson, 1987; Edquist et al., 2001:4). In institutional economics (Hodgson, 1991), the SIA explains innovation patterns on the behaviour of actors which are related to institutional rules, with a focus on the determinants of product and process innovation. According to the InnoSuTra research, the SIA approach takes *the evolutionary theory as one of the points of departure, to focus on the interactive mechanisms that shape the emergence and diffusion of innovations through the interaction of actors and institutions* (Arduino et al., 2013).

SIA is rather a broad framework than only one specific analytical tool, although it has several clear distinctive principals. It is explorative in its nature and gives insight in mostly qualitative variables that could explain the success or failure of an innovation. With respect to the assessment of the adoption of innovation, SIA allows to identify relations between actors and institutions within the innovation (adoption) system that contribute to innovation uptake or hinder it. More specifically, SIA helps to view innovation as an interactive, nonlinear process, in which actors interact with other organizations and institutions such as laws, regulations, values, etc. SIA is here best suited for in-depth analysis with a scope of identifying the reasons behind the lesser outcome in failed cases or how to foster the best conditions within the system to secure successful adoption when considering the initial stage of innovation adoption (Roumboutsos, 2013).

Through a matrix approach, these variables are linked to the identified network actors and institutions which makes them responsible for the innovation and which will be further explained and applied in this research. For now, a simple example can explain this. When infrastructure is needed to support innovation success, the responsible actor which can be a terminal owner or the port authority is linked.

Following characteristics of SIA are identified by Edquist (1997; Edquist et al., 2001):

- Innovation and learning process as central focal point;
- Holistic (wide array of innovation determinants is taken into account) and interdisciplinary (not only economic factors) view;
- Historical perspective (evolution of knowledge, innovation, organizations, institutions);
- Differences of systems are more important than identifying an optimal innovation system;
- Interdependence and non-linearity: innovation by interaction through complex inter-organisational and inter-institutional relations and not by isolation. Non-linear because of reciprocity and feedback mechanisms in several loops of evolution.
- Product and process innovation;
- Central role of institutions to understand the social pattern of innovative behaviour.

The SIA refers to network actors which is closer examined in the following part.

2.2.3. Innovation actors

The main actor is the innovation entrepreneur which is for Schumpeter not per se a rational-decision maker, but rather a creative pioneer surrounded by uncertainty, filled with personal imagination, beliefs and expectations. The innovator is the first mover which allows temporary monopoly power and profits, which invites imitators until profits erode and the innovation disappears.

Innovations disturb the economic equilibrium resulting in cycling attempts to restore the equilibrium. Actors are not only individuals, they are also understood as institutions which are defined by Schumpeter as: “*Institutions are all the patterns of behaviour into which individuals must fit under penalty of encountering organized resistance and not only legal institutions (such as property or the contract) and the agencies for their production and enforcement* (Hospers, 2005).” This relationship between innovations and institutions has paved the road for research and theories to analyse the link between institutions and innovative performance with authors such as Coase (1937), Porter (1990, 1998), North (1990), Lundvall (1992); Nelson (1993), Carlsson, (1995), Edquist (1997), Hospers (2005) and Kodama (2015).

The framework presented by Rouboutsos et al. (2013) introduces ‘dependency vectors’ to clarify the linkage between (potential) actors and the supply of relevant complementary actors. In this respect, the Systems of Innovation Approach (SIA) is a powerful tool (Vanelander et al., 2016). ‘Actors’ refer to all identified and active stakeholders interacting in the innovation system. The interactions between actors in the innovation network can fail. In all the basic elements (such as infrastructure), systemic imperfections (or systemic problems) can occur if the combination of mechanisms is not functioning efficiently (Rouboutsos et al., 2011). If so, innovation by actors may be blocked. These systemic failures are summarized by Norgren & Haucknes, (1999), Smith (2000), Woolthuis et al (2005) and Edquist & Chaminade (2006) and here where possible and relevant linked to IWT actors as follows:

1. **Infrastructural failures:** A lack of necessary infrastructure to have a successful implementation of the innovation. Mostly waterway managers, port authorities and terminal owners are linked with these kinds of failure
2. **Transition failures:** The inability of firms to adapt to new technological developments;
3. **Lock-in/path dependency failures:** Business does not look at evolutions outside the sector and only follows what is known, instead of adapting to new technological paradigms. Old habits prevail even if newer, more efficient products or services become available;
4. **Hard-institutional failure:** Failures in the framework of regulation and the general legal system prevent or slow down the innovation which is linked to actors such as governments, port authorities and standardization institutions;
5. **Soft-institutional failure:** The failures in the social institutions such as political culture and social values (i.e. informal institutions) which can inflict all actors within the innovation network;
6. **Strong network failures:** The ‘blindness’ that evolves if actors have too close links and as a result miss out on new outside developments (actors such as ship designers, engine manufacturers and ICT developers);
7. **Weak network failures:** The lack of linkages between actors as a result of which insufficient use is made of complementarities, interactive learning, and creating new ideas. The same phenomenon is referred to as dynamic complementarities’ failure (Malerba, 1997);
8. **Capabilities’ failure:** Firms, especially small firms, may lack the capabilities to learn rapidly and effectively and hence may be locked into existing technologies/patterns, thus being unable to jump to new technologies/business patterns which are not only firms on the supply side, but also on the demand side.

Woolthuis et al. (2005) designed a System Failure Framework (SFF) for innovation policy and used a matrix representation of actors and institutions to identify system failures (Arduino et al., 2013). Rouboutsos et al. (2011) added the stages of development and positive correlations to the matrix representation. This matrix was modified by Rouboutsos et al. (2011) and Arduino et al. (2013) for

port related innovation but can be easily adjusted to IWT innovation. So far this literature review on innovation, offers definitions, typologies and a useful qualitative analytical approach while linking actors and institutions with failure and success conditions (SIA).

2.2.4. Conclusion of innovation literature review

The innovation literature review provides different ways to look at innovation with different definitions and typologies. An innovation is seen within a network of actors, development stages, failure/success conditions or factors that can be shown in a matrix approach. This part of the literature review already gives a limited answer on several sub-questions:

Sub-question	Answer	Source
What is innovation in IWT and what are the main trends?	An IWT innovation is a technological or organizational (including cultural as a separate sub-set) change to the vessel (or IWT service) that either lowers the cost of the vessel (or IWT service) or increases the quality of the vessel (or IWT service) to the vessel owner and is mainly directed at reducing fuel consumption (e.g. improved ship design or the usage of LNG), maximization of scale (e.g. larger ships) or entering niche markets.	Adjusted synthesis between Hekkenberg and Liu, 2017 and Arduino et al., 2013
When is innovation successful or a failure? What are the conditions that lead to failure or to success?	Success: <ul style="list-style-type: none"> • Success if more than 20% adopters of targeted consumer group (plateau of productivity) • “The old is destroyed and replaced by the creation of a new economic structure” • “There is not a clear criterion for evaluating the success of the innovation process. The temporary failure or “not-yet success” may derive from the combination of various categories of key factors” 	Gartner’s hype cycle Schumpeter, 1942; Hospers G.-J., 2005 Arduino et al., 2013 Failure factors, Norgren & Haucknes, 1999, Smith, 2000, Woolthuis et al., 2005, and Edquist & Chaminade, 2006
How can innovation be analysed or measured?	How analysed? <ul style="list-style-type: none"> • Typologies of innovation • Systems of innovation approach • Matrix approach • Pattern recognition Water transport (maritime + IWT) measured by: <ul style="list-style-type: none"> • Number of patent applications • European Community Innovation Survey with micro-economic data on the level of the firm, • But no distinction possible between maritime and IWT. 	Arduino et al., 2013 Edquist, 1997; Edquist et al., 2001 Roumboutsos, 2013 Sys, Vanelslander & Carlan, 2018 Kleinknecht et al., in Andersson et al., 2012 Vertesy and Deiss, 2016 WIPO Statistics Database, 2019 CIS 2016, Eurostat 2019
Who are the relevant actors in IWT innovation?	<ul style="list-style-type: none"> • Actors are not only individuals, they are also understood as institutions • Innovation champion • Actors in port related innovation: maritime sector; ports and terminal operators; shipping companies / container operators; third parties; lobbyists; consultants; shipbuilders; knowledge institutes; EU Funding; Standards bodies. These actors are linked with an institutional environment. 	Schumpeter, 1942; Hospers G.-J., 2005, Arduino, 2013

Table 6: Lessons learned from innovation literature review and answers on sub-questions of RQ

Based on Arduino et al. (2011; Roumboutsos, 2013) and Sys et al. (2016), an overview of typologies becomes now possible that summarizes most elements of other typologies without losing their functionality (Table 7). In this research this line of typologies will be applied on the cases.

Type of innovation	I TECHNOLOGICAL	II TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - BUSINESS CHANGE	III TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	IV MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	V POLICY INITIATIVES (MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE)
Implementation level	Initiation		Development		Implementation
Degree of Innovation	Incremental	Modular	Systemic		Radical
Level of Success	Success		Failure		Not Available

Table 7: Typology of innovation

Source : based on Arduino et al. (2011); Roumboutsos (2013) and Sys et al. (2016)

The actors are fit to innovation in IWT as explained in the methodological Chapter and every case is categorized according to the typologies which makes it more comprehensible to gain insight in the innovation. Categorizing a phenomenon according to its features also provides a framework for the cross-case analysis. For now, several sub-questions of the RQ are answered, but other questions remain.

The following sub-section discusses literature on how to look at policy. This part helps to answer the RQ concerning the role of policy and to understand current developments and basic concepts. How can policy be defined and who could do what?

2.3. Policy literature

This part of the literature review aims at finding answers for the sub-questions of the second part of the RQ. It provides definitions, typologies and perspectives on how to view policy while referring to the paradigm of the New Institutional Economics. It also links the European integration literature with IWT innovation and explains some basic legal concepts that are used in European policy-making.

2.3.1. Public innovation policy

This sub-section deals briefly with the definition of policy, public policy and innovation policy. There are several ways to define policy. First, to make abundantly clear, what policy is not, is politics. Although closely related this distinction is important to make. Politics is part of the policy environment and it influences the inputs and processes that result in the actual policy.

According to Jenkins (1978), a policy is a decision or a set of interrelating decisions that are made by political actors according to objectives and means in a certain situation. Longest (1998) describes policy as guiding decisions that are made in the legislative, executive and juridical branches of government with the purpose to steer or influence actions, behaviours and decisions of others.

Smith and Larimer (2017) state that public policy is an intuitive concept that is difficult to define precisely, but that there is a general agreement that public policy includes the process of making choices. Anderson defines it as the purposive course of action or inaction undertaken by an actor or set of actors in dealing with a problem or matter of concern (1994; in Smith and Larimer, 2017). Furthermore, Birkland (2014) explains why this policy should be called public. All public policy choices are supported by the state which is a broad network of several public actors.

The definition of policy or public policy has no universal agreement and scholars are generally free to adopt their own definition. Policy can be compared with innovation. Whereas innovation aims at an improvement of a service, process or product by adding something new or replacing the old one, policy has similar targets in improving society. Policy is the result of pacifying a conflict between parties or ideologies which include different views on how to improve society and on the actual improvement.

Pacification includes also the use of power in the broad sense and policy makers have much more instruments to implement their policy than the innovator does with his or her innovation.

It is much more tangible to define the field of research in public policy. Studies can aim to evaluate or analyse policy or they could focus on the policy process. Policy evaluation is mostly ex post where researchers try to systematically assess what policy has done. The focus lies then on the outcome and the causal relation between the policy inputs and the consequences of the targeted change. (Mohr, 1995; in Smith and Larimer, 2017). Policy analysis is more ex ante and normative where analysts try to determine what policy should do or what the best policy is (Weimer, 2009; in Smith and Larimer, 2017). In this field concepts such as efficiency and effectiveness are the most challenging to define. The most efficient policy is not per se the most effective in this regard. Some authors attribute policy analysis back to the emergence of cost-benefit analysis (Fuguit and Wilcox, 1999) where governments started to adopt this analytical tool. Studies on policy process focus on how policy is made and observes why certain policy changes and where it comes from.

According to McConnell (2010), a policy can be successful if it *achieves the goals that proponents set out to achieve and attracts no criticism of any significance and/or support is virtually universal*. He makes a distinction between process successes whereby coalitions are successfully forged for the entire time needed for the policy cycle; program success whereby better results are achieved than doing nothing according to the agreed targets; political success that strengthens the perceived reputation of the policy maker for elections; resilient success whereby despite larger opposition than anticipated, the policy survives; conflicting success whereby policy has to solve problems, limitations, delays or substantial controversy followed by reviews and amendments; uncertain success whereby policy is close to failure.

Edquist et al. (2013) define public innovation policy as all combined actions that are undertaken by public organisations that influence innovation processes which also includes unintended policy effects on innovation. Moreover, he states that the objectives of public innovation policy can be economic (e.g. growth), environmental, social, health, defence, etc. An innovation policy intends to mitigate a problem which can be a low performance of the innovation system which he defines as the determinants of innovation processes and the innovations themselves. The choice of policy instruments to solve this problem entails firstly a primary selection of suitable instruments, secondly a customisation of the selected instrument and thirdly an instrument mix of different and complementary policy instruments.

Jaffe and Stavins (1995) make a distinction between three types of policy instruments to address environmental challenges. The first are market-based approaches such as taxes, subsidies or tradeable emission permits. The second type concerns performance standards such as limits for emissions per unit of economic activity. The last type involves technological standards that makes the implementation of an industrial equipment or process mandatory. The last two types are technology forcing while the first one is inducing innovation on the market. However technology forcing policy has the potential to constrain the available technological choices and may remove incentives to improve or to develop new technologies.

Edler and Fagerberg (2017) distinct first three types of innovation policy instruments where policy makers can invest in public production of knowledge in universities or other public organisations especially in research fields where private actors lack incentives to invest but where social benefits are possible. For similar reasons, the state can subsidize R&D in private firms. A third type is the protection of innovation by providing complete property rights. They suggest a broader taxonomy of 15 identified innovation policy instruments such as fiscal incentives for R&D; direct support to the firm; policies for training and skills; entrepreneurship policy; technical services and advice; cluster policy; policies to support collaboration; innovation network policy; stimulating private demand for innovation; public procurement policies; pre-commercial procurement; innovation inducement prices; standards; regulation; and technology foresight. These instruments each have their overall orientation (supply or

demand orientated) and goals such as increasing R&D; skills; access to expertise; improving the systemic capability, complementarity; enhancement of demand for innovation; framework improvement; and discourse improvement. Each of these tools are inspirational for other researchers such as Uyarra and Ramlogan (2016) who studied the impact of cluster policy and Guerzoni and Raiteri (2015) who examined public procurement. According to Guerzoni and Raiteri (2015), most literature on innovation policy is focused on the supply side of innovation where innovative firms can receive tax-cuts or subsidies. However innovation policy that focuses on the demand side is less known but the analysis of innovative public procurement is a growing trend in the literature. Guerzoni and Raiteri developed a quasi-experimental framework and consider policy tools as variables in a condition group and compared with a control group (innovative firms that do not receive support). Their results supported public procurement despite the possibility of hidden variables in the analysis.

Edquist and Zabala-Iturriagoitia (2012) consider public procurement of innovation when ‘a public agency places an order for a product or a system which does not exist at the time, but which could probably be developed within a reasonable period’. This kind of policy could indeed not only provoke an innovation to be developed, it could also inspire private consumers to join. The authors advocate strongly that public procurement of innovation should be part of a policy-mix that comprises more policy tools but without mixing up the different instruments, meaning that a clear distinction should be held.

So far it becomes clear what a policy, public policy and an innovation policy means. The literature on public policy and innovation policy shows a vast set of possible instruments which can be applied in a mix by different levels of policy. Policy can target the supply side with subsidies or tax-cuts for the innovators, but also the demand side where potential innovation consumers could be stimulated to actually buy the innovation (e.g. public procurement could inspire other private consumers; consumer-subsidies; etc.).

2.3.2. Policy tools

Some of the most known economic policy tools to support an innovation, are granting subsidies, enforcing the innovation by new legislation and taxing (fiscally discouraging the innovation). However policy tools can also be used to resist an innovation. Introducing these tools on the market could lead to changes on the supply and/or demand side. The size of this change depends on market structure and price elasticities. As De Borger et al. (2015) describes, taxes and subsidies can be used as indirect price policy interventions. Taxes could be ad valorem (tax on value) or a constant tax for each unit (product or service). It could be preferred by policy to discourage a certain product or service because of a negative impact on society by increasing the taxes and vice versa.

The following figure shows the consequences on the market when policy chooses to change taxes on a certain product or service.

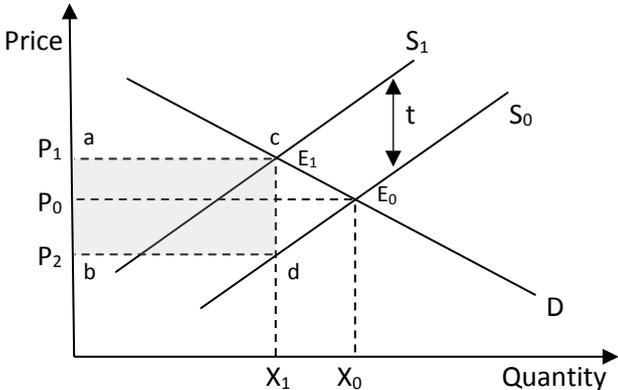


Figure 14: Impact of indirect taxes on the market
Source: De Borger et al. (2015)

The most important impact of the implementation of a tax per unit, is that the supply curve S_0 shifts towards S_1 with a distance that is equal to tax t . After the implementation or increased tax, the producers or suppliers will prefer to produce only the same quantity as before the implementation or increase, if they could increase the price towards the consumer. The shift of the supply curve reaches a new market equilibrium in E_1 against a higher price P_1 and lower quantity X_1 . Consumption is decreased and the market price is increased. Closer examination shows that the taxes are not shifted entirely to the consumer as desired by the producer. The actual price increase is smaller than the value of the tax per unit t . This means that the producer receives less, and that the consumer pays more than before the tax. The net price that is received by the supplier is presented by P_2 . The square $abcd$ shows the tax revenue for the government. The size of the tax shift towards the consumers²⁶, the decrease of consumption and the total tax revenue depend on the price elasticities of supply and demand. In case of a high price elasticity of demand, the tax shift to the consumers would remain limited. The decrease of the produced quantity is then relatively important and determines the size of the total tax revenue.

To summarize, if an innovation is considered negative for society but has benefits from an industrial-economics perspective, policy could decide to levy taxes to prevent too much diffusion, to slow down the innovation implementation or even stop further supply. If an innovation has social benefits but has difficulties to compete or to enter the market, policy could decide to tax the competition. This is also the case at a transport mode level. Taxing road haulage could favour a modal shift depending on cross-elasticities between the different transport modes in relation to the type of cargo.

Another policy tool to support innovation, is granting subsidies. At lower levels such as the national and regional level, subsidies are limited by EU state aid regulation (e.g. De Minimis regulation, EC, 2013a). Subsidies can be understood as negative taxes (De Borger et al., 2015) and have the opposite result of a tax increase. The following figure shows the impact of granting subsidies on the market.

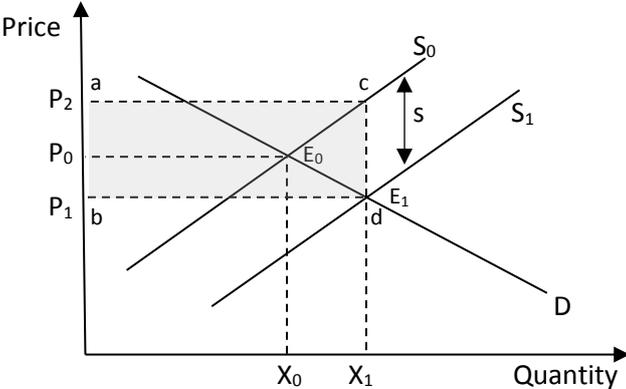


Figure 15: Impact of subsidies on the market
Source: De Borger et al. (2015)

If the subsidy for each produced unit equals s , the production cost reduction would shift the supply curve from S_0 to S_1 . The new market equilibrium is now e_1 and the market price decreases from P_0 to P_1 with an increased consumption from X_0 towards X_1 . As was the case for taxes, the size of the impact depends on elasticities of demand and supply. Subsidies can be given to the innovation producer, such as an engine builder, and/or the consumer, such as the vessel owner. In any case, policy makers should be aware of the possible changes they could cause on the market by implementing these tools and investigate if the benefits are higher than any potential market disturbance.

²⁶ Tax shift refers in this case to the additional tax cost that producers want to internalise in the market price to make consumers pay for it.

The following part views policy as the outcome of the ongoing policy cycle. Lasswell (1956) is regarded as one of the most influential authors in the political sciences. This literature review is of course non-exhaustive and dives only briefly in the work of Lasswell and others.

2.3.3. The policy cycle

Another way to define policy is to view it as an ongoing cycle, comparable with an industrial production process (Crabb et al, 2012). The theory of the policy cycle finds its origin with Lasswell (1956), who introduced this model with several functional components such as agenda-setting, policy construction, decision making and policy implementation. Since Lasswell, others have added parts or made modifications (Jones, 1970; Skok, 1995; Crabb et al. 2012).

For every part in the policy cycle, a vast literature exists, and it is challenging to know where to start in the cycle. The phase of agenda-setting, for example, determines which problems will be targeted for policy and which will be not. The agenda-setting theory with authors such as Lippman (1922) -, McCombs (1972), and Williams (2003), gives more insight in influencers (e.g. role of the media) and decision makers in this stage. Furthermore, the nature of the problem can be decisive, whereby the possibility of short-run solutions and electoral appraisal become important determinants. More intangible issues or issues without sufficient public attention, will have it more difficult to be placed on the agenda. Through every phase, a dynamic network of public and private actors, civil society, knowledge institutions, media, government levels and politicians in power (and those not in power), try to use influence for their interest. The policy cycle is not a linear approach, but an ongoing cycle that targets new emerging problems or even could clean up the unintended affects of former policy.

The policy cycle and its phases are shown by the following schematic of Crabb et al. (2012):

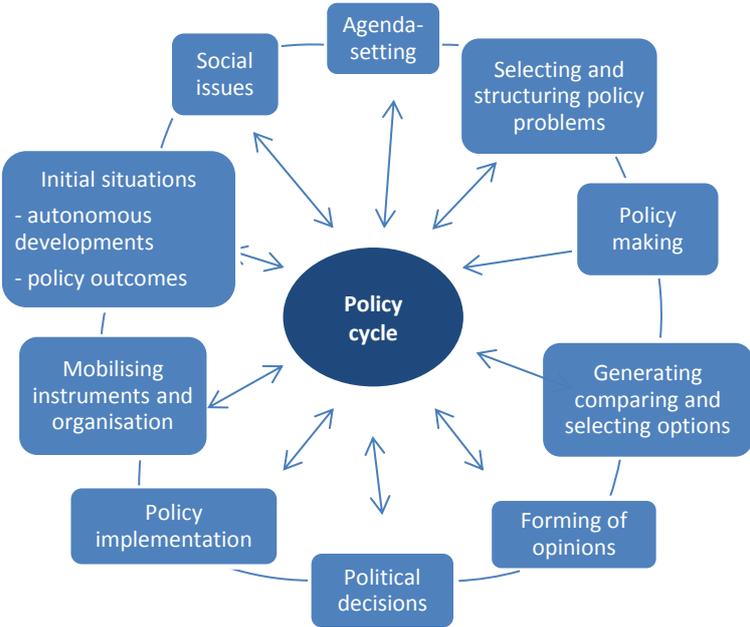


Figure 16: The policy cycle
Source: according to Crabb et al. (2012)

The definition for (public) policy is not that clear-cut as it seems. Furthermore, the policy cycle as presented so far, is rather unidimensional. When several distinctive policy levels are involved over multiple countries, the policy cycle becomes more complex and linked with other policy cycles with other issues that have perhaps nothing to do with the first issue or problem. The mostly political search for balances and political deals goes through every phase in one or more policy cycles and has consequences for other cycles on different policy levels.

The following sub-section discusses briefly the paradigm that significantly influenced and even framed this research. It links the New Institutional Economics, an addition to the more general paradigm of the mainstream neoclassical economics, with public innovation policy. It includes the transaction cost theory and offers a perspective how to view policy through a lens of institutions and what the consequences are for this research. Especially transaction costs explain why institutions change or not and how they relate to policy and economic change.

2.3.4. New Institutional Economics

The New Institutional Economics (NIE) literature comprises a set of analytical instruments from different scientific disciplines and is aimed at the origin of institutions and on their impact on economic performance (Alston, 2008). It adds to the neoclassical framework which defines the central economic problem as the organization and allocation of scarce resources according to Boerger (2016), and it rediscovers aspects of classical political economy. North (1981) considered the neoclassical tools as incomplete and not able to understand long-term change. He turned to transaction costs and institutions as important factors for economic change. The paradigmatic core of neoclassical theory still forms today's economic mainstream in research and education (Boerger, 2016). The NIE offers a framework to view reality as institutions with distinct features.

According to Button (2005), hardly any research has been done concerning institutions such as policy, property rights, conventions, types of contract or authority from a new institutional economics perspective which makes this field rather young. The issue of governance in this context ('institutional arrangements') is really about how those involved interact with each other within a particular institutional environment (Button, 2005). These institutions shape formally and informally social, economic and political behaviour and have an impact through rights on equity and transaction costs. The objective of these institutions is mainly to generate benefits from transactions that stimulate economic welfare (Alston, 2008). These transaction costs are further discussed in the following sub-section.

A. Theory of transaction costs

Authors such as Coase, Williamson and North contributed significantly to this part of the literature. Transaction costs are according to Williamson (1981) "*costs that are made whenever a good or a service is transferred from one level in an organization or a company towards another level where a new set of technological possibilities are needed to finish the product or service*". These costs involve uncertainty, risks, scarce means and limited information of all possible alternatives.²⁷

Transaction costs refer to the exchange of well-defined propriety rights and to the defining process of these propriety rights. Propriety rights are the rights of actors and agents over means of physical, human, financial or intellectual nature which can be traded such as user rights. For a policy maker, transaction costs relate to legal consistency, policy administration, the costs of asymmetric information, evaluation and enforcement costs that occur during the policy making process or cycle.

Coase (1937) discovered that when people search for a good or a service, the searching process generates transaction costs. The process of negotiating and signing a contract also includes these costs. In his book "The Problem of the Social Cost", he develops two scenarios: one with transaction costs and one without. Coase concluded that neoclassical market could only reach efficiency when there were no transaction costs (Coase-theorema). If transaction costs are important, political and economic institutions also become important to manage and reduce these costs to improve welfare (North, 1992). The theory of Coase was related with the theory of opportunity costs. To know the opportunity costs of the other counterparty within a contract, transaction costs emerge. However most of the time, knowledge concerning the opportunity costs of the counterparty is not given. This could lead to asymmetrical information and which provokes relatively high transaction costs.

²⁷ View <http://www.businessmate.org/Article.php?ArtikelId=182> for a broad overview as seen on 17/08/2017

Most of the literature considers transaction costs within the context of a private company. Only a few authors (North, 1992; Ostrom 2011) tried to apply the transaction cost theory on public goods and services. They identified internal transaction costs such as administration costs, legal consistency costs (where legislation must be consistent with supranational legislation and of legislation on the same level in other domains) and asymmetrical costs within public administrations in dealing with other policy areas or even on the micro level between heads of policy departments. Enforcement costs are also an example of public transaction costs. North builds further on Coase and makes a distinction between institutions and organizations while explaining institutional changes. These changes one of the reasons why any attempt to define an optimal decision level can be problematic and challenging. Literature in how to quantify transaction costs applied on public actors was not found.

The following part defines the reference to institutions and organisations in NIE, next to institutional changes. It dives briefly in some examples of transaction costs related to public goods and services such as the problem of the principal-agent and compliance costs which could be interesting to explore for the purpose of the second part of the RQ. Can transaction costs be important determinants in assessing policy and answer what a policy should do or not do to stimulate or to resist an IWT innovation?

B. Institutions and organizations

Institutions are a set of formal and informal limitations such as social conventions and behavioural norms and the characteristics of each limitation. Institutions are the structure where people correspond to when interacting with others. Institutions are shaped in such a way that they reduce uncertainty by structuring human behaviour, but they do not guarantee efficiency (North, 1992). If institutions are the rules of the game, organisations are the players or actors in the same game. Organisations are a group of individuals that are committed to common actions. The objective of an organization can be profit maximisation, winning an election (e.g. political party), regulate the economy (economic policy), teaching students (e.g. university) and so on.

C. Institutional changes

The ongoing interaction between institutions and organisations in an economic reality of scarcity and competition, is the main incentive of institutional changes. Institutions are in this sense also subject to changes in their environment. These external changes have an influence on the effectiveness of institutions and organisations to achieve their objectives. Institutional changes are then a way to survive institutionally. Institutional changes evolve gradually or incrementally. These changes are often unconscious, and individuals develop alternative behaviour patterns that are more consistent with their changed perception on costs and benefits (North, 1992). Institutions can be quite stubborn to change because changes generate significant transaction costs.

D. Principal-agent problem and moral hazard

As explained by North (1992), regulation is a contract whereby a regulator has the dominant position and presents itself as a principal towards agents such as companies, lower level regulators or organisations and individuals that must comply to the regulation. All types of contracts are submissive to transaction costs and are therefore usually equipped with mechanisms to prevent that agents would refuse to honour the contract (Feiock, R., 2008). The principal has trade-offs when choosing to produce the regulation by itself, to transfer the competence to agencies or to decentralise to lower levels of policy. In Coasian terms, this would mean that transactions that bring along relatively high negotiation costs, are not transferred. The agent could benefit from cooperation with the regulator but also could decide not to cooperate and by doing so the transaction costs of the regulator increases. All levels of government have their own agenda such as re-election. Negotiations between policy levels are implicitly determined in the political economy by the maximisation of the chance for re-election against a minimum political transaction cost.

The principal-agency relationship is according to Moe (1984) influenced by the phenomena of adverse selection and moral hazard. A relation that is defined by repeated asymmetrical information, where one contract party has more strategic information than the other, is not sustainable and could lead to moral hazard. Information is asymmetrically divided between the agent and the principal, but the adverse selection is in favour of the agent that has more knowledge than the principal. The information is used for the own benefit of the agent and only second for the common good. This behaviour of the agent relates to the moral hazard. The following example which is relevant to innovation explains this more clearly. An innovator tries to achieve success and to diffuse its innovation on the market and creatively destroys or pushes away the old dominant player on the market. The regulator confronted with the new market player, could find it necessary to adjust existing standards or create them to improve regulation or standards on the market. The innovator in this case is the agent and could provide the regulator with their best practices to convince the regulator to adjust the regulation accordingly. The agent has the moral hazard in lobbying for its own interest by advocating new standards or adjustments that would make it more difficult for other potential innovators to come on the market. The regulator could be not aware of this (asymmetrical information) and how more technical and complex innovation becomes, the easier it is for experts to fool government. To avoid this, standards and regulation should be universal neutral. Otherwise, the principal might become perhaps unwillingly and unconsciously, an obstacle or failure factor for any future innovation.

Another example of adverse selection can be observed in insurance. When mostly ill people would buy a health insurance, the premium increases, also for people with low risk until they leave the system and the premium increases again. The insurance company in the latter example does not know all the information about their customers and chooses to select adversely the customers according to their personal health risk profile.

The following paragraph explains compliance costs as transaction costs. In IWT vessel owners must comply to all sorts of regulation such as technical requirements.

E. Compliance costs

Compliance costs are generally known as costs that are made by the agent (company, organisation, etc.) because of regulation or other institutions (the principal). These rule conformity costs are the costs an individual must make in order to adapt to new regulation. Emission standards are an example of such contract between agent and principal whereby the agent will have to comply and pay for investments and transactions in order to avoid enforcement or higher transaction costs such as penalties. It is also a benefit to avoid compliance costs by taking the risk that the principal will not find out the deviant behaviour (which is an example of moral hazard). The transaction costs related to enforcement of the government increases by more inspections, monitoring or more river police. However on the level of the public organisation compliance costs also exist. Especially in multi-level policy, a significant part of the policy process is spent on checking compliance of created legislation with other legislation from other, usually higher, levels of policy. These type of transaction costs can emerge on the side of the regulator but also inside a private organization between departments, teams and even between individuals.

Compliance costs can increase because of:

- posing blurry and unclear or even incompatible policy objectives that require higher compliance costs to solve this;
- a lack of policy quality because of too selective use of evaluation, incorrect assumptions of policy makers, incomplete information, usage of outdated data;
- when stakeholders are not involved in the drawing of the policy or committed enough to the policy objectives, their effort will be small.

For now, it is important to understand the transaction cost theory and where it is rooted in. Transaction costs will return in the SIA, CBA and policy analysis in this research. The following part gives a brief

overview of European integration with specific attention on cross-border externalities (including transaction costs) as a reason for integration.

2.3.5. European integration

In *Europeanization and the Weakening of Domestic Policy Concertation*, Fontana (2014) studies the impact of transferring national competences to the European level on national decision making. She focuses on the behaviour of special interest groups and policy actors within a cooperative policy model. The term Europeanization is frequently used in literature, but there is no generally accepted definition. A narrow definition refers to the domestic impact of Europe (Börzel et al 2006: 485; Fontana, 2014:36) in most cases of the EU. Europeanisation is more a process instead of a result or a cause (Exadaktylos et al, 2009; Lenschow 2006; Fontana, 2014:36). This process happens top-down and bottom-up. Individual Member States (MS) could decide to take part in this process or not. MS have the right for opting-out EU legislation and could even leave the EU (e.g. UK).

A more economic approach is pursued by Pelkmans (2006). In his book *European Integration, methods and Economic Analysis*, the economic analysis of economic integration is combined with the different integration methods that are applied in the European Union. Pelkmans focusses on the conditions that are necessary to achieve within robust legislative and policy frameworks. Conditions that are needed to be able to design different intensities of economic integration. He claims that an economic analysis that is based on the principle of subsidiarity results in a framework that contains information about the public economic functions of supranational organisations such as the EU. European integration in this sense, means the removal of economic barriers between two or multiple economies. Integration combines different economies to one whole, with a possible increase of competition and a larger variety of goods and services, lower prices, larger production- and distribution systems. Collaboration on the European or supranational level could decrease costs (for private and public actors) by creating a larger scale of economy. Common standards that are legit and support efficiency and effectiveness (Pelkmans, 2006) level the playing field within this larger scope of economy.

Through a micro-economic lens, European integration relates in a certain sense to economies of scale which dates to Adam Smith (1776). Economies of scale are the cost advantages that organisations get when production quantity of one product increases because of the increased scale until the average cost of each produced unit decreases. It also relates to economies of scope whereby the average cost of a company's production decreases when there is an increasing variety of goods produced (Nickolas, 2019). It could be more efficient for several products to use the same resource inputs than each separated.

By combining scarce resources from MS to a higher level, higher investments can be done which could result in a larger production of policies or just one larger policy until the optimum design point is reached where costs per additional policy begins to increase. This could be cheaper than having a similar policy developed on each level. The possibility to use more means to produce a larger policy could result in larger benefits as the policy scope increases then on the MS level while using similar inputs. A disadvantage lies in the lack of more customized policy to the preferences of individuals. Indeed, following the principle of subsidiarity, creating a larger public policy to a larger scope on a higher level, could lose important information concerning the preferences of individuals, consumers or in this case citizens. Under assumption that a local policy level or organisation will have access to more information concerning the preferences of its citizens, then a higher level. Not only space or public level is an important determinant, also the time dimension. Local organisations will need less time to adjust their policy production to changing preferences of its citizens. Although, this might be true, at the end, the benefits of a successful higher policy level should outweigh its costs such as the explained information loss.

The EU framework is determined by the *Acquis Communautaire* (all EU regulation and case law) and all policy actions are aligned by this *Acquis*. Without going too deeply in the working of the European

Union or other supranational organisations, it is relevant to know that the European Commission which can be considered as a sort of executive branch, has no right to have European taxes and depends for its income from the MS. Furthermore, the European Union divides competences between MS, the Council and the European Commission and has a multi-level policy model which is explained in the following sub-section.

2.3.6. Multi-level and multi-layered pan-European policy

“Multi-level” refers to all policy levels and their interdependent relations. “Multi-layer” refers to the different layers in each of the levels. A core layer is the executive branch of the government level such as the European Commission. Other layers are the juridical and legislative arenas on the same level such as the European Parliament and the Council. Every level has five core dimensions which cut through each layer of policy (Osofsky, 2011):

- Horizontal: on all levels there is an equal parallel actor with other competences but with possible influence on IWT e.g. every Member State has an environmental minister next to the minister of transport.
- Vertical: the top-down approach of a higher level towards the policy level that lies beneath (e.g. precedence law of the EU)
- Direction of hierarchy: refers to the origin of power in policy issues. On the same level or layer, the direction of hierarchy focuses on who is in control and the direction in which that authority flows.
- Cooperativeness: assesses when key individuals and institutions cooperate, when they are in conflict or when they choose not to cooperate at all
- Public – private: in both regulatory process and private initiatives, the governmental regulator and the corporations involved in it hold intertwined roles that complicate policy

All these dimensions demonstrate multi-actor interactions between institutions and can be identified in all levels and layers of policy²⁸.

The technical nature of innovation adds to the complexity of the public-private dynamics in every layer, dimension and level of policy. If an innovation is presented in one policy dimension, layer or level, the inter-institutional dissemination of this knowledge is not necessarily optimal. The innovator will often repeat his or her presentation of the innovation at different levels sometimes towards the same experts.

All these levels are assumed to have shared objectives concerning the welfare of society. The economic analysis of a multi-level policy can help identifying the conditions to transfer competences from one level to another (if needed). The functional application of these conditions is limited by the political willingness to transfer which does not always correspond with an economic rational. The starting point of the economic theory of multi-level policy rests in the key question if centralization or decentralization of a public function would improve welfare. Pelkmans claims that a complete centralization would be suboptimal and therefore federal states rather decide to decentralize. In the context of Europeanisation or integration, the same reasoning relates to centralization.

There are according to Pelkmans four main differences between a federal state and European integration:

1. The political logic of a growing economic integration differs with the logic of decentralization within a federal state. The political costs of transferring competences towards more economic or institutional centralization can be quite significant;
2. The degree of finalization of the internal market must be political acceptable before the application of the principle of subsidiarity makes sense;

²⁸ an interesting paper highlighting the 5 core dimensions in a clear manor is Osofsky, Hari M. (2011)

3. The EU has no right to levy taxes, to have an army, nor does it have a single currency in all Member States;
4. The EU has no real central government.

In the view of Pelkmans, transferring competences are not a one-way stream. If an economic rationale is proven that a policy could be more optimal on a supranational level, it could centralize and vice versa. According to Pelkmans (2006), a full centralisation is suboptimal because of the following reasons:

- Welfare improvement relates to preferences. If a representative democracy fails to understand the preferences of its citizens, a lower level of policy can be a better option. When voters are close-by, preferences could be easier read. However the closer the policy maker is to voters, the more information is lost from other more distant areas such as regions, countries, cities, etc. This principle of adjacency implicates that there are no interdependencies between areas but which is not realistic;
- There are strong connections between areas which are expressed by cross-border policy. In order to reduce costs in tackling a cross-border externality, lower policy levels could decide to cooperate with each other. A higher level of policy could do the same perhaps with less information but with more means. There are different forms possible on all levels and with all levels to create policy. These forms can be structural, ad hoc, temporary, formal (even informal), and could be centralized or decentralized, bilateral or multilateral. Every form has its own cost-benefit ratio.

Nevertheless, cooperation between levels or centralization towards a higher level has advantages to tackle cross-border externalities and there are also other reasons why centralization could be an option. Pelkmans identifies following scales of advantage such as uniformity of community law and more resilience against macro-economic shocks. However disadvantages or higher costs are related to the loss of information of individual preferences. When these preferences are homogenous (which is often not the case) at the European level, this could advocate centralization against a relative low cost. To respect and to keep political support and legitimacy, Europeanization needs to be checked according to principles of proportionality and subsidiarity in respect with the differentiated preferences of citizens in all MS.

Another way of integrated policy is by mutual recognition which is more a method to create one single market that is situated on the level of the Member States or between European institutes by mutually and equally recognizing their national legislation and/or policy aiming at the same targets, by which the system of mutual recognition adds to one internal market. The EU, DC, CCNR and other public actors use the system of mutual recognition of equivalence of Rhine, Danube and Community boat master certificates, service record books and radar certificates between Romania, Hungary, Czech Republic, Slovakian Republic, Austria, Poland (excl. radar) and Bulgaria in the absence of one uniform training or regulated examination. In the system of mutual recognition, there is no need for one harmonized regime that gives a detailed set of regulation for all countries. Between countries and between institutions, it could be accepted that the suitable comparable quality standard is met under different policies.

It is important to understand that the EU is not a real state. As said, it does not have the right to levy taxes, but it is also not allowed to offer public goods such as an army and a juridical system to enforce basic civil law (police service) as a state does. To address market failures, a government has several tools such as subsidies, regulation and even nationalization. The EU only has mainly regulation and subsidies for different fields such as research, innovation, agriculture and fishery. Nevertheless, the (innovation) policy mix in this perspective has become multileveled (Magro & Wilson, 2013; Lanahan & Feldman, 2015) which requires extra transaction costs to govern instruments from different levels of policy. As Pelckmans explains, the European integration takes in account legal concepts such as subsidiarity and proportionality which are briefly defined in the following sub-section.

2.3.7. Subsidiarity and proportionality

In determining the 'right' policy level in European integration theory two legal concepts are important: subsidiarity and proportionality. Subsidiarity suggests *that a higher level of policy should be involved only if it is better suited to solve the problems than lower-level policy*. Following this definition, the lower policy level comes first and if that does not work, higher level of policy can take over. However this hierarchal approach contains rather a political decision and not an economic one. The definition of subsidiarity can therefore be interpreted from a broader perspective (Pelkmans, 2006). Pelkmans defines subsidiarity not as a one-way stream but looks for the most efficient level to tackle externalities in case of centralization or decentralization with a more neutral perspective on both.

The policy problems or externalities at different levels differ and relate to the competences of each level. Furthermore, policy success depends on transaction costs such as compliance, legal consistency, enforcement, coordination, etc. By whom and how these externalities should be tackled is included in the European Treaty of Maastricht (art.5): "Art. 5 (3) Under the principle of subsidiarity, in areas which do not fall within its exclusive competence, the Union shall act only if and in so far as the objectives of the proposed action cannot be sufficiently achieved by the MS, either at central level or at regional and local level, but can rather, by reason of the scale or effects of the proposed action, be better achieved on the Union level. The institutions of the Union shall apply the principle of subsidiarity as laid down in the Protocol on the application of the principles of subsidiarity and proportionality." (European Treaty of Maastricht)

Subsidiarity suggests that a policy should be executed on the level that can offer the most effective and efficient way to solve a problem or externality. Multileveled policy provides policy arenas where institutions compete in search of power (Portuese, 2010). It is generally accepted that the lowest policy level is the most efficient because of better and faster access to voters' preferences and if proven inefficient, higher levels of policy gain initiative. Proportionality checks if the allocated means for conducting the policy are proportional according the policy objectives (Emiliou, 1996) or if the costs are proportional towards the benefits.

The costs and benefits of a differentiated or fragmented policy could be higher than the costs and benefits of a centralized supranational policy. The legal concept of subsidiarity gives priority to decentralization but in the theory of multilevel policy, this principle is rather an allocation rule of competences. It can be used to enable the design of the institutional setting from a bottom-up or top-down perspective. The linkage between these legal concepts and costs/benefits in innovation policy is interesting but evidence is rather lacking in literature. Which is true for the specific field of innovation in inland navigation which has a specific multilevel policy with the existence of river commissions and even the Pan-European dimension of the UNECE as explained in Chapter 4.

The following sub-section summarizes the findings the policy literature review and explains the relevance with this research.

2.3.8. Conclusion of policy literature review

The policy literature review shows definitions for a public policy in innovation within a multilevel policy emerged from European integration. It sets the scene of the developed policy analysis in this research and offers more insight in legal concepts such as subsidiarity and proportionality. It also shows that there is a gap in literature concerning the New Institutional Economics view and the transaction cost theory when it is applied on public innovation policy in Europe and especially on IWT.

No attempts to quantify these transaction costs within public innovation actors were identified which questions if this is possibly and how this can be done. (Pan-) European Public innovation policy shows a multilevel policy mix with different policy tools such as public procurement (Guerzoni and Raiteri, 2015) which still lacks robust empirical evidence. The paradigm of neoclassical economics with the addition of NIE offers an understanding of the setting of the SIA and CBA. In this sense the SIA failure

or success factors can also be viewed as institutions. The later policy analysis in this research is also developed within this paradigm.

The second part of the RQ and its sub-questions can be partially answered (Table 8).

Sub-question	Answer	Source
<p>What is (IWT) innovation policy, how is it organized and which role plays the IWT innovation policy?</p> <p>Which policy measures are applicable for IWT?</p>	<p><i>Public innovation policy are all combined actions undertaken by public actors and their networks (including private actors) with objectives than can be economic, environmental, social, etc., and aims to stimulate, facilitate, participate and / or even lead or enforce innovations towards success (or failure in case of an unwanted innovation) and to improve the innovation system in both produced quantity as quality while following a cyclic policy path and using policy instruments that could target both demand and supply of innovation.</i></p> <p>Refers to public policy and is multilevel, nonlinear, cyclic, subject to European integration (subsidiarity and proportionality) and is here defined following the NIE addition to the neoclassical economics paradigm as a network of public actors which include institutions and organisations with each their set of transaction costs. Transaction costs refer to compliance, enforcement, coordination and can be increased by asymmetric information. Lack of literature concerning transaction costs in public organisations such as policy, property rights, conventions, types of contract or authority, legal consistency, policy administration, the costs of asymmetric information, evaluation and enforcement costs. Multileveled policy provides policy arenas where institutions compete in search of power. Has a potential benefit when effective: scale of economy; level playing field, internal market.</p> <p>Instruments such as investing in knowledge centres; subsidizing R&D in private firms; protection by complete property rights; public procurement; cluster policy; Training and skills; standards & regulation; innovation inducement prices</p> <p>EU has no right to levy taxes, nor does it have a single currency in all its Member States, or a central government.</p>	<p>Policy definition developed from Edquist et al. (2013); Birkland (2014); Smith and Larimer (2017); Lasswell (1956); Crabb et al. (2012) Magro & Wilson (2013); Lanahan & Feldman (2015)</p> <p>Reference to NIE: Alston (2008); Coase (1937); Williamson (1981); North (1992); Ostrom (2011)</p> <p>Portuese (2010)</p> <p>North (1992); Ostrom (2011)</p> <p>McConnell (2010)</p> <p>Weimer (2009)</p> <p>Button (2005)</p> <p>Pelckmans (2006); Fontana (2014);</p>

Table 8: Conclusions policy literature review and answers on sub-questions of RQ

After reviewing the policy literature, the following section defines briefly the origin of the SCBA and discusses relevant findings from literature.

2.4.Social Cost-Benefits Analysis literature

SCBA finds its origin in welfare economics and became more popular within the mainstream neoclassical economics, whereby impacts of a change such as an infrastructure project or an innovation is described by using monetary values. This tool finds its way at almost every policy level to inform politicians and policy makers about what ought to be done, in what one should invest, and which costs and benefits could be taken into account. As the research shows, a complete SCBA is very challenging. Depending on available data or other constraints, sometimes only a CBA is possible. The difference between CBA and the SCBA becomes clear further in this research, but the SCBA gives an important framework for the development of the CBA.

2.4.1.Origin

In 1844, Dupuit published “De la mesure de l’utilité des travaux publics” which can be considered the first SCBA (Blauwens, 1986). SCBA gained importance after WWII. Nowadays, this method is popular for analysing infrastructure projects and for organizational, system-, managerial or technological changes such as innovation. SCBA is a decision-making tool that is frequently used by people such as

planners, project managers, investors and policy makers. The tool gives insight on the potential outcome of an investment. It is not only useful to calculate the potential private revenue over the life-span of an investment but also the impact on society.

Within an SCBA, the analyst can use different tools such as sensitivity and probability analysis (Makowsky et al, 2009; Misuraca, 2014:4). The most common are:

- *Engineering Estimate*: From a bottom-up approach, costs and benefits are calculated as detailed as possible. The cost can be calculated of every production unit in a similar way as other cost elements such as the needed labour. Every cost is accounted in order to calculate the net present value of a project (NPV).
- *Parametric Modelling*: From a top-down approach, statistical relations are identified using historical data. The estimation is based on experience (Misuraca, 2014). Regression analysis can be used within a parametric model to look for significant relations between an independent variable and the costs of a dependent variable.
- *Delphi method*: Through an anonymous questionnaire, experts could frequently be asked to give cost estimations. Within the results a consensus is reached by applying statistical methods by judging the most frequent returning value.

Whenever effects on the project could not be expressed by money, the effects need to be mentioned separately and kept outside the cash flow analysis and explained. For the developed CBA in this research, a bottom-up approach is used (engineering estimate).

An SCBA can be performed ex ante or ex post. Although there is a degree of contamination in literature according the correct abbreviation whereas some authors refer to a CBA instead of a SCBA although they take in account externalities²⁹. Because of the fact that in the examined cases it was not always possible to identify all relevant costs or all beneficiaries/losers of the innovation and with the chosen approach to view the innovation from vessel owners' perspective and less from a social perspective, although externalities are taken into account, the term CBA is more appropriate to use in this research.

The *Leidraad voor kosten-batenanalyse* (roadmap for CBA) of the Dutch Ministry of Transport, Waterways and Economy (Eijgenraam C. et al, 2000:43-50) gives a very useful overview of all steps that can be taken. Another source is the European Commissions' Guide to Cost-Benefit Analysis of Investment Projects, Economic appraisal tool or Cohesion Policy (2015). The European Commissions' guidelines refer to economic performance indicators such as net present value (NPV), the economic rate or return (ERR) and Benefit-Cost ratio (B/C ratio). A positive economic return shows the society is better off with the project; the expected benefits on society justify the opportunity cost of the investment (2015: 18). Since its origin, the SCBA has grown from a framework focusing on out-of-pocket cost towards including external costs (as explained in 2.4.2.B.). Not only direct effects on the investor (in this research the innovation consumer) should then be examined but also all those who are affected by the investment (directly and indirectly). The following part explains further how to view costs and benefits.

2.4.2.Perspectives on costs and benefits

Costs are related to production factors that are derived from the economy, the society and/or the environment. The costs express the willingness to pay of those that are willing to provide the production factors. Not only direct costs are considered but also opportunity costs concerning irreplaceable production factors. Means that are used for one project cannot be used for another. Costs have a negative impact on welfare.

The benefits represent the products or the added value of the project or policy and express the willingness to pay of those that profit from the project or policy. The benefits are the monetarized advantages of the project or policy (Blauwens, 1986). It is possible to transform costs into benefits and

²⁹ De Langhe (2019) addresses this topic in more detail.

vice versa by changing the symbol, but in this research, costs contain all effects of the investment that require welfare resources. The benefit side of the project contains the effects on welfare by delivering the added services or products which are the reason of the project. If a cost has a positive aspect or a benefit a negative one, they remain at their side but with a negative symbol (Blauwens, 1986:170-188). The area under the demand curve shows the benefits of the project or the total willingness-to-pay for the demanded products or services in a perfect economy (Figure 17). The supplied quantity is represented by x and the price by p .

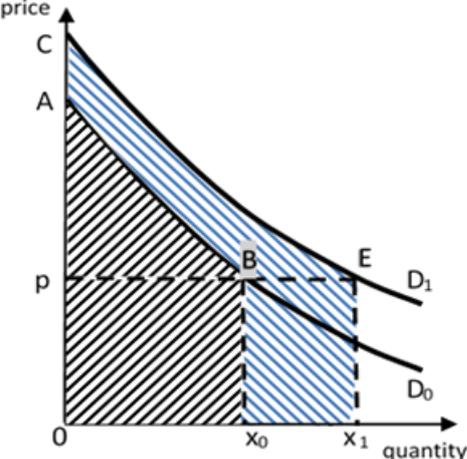


Figure 17: Benefits and demand curve
Source: Blauwens (1986)

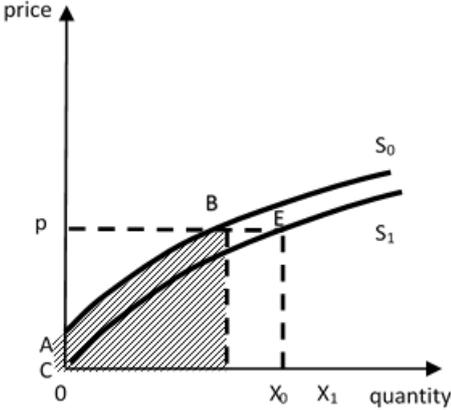


Figure 18: Costs and supply curve
Source: Blauwens (1986)

The benefits are comprised by two parts: total revenue ($pB0x_0$) and the consumer surplus (pBA). The latter is the difference for every unit of quantity between the marginal willingness-to-pay (expressed by the demand curve) and the paid price p . This consumer surplus refers to the value that consumers pay under the real value of the product/service (based on Blauwens, 1986). The original demand curve is D_0 . Because of the quality improvement of the product or the service (e.g. because of an innovation), the demand curve shifts to D_1 . If the price stays at p , the demanded quantity will increase from x_0 till x_1 . The benefits of the quality improvement are expressed by the area $CABx_0x_1E$, which equals the increase of the consumer satisfaction (based on Blauwens, 1986).

The costs are expressed by the area under the supply curve in a perfect economy. Figure 18 shows the costs area $OyAB$ with a supplied product or service quantity equal to y and sold against a price p . The global willingness-to-pay or the quantity that the market is willing to sell, is marked by the shaded area under the supply curve, which is smaller than the total expenditure $OyBp$. This shaded area should be corrected by the factor surplus (area Abp) to find the cost calculation from a society's welfare perspective. For both the demand and the supply curves, the function can be assumed linear, which makes the calculation easier, but more curved lines are closer to reality. The following parts identify costs and benefits that are commonly found in a SCBA.

According to Arduino et al. (2010, as cited from Aronietis, 2013), the distinction can be made between two perspectives on costs and benefits:

A. Industrial-economics perspective

From the point of view of the customer of the innovation or the innovator following equation is derived:

$$\Delta R_p - \Delta C_p$$

With R_p = private revenues (before innovation) and C_p = private cost (before innovation) and logically: ΔR_p = change in private revenues as a result of innovation and ΔC_p = change in private costs as a result

of innovation. In this case the producer or service provider is interested in innovation that reduces costs or improve the quality or quantity of the product/service. The supply curve shifts to the right.

B. Welfare-economics perspective

From the point of view of society, as mentioned in Aronietis (2013), following derived equation shows the impact on society:

$$\Delta B_s - \Delta C_s$$

With s representing society, B_s the benefits for society and C_s the costs for society before the innovation and with ΔB_s representing the change in social benefits as a result of the innovation. The demand curve shifts to the right, showing the consumer surplus or benefits for society.

Subsidies or other policy tools to stimulate innovation have impacts on market and price setting. For instance, if a policy decides to invest in a new type of vessel for freight transport, this vessel will compete against other market players. Without compensation (S_s), this policy intervention will endure resistance for this 'unfair' competition.

Resistance from other operators can be expressed by disrespecting waiting time at locks, disadvantaging the innovated and subsidized vessel and in the worst scenario by completely blocking a lock or canal. However the latter method has only been seen so far in times of perceived (by most of the sector) crisis and not so much towards subsidized innovation.

Subsidies for one mode such as railways can also disturb the competition between modes. The benefits for society can be considered high enough to continue even with a market disturbance. A policy-driven innovation is usually accompanied by a subsidy S_p .

For an innovation to succeed, in general, following relations should be respected³⁰ in case of subsidy S_p or compensation S_s .

$$\left\{ \begin{array}{l} \Delta R_p - \Delta C_p + S_p > x \\ \Delta B_s - \Delta C_s + S_s > \gamma \end{array} \right.$$

If an innovation is not attractive (insufficient x) for a private innovator to continue, but γ is considered high enough, the low revenue or loss of the private innovator can be (over)compensated by the subsidy S_p in order to proceed with the innovation. If x or γ equals to zero or even negative, there is no incentive to continue. The threshold x or γ depends on the preferences of the innovator, the investors or the policy makers.

The innovation path shows the conditions in which costs and benefits determine the failure or success of the innovation for both private and/or policy driven innovation. This is shown in Figure 19.

³⁰ Aronietis (2013) focuses on policy driven innovation and mentions also hybrid forms between policy and privately driven innovation. The hybrids are not mentioned here.

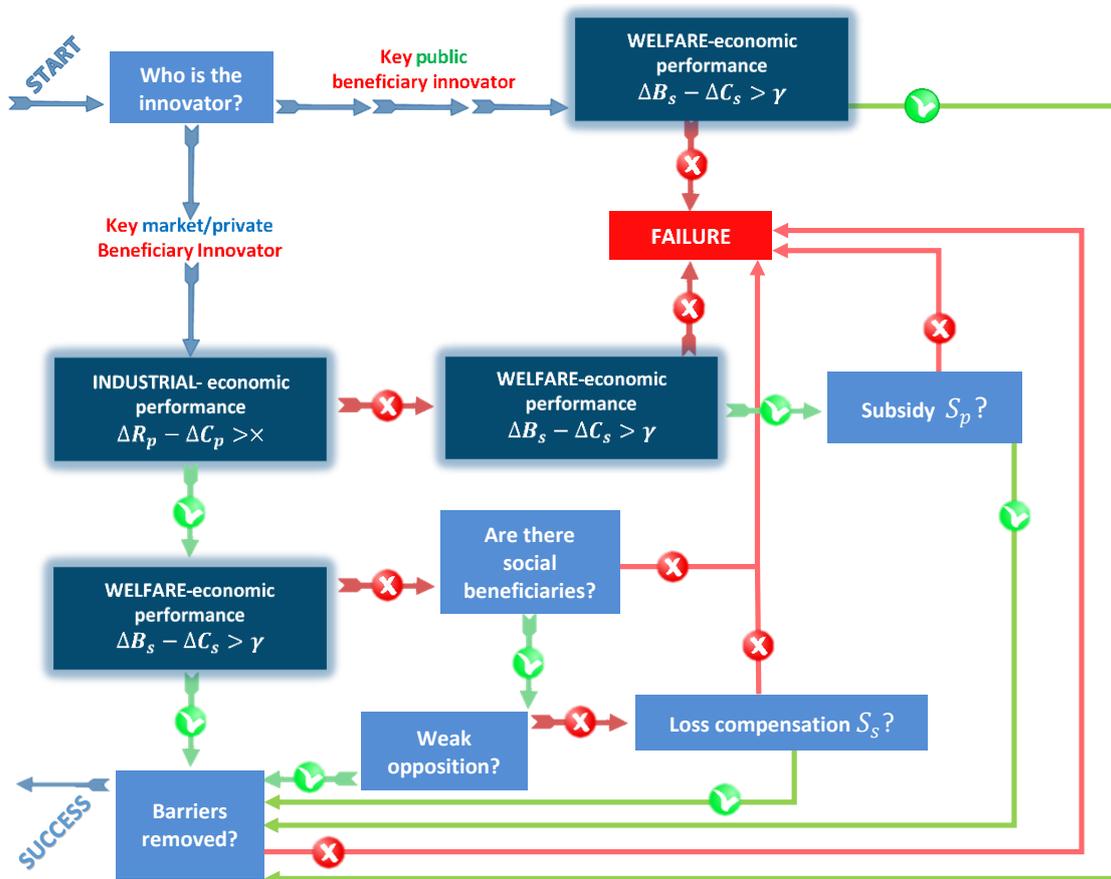


Figure 19: Path to innovation success
Source: based on Aronietis (2013:51)

If the key innovator is public, there could be less focus on private revenue. The benefits for society could be considered higher than the identified costs, but barriers could still possibly arise during the innovation path. Private players can resist a public innovation because of expected negative impacts such as unfair competition or other market disturbance.

A public innovator should also be aware of success and failure factors such as identified in the SIA. If there are losers, societal resistance can grow against public innovation. The public innovator can therefore choose to compensate the losers, to ignore them all together or to abandon the innovation path. Both the public and the private innovator must deal with possible barriers. For the calculation of the equations, information is needed for the private revenues of the innovator ΔR_p , its costs (ΔC_p), the social benefits (ΔB_s) if any, and the social costs (ΔC_s).

In this research the path to innovation success (Aronietis, 2013) gives a perspective on the application of the CBA on the innovation cases and the policy analysis. The consequences of the schematic can argue in favour of policy support or not. The following paragraph explains that a positive net result is not necessarily an indication to proceed with the innovation. It shows that both the innovator as the public actor prefer are sufficient threshold to be satisfied.

C. Possible situations of public and private innovations

The thresholds as described, determine the outcome in several scenarios. Table 9 shows a private innovator that has a return on investment that is higher than threshold x , but from a welfare-economics perspective the threshold γ is not reached by the innovation. This could be the case of innovation that improves productivity but threatens safety and could therefore lead to more accidents. The innovator could choose to compensate victims in case of an accident, pay higher salaries with risk premiums or introduce supportive safety measures to reduce the extra accident risk. Policy makers could also decide to forbid the innovation if social resistance is too high for the offered compensation.

	$\Delta R_p - \Delta C_p$ with x as net result ³¹	$\Delta B_s - \Delta C_s$ with y as net result	description
Private innovator	$> x$	$< y$	Private actor has high enough positive net result but at a too high external cost. Innovator can compensate society or face policy resistance, but will try to continue
	$< x$	$< y$	Not enough positive net result for innovator and for society. Innovation will probably fail.
	$< x$	$> y$	Innovator does not receive sufficient profits, but there are enough benefits for society. Policy can decide to support this innovation by a subsidy S_p otherwise the innovation will fail
	$> x$	$> y$	Private innovator and society benefit. Innovation will likely succeed.
Public innovator		$> y$	Welfare benefits, public innovator will continue. Innovation likely succeeds if no other barriers
		$< y$	Welfare benefits are too low or even negative. Innovation will probably fail.

Table 9: Possible situations of benefits and costs between private and public innovators
Source: based on Aronietis (2013)

Although, this approach is very appealing by its simplicity and comprehensibility it does not avoid any subjectivity. Indeed, the height of the preferred x or y is not always given and significantly influenced by the behaviour of the public or private innovator. The private innovator is generally considered to act as a rational economic agent according the neoclassical rules of supply and demand, but the public actor is more subjected to the policy cycle which is whirling with a political rational. The estimated and the preferred y at the beginning of the innovation can change during the policy cycle, where former deals between the innovator and policy can become uncertain. The innovation even leads to failure if policy uncertainty or inconsistency influences the appraisal of the welfare-economic function.

The following parts give an overview of possible private and external costs which can be counted as social costs. The private costs do not need much explanation as they are quite straightforward.

D. Private costs

Private costs for an innovation can be split in basic categories and in sub-categories:

- Investment
 - Technological, managerial and/or research
 - Design prototype, planning and development
 - Capital: laboratory/equipment, plant, machinery, land, building, construction site
 - Business analysis: e.g. customer/end user survey, publicity
 - Compliance
 - Fees for compliance agents, checking formal standards
 - Safety tests (e.g. type-approval), feasibility studies
 - Compliance to complementary products/services
 - Internal resistance
 - Appeasing internal stakeholders in business cycle
 - Convincing management (if needed)

³¹ The innovator can decide to aim at a higher threshold than 0 for x or y in order to decide. For society $x = 0$ as net result can also be defensible but a net result achieving 0 is rather theoretical. In most cases C and B are not equal. For reasons for simplification, 0 is here used as threshold.

- Yearly operation and maintenance
 - Quality control: evaluation and problem analysis
 - Personnel: salaries
 - Energy
 - Equipment
 - Storage
 - Repair
 - Management
 - Administration
 - Insurance
 - Waste disposal
 - Emission charges (if any) and taxes
 - Information or technology: e.g. upgrade of software
 - Compliance by changing policy: e.g. technological standards

The following part explains external costs that together with the private costs form the social costs of an investment.

E. External costs

Over the past decades, a vast literature emerged concerning external costs. They are often called marginal because they refer to the additional costs that are generated by adding a single user (Delhaye et al., 2017). These costs comprise also the negative effects of transport, such as climate change, energy use, emissions, accidents, noise, congestion and infrastructure (Ricardo-AEA, 2014). In a pure sense, an external cost is a cost which is caused by one person but is imposed on another (Blauwens et al., 2008).

During the past decades, researchers have tried to monetize external costs, which led to more acceptance as an element in modern social cost-benefit-analyses. When external costs are not included, the investment could lead to a form of market failure which must be compensated by government interference (Leijssen, Korteweg and Derricks, 2009). According to Fridell et al. (2011), the external costs come from market failures because markets for environmental goods and services usually do not exist or the market price underestimates the social scarcity value. For transport the marginal external costs (external costs for each additional user) are comprised in six categories: infrastructure costs (or habitat damage costs), emissions, energy use, accidents, congestion and climate change.

The effects of external costs are detrimental for human health and/or the environment and are paid by society in general. In contrast internal costs such as fuel cost, vehicle repair, insurance, etc. are paid by the transport provider and thus ultimately by the customers of the transport service.

Table 10 gives an overview of the external costs for all freight transport modes. The estimated values are based on the Flemish region and are according to constant prices of 2015. The table is adjusted according to the findings in this research. The total estimation of the accident cost is EUR 0.017 / 100 tkm and is divided as an average for both categories of IWT vessels and is higher than estimations from other sources. Another assumption is that rail freight is mostly transported by diesel trains and that road competitors for IWT are mostly heavy-duty trucks.

The discussion concerning the internalization of external costs lies outside of the scope of this research, but it is important to understand, that the debate concerning internalization of external costs is mainly focused on road haulage. If road haulage would become relatively more expensive by internalization of external costs, alternative modes such as IWT could become relatively more competitive depending on the cross-modal elasticity relation and the designed policy. If internalization of external costs would be done in all modes, alternative modes will still be relatively cheaper, which could attract more demand. If demand increases, this could increase the market price or freight rate in IWT.

EUR/100 tkm		Congestion	Emission	Accident	Noise	Infrastructure	Total
Aviation	long distance	0.00	3.19	0.01	0.02	0.00	3.22
	short distance	0.00	4.40	0.01	0.33	0.00	4.74
Maritime	bulk	0.00	0.27	0.00	0.00	0.00	0.27
	container	0.00	0.51	0.00	0.00	0.01	0.52
	RoRo	0.00	1.17	0.00	0.00	0.02	1.19
IWT	average all sizes	0.00	0.95	0.02	0.00	0.31	1.2
Train	electric	0.00	0.09	0.04	0.10	0.06	0.29
	diesel	0.00	1.25	0.04	0.10	0.05	1.44
Truck	heavy +12 t	2.94	1.81	0.19	0.12	0.28	5.34
	heavy 3.5-12 t	7.85	3.31	0.50	0.33	0.34	12.34
	light diesel	17.11	7.41	3.24	1.42	0.00	29.17
	light gasoil	17.11	6.70	3.24	1.42	0.00	28.46

Table 10: Marginal external costs in EUR/100 tkm – constant prices from 2015 for the Flemish Region
Source: based on MIRA (2017), Delhaye et al.(2017), own IWT accident cost calculations are added. For IWT an average is calculated to replace the division in the original source of different ship sizes

According to Blauwens et al. (2008), van Hassel (2011a) and Fridell et al. (2011), the effects of not internalizing the external costs in the transport price are shown in Figure 20. The marginal social costs (MSC) are higher than the marginal private costs (MPC) because they include the internalized external costs. MSC equals then the sum of the MPC and the MEC (marginal external cost). The offered transport service price is lower than the real social price, which leads to overproduction and a welfare loss which is equal to the area *abc*. In order to avoid this welfare loss and reach the market equilibrium, demand *D* should be equal to MSC at quantity Q_1 at a price P_2 which is obtained by internalisation of the MEC.

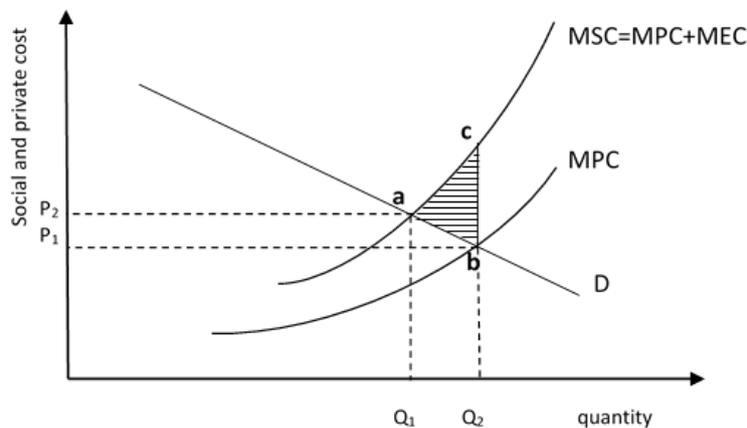


Figure 20: Graphical presentation of external, private and social costs in a failing transport market
Source: Blauwens et al. (1986; 2008), van Hassel (2011a) and Fridell et al. (2011)

An important distinction is hereby made (to avoid interchangeable use), between social and external costs. All costs are social because they have a negative impact on welfare by using scarce irreplaceable production factors. Internal (private) costs and external costs (costs not paid by the consumer and producer) result in the social cost.

The following parts give examples of external costs and explains how they can be calculated according to different authors with a focus on IWT.

E.1. Infrastructure cost

Definition of Marginal Infrastructure costs: the increased costs of operating, maintenance and repair of infrastructure and technical facilities for each additional vessel. These costs include for instance the costs of maintenance of embankment, dredging of the waterway, operating locks and bridges and upholding waterway regulations. (based on Ecorys, European Commission, 2005:25).

CE Delft (2010) calculated the average infrastructural costs in the study of the Paris-Amsterdam corridor (Ricardo-AEA, 2014) for France, the Netherlands and Belgium. Marginal costs were considered equal to the average variable costs. Ricardo-AEA (2014) collected data from several sources and compiled an overview for external costs of all transport modes as shown by the following table:

France						
	Large channels			Small channels		
	Fixed	Variable	Total	Fixed	Variable	Total
Total costs (mln. €)	80	35	115	113	71	185
Average costs (€/tkm)	1.39	0.61	1.99	6.38	4.01	10.39
The Netherlands						
	Fixed		Variable		Total	
Total costs (mln. €)	654		33		687	
Average costs (€/tkm)	1.5		0.08		1.58	
Belgium						
Average costs (€/tkm)	2.05		0.14		2.19	

Table 11: Infrastructure costs of IWT in France, Netherlands and Belgium for 2010 for the Paris-Amsterdam Corridor
Source : CE Delft et al. (2010) as mentioned in Ricardo – AEA (2014); for Belgium no total costs were presented in the study

The average infrastructure costs are calculated by dividing the total costs of infrastructure by the traffic performance (tkm). The total costs include fixed costs such as maintenance of canal banks, bridges, beacons, radars, dredging costs, etc. and variable costs which include traffic control, vessel patrols and operational costs of locks and bridges. The fixed costs are mostly covered by fairway dues and the variable costs are paid by society.

An important challenge in evaluating infrastructure data for IWT, is the distinction of costs direct in relation with waterway users and other users. The total infrastructure costs for waterways are not only for IWT. Flood prevention, recreation, irrigation, industrial use, water consumption and bridges for road traffic cannot be allocated on users of IWT (ECORYS, 2005).

E.2. Accidents

Accident costs represent the economic value of the change in accident risk when a user enters the traffic flow. This change in risk relates to all users, new ones and existing ones. The costs of accidents are repair costs, medical costs, suffering and delays for others resulting from an accident (Ecorys, 2005). The annual benefits B_t equal the VSL value multiplied by the expected number of reduced (or increased) fatalities $\Delta(n_{old}-n_{new})$.

$$B_t = \Delta(n_{old}-n_{new}) \times VSL_i$$

The willingness-to-pay (WTP) estimates are based on people's preferences regarding trade-offs between reducing risks for their own lives and other uses of their available resources. It concerns how much does one want to pay to have a smaller chance of a premature death (OECD, 2011). The WTP is needed to calculate the value of statistical life (VSL) which is the aggregate of the WTP of all individuals or individual values for small changes in risk of premature death.

First step is to estimate the number of deaths expected to be prevented in a given year by multiplying the number of people affected by the innovation with the annual average risk reduction. Then the VSL is applied to each death that is prevented each year because of the innovation as a present value using the social discount rate (rephrased to fit innovation instead of policy from OECD 2011).

The main cost drivers behind accidents are related to vessel size, technological development, maintenance level of the waterway and its construction, segregation level between systems, the degree of intensity, the location of the accident, the time of the day and the weather conditions (Ecorys, 2005). These parameters contribute to the risk of having an accident.

The number of accidents in German IWT is shown by the next figure:

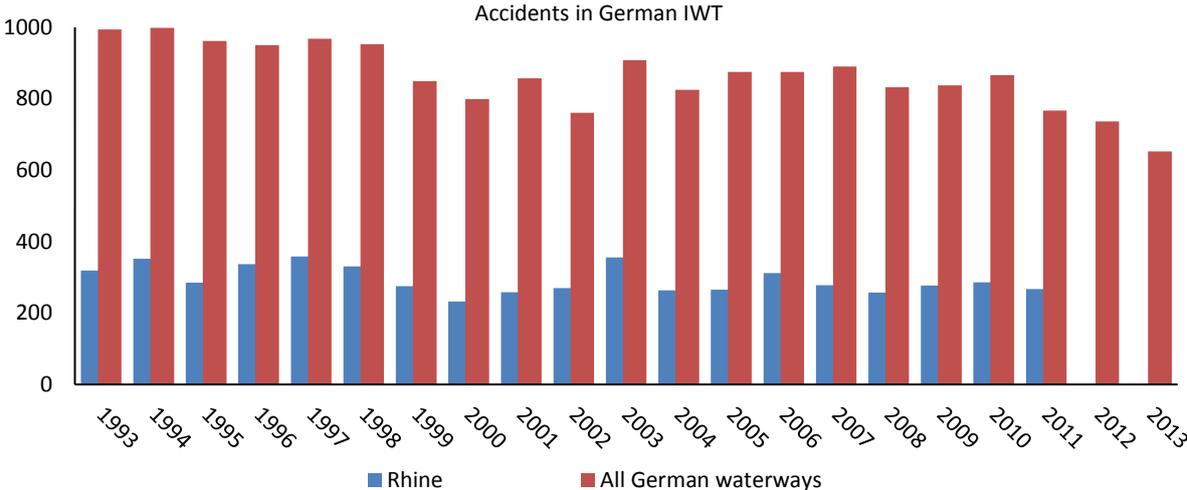


Figure 21: All accidents in IWT on all German waterways and the Rhine
Source: CCNR (2018), German Ministry

Figure 22 shows the number of accidents for each transported 1000 tonnes on the traditional Rhine (without the Dutch Rhine) based on German data. A small decrease is noticeable despite more transported volumes and grown traffic density.

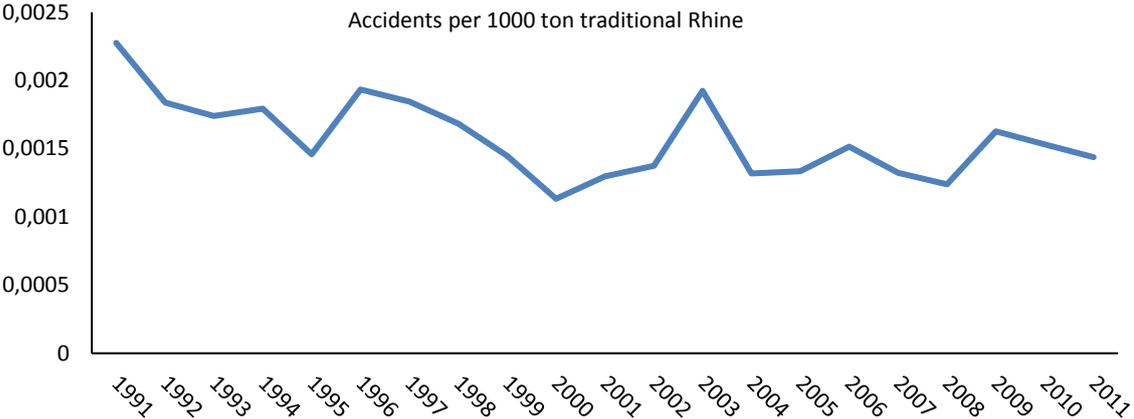


Figure 22: Accident rate for every transported 1000 tonnes by IWT on the traditional Rhine
Source: based on CCNR archive of market observations, and German Ministry

In 2017 on the Dutch waterways, eight people died in an accident with the involvement of at least one craft (CCNR, 2018). In the same year on the Dutch roads, 613 people were killed. In the Netherlands, IWT represents 314 million tkm of freight transport against 744 million tkm of road haulage

(Rijkswaterstaat, 2018; CBS, 2018).³² Looking both at the available German and Dutch accident data, the external costs of accidents are not significantly high.

The social benefit of adding safety to IWT is therefore considered rather small but transferring road tonnes to inland navigation (mode shift), could add to a significant safety benefit. The measured number of accidents in IWT is already relatively low, which indicates that further safety improvements are rather difficult to measure empirically.

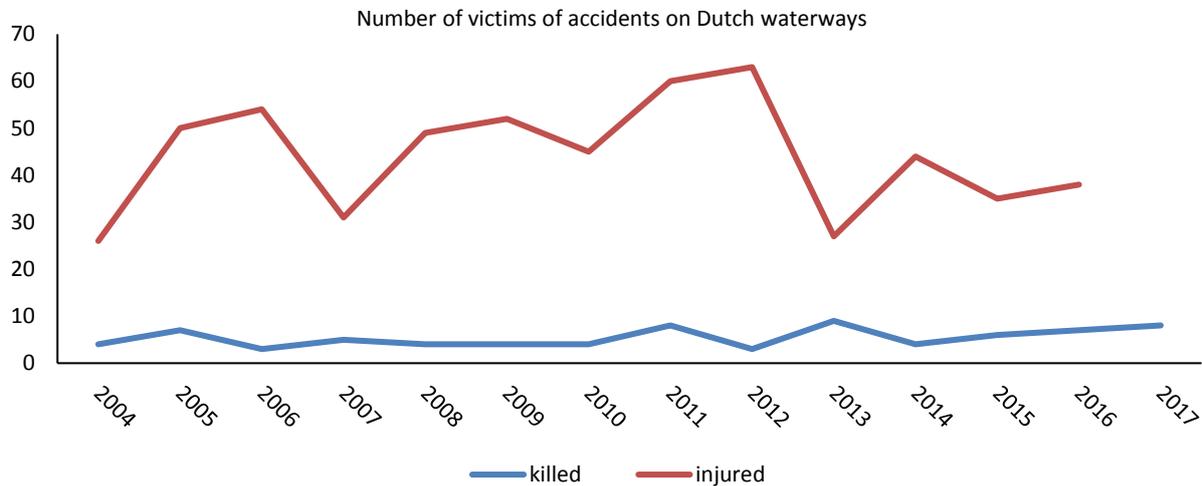


Figure 23: Victims of accidents on the Dutch waterways
Source: own compilation of Rijkswaterstaat, (Movares, 2013b) and CCNR (2018)³³

According to Ricardo-AEA (European Commission, 2014e), the evaluation of external costs of accidents for IWT can be based on the average number of all accidents across several years, but the social benefits of a safer inland navigation can also be measured by the possible damage of occurred larger accidents.

Other sources³⁴ such as VITO (2004), estimate the external accident costs for IWT at EUR 0.0000663/tkm for the Flemish region (current prices of 2004). Ecorys (2005) made an estimation for the Netherlands at EUR 0.002 and EUR 0.03/tkm (current prices of 2005). Planco used EUR 0.0003 / tkm for Germany and finally Ricardo-AEA (2014) considered the external accident cost as zero (as mentioned in Delhaye et al., 2017: in prices of 2014).

E.3. Congestion

Congestion occurs when demand and supply of transport infrastructure is not in balance. Demand in this case relate to all infrastructure users while supply refers to the actual infrastructure such as a road, waterway or a railway. Congestion causes additional trip time for the transporter and disturbance in the supply chain, increased fuel consumption, emissions and even accident risk. European policies struggle with this phenomenon since it emerged. This resulted in actions such as the implementation of traffic management systems, more infrastructure capacity or introduction of transport pricing (e.g. road pricing). Indirectly, road congestion gave more support for the development of modal shift policies towards railways and IWT. All these policies try to decrease congestion or the loss of time

³² <https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83101NED/table?ts=1535501457148>

³³ Visited websites: <https://www.rijkswaterstaat.nl/over-ons/nieuws/nieuwsarchief/p2017/06/aantal-ernstige-scheepsongevallen-blijft-nagenoeg-gelijk-in-2016.aspx>
<https://www.varendoejesamen.nl/kenniscentrum/artikel/aantal-ernstige-scheepsongevallen-nagenoeg-gelijk-2017>
https://staticresources.rijkswaterstaat.nl/binaries/MNV%202013%20-%20binnenwateren%20deel%20%20ondersteunend%20cijfermateriaal_tcm174-367159_tcm21-39482.pdf

³⁴ VITO (2004) Groen Imago Rapport; Ecorys (2005) Charging and pricing in the area of inland waterways. Practical guideline for realistic transport pricing; Planco (2007) Economical and Ecological Comparison of Transport modes: road, railway, inland waterways

which has negative welfare-economic impacts, not only on individual drivers and logistics firms that must wait on their delivery, but also on society at large.

There is unanimity in literature that IWT performs better than conventional road haulage concerning congestion. Indeed, the waterway network in Europe is not saturated although congestion can exist at terminals where sea-going vessels have priority on inland vessels while they compete for the same quay to commence loading or unloading operations. Ad hoc lock or bridge maintenance can also generate congestion although within the RIS environment, most skippers receive notices to skippers well in advance concerning possible delays. Literature about this kind of IWT congestion is scarce.

The congestion costs for IWT are according to Ricardo – AEA equal to zero, but it could be the case that capacity at certain locks and terminals causes congestion in certain conditions. Moreover, periods of low water depth present a special case. Or as Ricardo – AEA (2014) describes: *“COMPETE results suggest that European countries do not face any capacity problems in their inland waterway networks. However the GRACE case studies found several local bottlenecks at locks, although they largely depend on local conditions. Delay times range between zero and 160 minutes; in the latter case passage costs per ship are found to increase by €50 in case demand increases by 1%. Besides lock capacity, the availability of sufficiently deep-water levels to operate all vessel types is a problem, particularly in summer time. Based on the Low Water Surcharge, which has to be paid on the river Rhine when water levels fall below a certain value, GRACE estimates scarcity costs between €0.38 to €0.50/TEU*km at Kaub and €0.65 to €1.25/TEU*km at Duisburg.”*

Time benefit for society is in this study equal to zero because of the lack of capacity problems on the waterways. More efficient sailing because of automation, can be the case in certain circumstances and be beneficial for the private business case, but for society, there is no convincing benefit.

E.4. Emissions and greenhouse gases

These costs are especially important for the case analysis of the LNG vessel. Emissions influence public health and the environment while greenhouse gases impact on climate change. Emissions from human activity can be small particulate matter (PM), nitrogen (NO_x) or Sulphur (SO₂).

Transport is also responsible for greenhouse gases (GHG) that affect climate change such as CO₂, methane (CH₄) and N₂O. Delhaye et al. (2017) provide an overview of all emission and GHG costs as presented by following table.

Emissions – euro (2015)/kg	VITO	Ricardo
CO ₂	0.04	0.10
CH ₄	1.10	2.43
N ₂ O	13.17	28.97
NO _x	4.96	11.80
NMVOS	8.94	3.49
PM coarse (PM10-PM2,5)	30.86	-
SO ₂	12.91	14.71
Pb	384.02	-
Cd	121.54	-
Ni	5.51	-
Cr	31.27	-
PM2,5_weg	257.96	-
PM2,5_IWT	167.49	65.24
PM2,5_RAIL	174.14	65.24
PM2,5_CITY	587.42	224.27
PM2,5_HIGHWAY	167.49	65.24
PM2,5_farming	172.97	37.57

Table 12: Emissions in EUR/kg (values of 2015)
 Source: Calculations of Delhaye et al. (2017) based on Ricardo-AEA (2014) and VITO (2010).
 The CO₂ equivalent factor for CH₄ is 25 and 298 for N₂O

Direct emissions relate to the actual transport and can be measured of exhaust sources from different areas in multiple situations. There is a difference when the engine is warm for several hours, when it ignites, when it is performing low (slow speed, unloaded or stationary) or high (high speed or loaded).

The indirect emissions relate to the fuel production and distribution from well to vehicle or vessel. In literature, the distinction is often made between well-to-tank and tank-to-wheel or well-to-wheel. When explaining in more detail, also the distinction can be possible between ways of distribution the fuel. This is expressed by truck-to-ship or ship-to-ship. Especially, in order to compare the different emission of all transport modes or to examine alternative fuels, the inclusion of indirect emissions in any analysis is relevant. Electric trains for instance, may have no direct emission costs, but the emissions that are caused by the transformation sector by adding one more electrical user, still expresses a marginal external cost.

E.5. Other external costs

Other external costs such as noise costs are not taken into account in this study. Ricardo – AEA (2014) and Delhaye et al (2017) also provide an extensive overview of these costs for all transport modes. Because they are not relevant for this research, they are not discussed. Loading and unloading operations of vessels are mostly not in urban populated areas which could cause noise nuisance to people living in the proximity of this operations.

F. Social benefits

Benefits in the simplest approach are the sum of derived changes in consumer and producer surplus (CS & PS), minus the changes in tax revenues (TR) and in external costs (EC) (De Borger, 2017) or as following equation expresses:

$$\text{Benefits} = d_{CS} + d_{PS} - d_{TR} - d_{EC}$$

Consumer surplus is the excess of users' willingness to pay over the prevailing generalized cost of transport for a specific trip (EC, 2015a). The generalized cost of transport expresses the overall inconvenience to the user of travelling between a particular origin and destination using a specific mode of transport. In practice, it is usually computed as the sum of monetary costs borne (e.g. tariff, toll, fuel, etc.) plus the value of the travel time (and/or travel time equivalents, such as the inconvenience of long intervals) calculated in equivalent monetary units. Any reduction of the generalized cost of transport for the movement of goods and people determines an increase in the consumer surplus.

Producer surplus are the revenues accrued by the producer (i.e. owner and operators together) minus the costs borne. The change in the producer surplus is calculated as the difference between the change in the producer revenue minus the change in the producer costs (2015a:87)

More specific benefits from innovation could be lower emissions, energy savings, more safety, more efficiency, etc. Table 13 presents a non-exhaustive list of possible objectives of the innovation which can be targeted by the innovative entrepreneur or policy according to Vanellander et al.(2016) and which provides an interesting overview of possible benefits.

The mentioned benefits in the column 'profit' are in most cases private benefits that are borne by the innovator. The benefits concerning planet and people are external benefits that are only to a smaller extent a benefit for the individual innovator. Together (external + private) they form the social benefit of an innovation.

Profit	Planet	People
Minimizing Costs Optimizing operations Gaining market share Obtaining first mover advantage Avoiding depletion of resources Impacting positively on competitiveness Growing (marketing) Generating employment Using resources efficiently Differentiating from competitors Increasing scale of operations Improving energy efficiency Integrating with other actors Offering larger and equitable access to service Encouraging other investments Facilitating transfer of official documents	Reducing CO ₂ emissions Reducing air pollutants emissions Minimizing impact on landscape Reducing noise Reducing water/soil pollution Improving management of waste Recycling Integrating other developments in sustainability Complying with environmental regulation	Offering new employment Retaining human capital Relations with local communities Reducing number of accidents Reducing fraud Improving security efficiency Complying with labour regulation Complying with safety regulation

Table 13: Non-exhaustive list of possible objectives of innovation
 Source: based on Vanellander et al. (2016)

The next part explains the distribution of welfare which is an important component of a SCBA that examines how the social benefits and costs of an investment are divided amongst different groups in society.

2.4.3. Distribution of welfare

An important question within the SCBA framework is how costs and benefits of the investment (in this research innovation in IWT) are distributed. It is a question about who wins and who loses and should be asked in every ex ante analysis. The Hicks-Kaldor compensation states that the net result of an investment (policy measure or a project) compensates the losers without making any actor worse off than before the investment which also corresponds with a potential Pareto improvement (van der Pol et al., 2017). The 19th century economist Vilfredo Pareto described the latter as a situation where resources could not be reallocated in order to improve the utility of at least one person without decreasing the utility of others. Pareto did not accept losers. In reality, there can be welfare losers and compensations are not always that well distributed to those who lose.

As this research continues from the perspective of an individual skipper (vessel owner/operator), whereby the external costs are linked with the cost structure of the IWT firm, the potential affected individuals or groups are rather limited. If more vessel owners follow and invest in the innovation, more significant effects could be identified. By lowering the MEC which is for IWT considered similar to the average external cost (Ricardo-AEA, 2014; van Essen, 2019), the impact on society (especially those who live close to waterway infrastructure) will be positive although relatively small as only one ship is analysed. If more consumers follow, the effects will be larger. More specific, in case of LNG, the conventional engine-builders will sell less diesel engines if LNG engines become more diffused. In case of the automated vessel, the potential effects on the labour market are briefly discussed in the specific case analysis (Chapter 5).

2.4.4. Conclusion of SCBA literature review

The literature review concerning SCBA offers a clear view on this powerful method which can help to develop an analytical tool to answer the following sub-questions of the RQ:

- What is innovation, when is it successful or a failure and how can innovation be analysed? The SCBA is an appraisal tool for an investment and it can show if investing in an innovation is attractive for the private investor (industrial-economics) as well for society at large (welfare-economics). If the SCBA shows a negative result for both perspectives, the innovation is most likely to fail.

- Which role plays IWT innovation policy? When the SCBA shows that there is negative effect of the investment on society, any policy that supports that investment can be considered as failed. It also offers a perspective in how to view policy through a lens of quantified costs and benefits which can be patched to the SIA.

In this research the SCBA provides a basis to develop an important quantitative addition to the qualitative approach of the SIA and a more thorough policy analysis of the young research field of European IWT policy. As a complete SCBA can be time-consuming and highly depends on the availability of more cost data to calculate the full social costs (together with private and external costs of producers), it is not always feasible within a case or a research to apply. Furthermore, the SCBA looks at social costs and benefits from a societal perspective. This means for innovation that the costs and benefits of the innovation producer are taken into account next to the costs and benefits of the consumer of the innovation and the society at large. It requires to identify all beneficiaries and those who lose within the society. Therefore, a CBA is applied including external cost analysis and a cash flow analysis in the cases where it is found to be feasible. The developed CBA of the IWT innovation from the perspective of the end-user (vessel owner) can then take in account the related external costs. This is further developed in the Chapter concerning the methodological framework.

2.5. Case studies literature

To answer the research questions a framework of a multiple case study is selected. This offers a way to explore the largely unexplored field of innovation in the European Inland Navigation. This case study literature review provides relevant information and insights on how to perform an actual case study with authors such as Eisenhardt, MacIntyre, Thomas, Ketoviki, Yin, Cousin and many others.

A case study can be applied on one single case or on multiple cases. A multiple case study includes, according to Yin (1984), multiple cases that are presented as a sequence of experiments whereby every case has the purpose to accept or reject the conclusions of the previous case analysis while following the developed replication logic (Eisenhardt, 1989). As Cousin (2005) says: “the case study method is not aimed to analyse cases, but it is a good way to define cases and to explore a setting in order to understand them.” Indeed, a multiple or a single case study does not imply one single analysis but a setting to apply a diverse arsenal of analytical tools to gain in-depth insight in a phenomenon and between phenomena. Moreover, Thomas (2016) claims in this regard that a case study should not be viewed as a method, but as a research framework whereby several research methods can be applied: “Case studies are analyses of persons, events, decisions, periods, projects, policies, institutions or other systems which are studied holistically by one or more methods. The case that is the subject of the inquiry will illuminate and explicate some analytical theme, or object” (Thomas, 2016).

The following part of this literature review elaborates further on this approach of (multiple) case studies and explains first how cases can be selected.

2.5.1. Case selection typology

Every case study begins with the selection of a case or multiple cases following the RQ. There are different ways according to related literature to select cases. John Stuart Mill (1822) made a distinction between selection methods of, agreement, difference, joint (agreement and difference), residue and concomitant variations. The first method looks for cases that show a similar phenomenon. The condition or circumstance that all cases have in common is then the cause of the phenomenon. The method of difference relates to cases that are similar except for a certain circumstance. Different circumstances cause a different phenomenon. The third category joins both methods. The method of residue focuses on that what is not yet explained of a phenomenon. If variables *A*, *B* and *C* occur together with *x*, *y* and *z*, and *B* is known to be the cause of *y* while *C* is the cause of *z*, then only *x* is not explained. Using the residual method in this example, means that *A* causes *x*. The concomitant

variation method helps to select cases where the variation of one phenomenon causes or results from the variation of another phenomenon.

A century since Mill, other authors have built further on the development of case selection methods and typologies. Others such as Gerring (Box-Steffensmeier J.M. et al., 2008) described 9 methods to isolate a sample of cases that both is representative and provides variation along the dimensions of theoretical interest. These methods are typical, diverse, extreme, deviant, influential, crucial, pathway, most-similar and most-different. The following table gives an overview which explains the types of Gerring (2008):

Case selection type	Explanation
Typical	<p>Typical examples of some cross-case relationship:</p> <ul style="list-style-type: none"> Selected cases are representative of a broader set of cases Causal model with relevant dimensions Hypothesis-testing Quantitative selection by looking at the size of case residuals compared with large-N
Diverse	<p>Shows full range of variation on dependent, independent variables and their relationship:</p> <ul style="list-style-type: none"> Used for hypothesis-generating or testing Diverse cases are likely to represent the full variation of population on relevant parameters
Extreme	<p>The selected case shows an extreme value on the independent or dependent variable of interest:</p> <ul style="list-style-type: none"> An extreme value is an observation that is far away from the mean of a given distribution. Distance from mean (of X_1 or Y) can be in either direction Danger for bias by selecting on dependent variable within cross-case analysis to represent population
Deviant	<p>Cases that demonstrate a surprising value towards a specific theory:</p> <ul style="list-style-type: none"> Model dependent: deviant case is judged in relation with a general model of causal relations Logical contrary of typical case Hypothesis-generating
Influential	<p>Cases with configurations that influence independent variables and casts doubt upon a theory</p> <ul style="list-style-type: none"> Hypothesis-testing Verification of assumptions behind general model of causal relations
Crucial	<p>Cases must closely fit a theory or must not fit equally well. It fulfils a theoretical prediction or least-likely:</p> <ul style="list-style-type: none"> Cannot be employed in a large-N context Hypothesis-testing
Pathway	<p>Cases with a clear causal relation are selected:</p> <ul style="list-style-type: none"> Imply a similar and distinct causal path from X_1 to Y: Usage: cross-tab (categorical variables) and residual analysis (continuous variables) Hypothesis-testing Representativeness can be tested by examining the residuals of the selected case
Most-similar	<p>Minimum 2 cases are selected which are similar in all aspects except for the variable(s) of interest:</p> <ul style="list-style-type: none"> Cases match which each other Hypothesis-testing and generating Representativeness can be tested by comparing residuals
Most-different	<p>Cases are more different on specified variables other than dependent and independent variable</p> <ul style="list-style-type: none"> Hypothesis-testing and generating Reversed most-similar X_1 causes Y both other factors are different

Table 14: Case selection methods
Source: based on Gerring (2008)

Gerring (2008) concludes that, evidently, case selection is often influenced by the researcher's familiarity with the topic or personal entrance and knowledge. Indeed, this familiarity leads to a more pragmatic approach. Context and entrance into the relevant network surrounding the case, were next to other developed selection parameters, decisive for the selection of the five cases. Although, such approaches have been challenged according to Poulis et al. (2012), to be arbitrary and too much relying on convenience logic. The authors suggest a sampling framework that "promotes contextualisation and thoroughness of sampling decisions (Poulis et.al, 2012)." They stress the importance of context during case selection for qualitative case study research as they quote: "*The choice of methods is shaped not only by the research aims, norms of practice, epistemological concerns but also by a combination of organisational, historical, political, ethical, evidential and personally significant characteristics of the field of research* (Buchanan and Brynan, 2007; Poulis et.al, 2012)." These influences are not necessarily problems that have to be solved, they are rather inevitable according to Buchanan and Brynan (2007).

In more recent work Gerring (Gerring and Cojocar, 2015) reduced the typology to five types (representative, anomalous, most-different, crucial and most-similar) including several sub-types (e.g. random, typical, conforming, diverse, census, idiographic, outcome, deviant, influential, exploratory, pathway, testing, most-likely, least-likely, exploratory and testing). However diving any further in these kinds of typologies of case selection, lies outside the scope or does not meet the objective of this research. Important to know for now, is that there are different ways to select cases and that every type has its own consequences for representativeness and variation. In the end, the researcher must decide, and literature only provides suggestions and signals several caveats during any case selection.

2.5.2. Methodological approaches within case studies

Ketoviki et al. (2014) distinguish among three different methodological approaches, to clarify the methodological diversity in case research and the heterogeneity of theoretical and epistemological premises: theory generation; theory testing; and theory elaboration. All three approaches look for theoretical insight in what can be understood as the result of the interaction between the general theory and the empirical context. These approaches find their origin in the general methods literature of organisations and social systems (Eisenhardt, 1989, Ragin and Becker, 1992, Yin, 2003).

Theory generation or an inductive case study as Eisenhardt (1989) calls it, generates a theory through the process of induction whereby the particular (the case), gives building material for new theories. The explanation (theory) follows the exploration (analysis). Theory generation is fundamentally based on the particular and the contextual situation of every case.

Theory testing starts from an existing theory and test this theory on a case or multiple cases. This approach is deductive, but the contextual situation of every case makes the point of departure also particular. The existing theory remains standing until another case proves otherwise.

Theory elaboration concentrates on the logic behind the existing theory. The researcher does not test the theory but develops the logic behind it. It could be possible that knowledge about the particular is insufficient to develop detailed preconditions that can be used together with the existing theory to deduct verifiable hypotheses. During the development of the logic, the theory is examined together with the context of the particular (Ketokivi, 2014). Another definition comes from Fisher and Aguinis (2017). They define theory elaboration as "*a process of conceptualizing and executing empirical research using pre-existing conceptual ideas or a preliminary model as a basis for developing new theoretical insights by contrasting, specifying, or structuring theoretical constructs and relations to account for and explain empirical observations.*"

Theory elaboration is related to grounded theory and abductive reasoning. The first one is pragmatic and sees the empirical reality as an ongoing interpretation of meaning produced by individuals engaged in a common project" (Suddaby, 2006, p. 633; Fisher and Aguinis, 2017).

Abductive reasoning yields a possible or plausible conclusion but invites doubt and uncertainty (Weick, 2005, p. 433; Fisher and Aguinis, 2017). It gives the “best” or “most likely” explanation after an observation of a phenomenon when deductive or inductive reasoning is not possible.

Concerning theory elaboration, several limitations are identified according to Fisher and Aguinis (2017). The first limitation concerns the possible outcome of even more complex theories through the integration of already complex contextual relations. Secondly, the result can also be so specific to a certain context that there is no generalisation possible. Thirdly, the strength of the elaborated theory that serves as a starting point, determines the strength of the outcome. Fourthly, a potential limitation is the basis of formal statistical tests and standards. Conclusions are not always based on this and insights from qualitative elements of theory elaboration can be reviewed as rather subjective. Unfortunately, literature was not found to tackle these limitations.

2.5.3. Generalisation of results of a case study

The generalisation of conclusions of case studies can be problematic. In more exact sciences, this is hardly the case, but generalisation in human sciences can become unrealistic. MacIntyre (1985) and Thomas (2016) claim that this is a fact in social sciences where they call it probabilistic generalisation (as mentioned above). Not only time and space are determinant factors, but also the unpredictability of human behaviour makes generalisation based on case studies rather challenging. This kind of generalisation is limited or even hypothetic to verify or falsify a general theory.

Case studies try to link particular cases with a higher theoretical thinking or theory. It is often qualitative of nature or is perceived in such a way (Barrat et al., 2011, Ketokivi, 2014:233). Despite this reputation, it is perfectly possible to apply quantitative methods. The quantitative orientation can manifest itself already in the research design of a multiple case study whereby the cross-case analysis includes explicit comparisons between the cases according to measurable variables.

A second characteristic of theory generalisation lies in the duality. The researcher depends on the selected case(s) according to contextual particularities, while he or she searches for a generalisation or a theory at a higher aggregated level. During this quest for a generalized theory, the researcher tries to transcend the empirical context with the attempt to find a broader theoretical understanding through abstraction. It is not merely the question if the results of a case study could be generalized to other cases or empirical contexts, but to what extent a general theory can be constructed. This duality contributes to the balance between contextual particularities and the implications of a more general theory (Ketoviki et al., 2014:234).

During the process of generalisation, it is necessary for the researcher to separate existing theoretical insights and concepts. Researchers are already preconditioned by existing general assumptions when examining particular cases (O’Reilly et al, 2012:250, Ketokivi et al, 2014:237). Scientific reasoning is hereby divided in two categories: mathematical and cognitive reasoning. The former category implies the usage of predetermined rules and procedures whereby cognitive reasoning is only an instrument to perform calculations. In the category of cognitive reasoning, this kind of reasoning goes further and is not only a predetermined instrument.

During a case study less formalised and undefined paths are being followed and cognitive reasoning becomes more central in looking for solutions. Cognitive reasoning is less transparent than a more calibrated and mathematical way of reasoning. To obtain transparency concerning the applied methods within a (multiple) case study, the process of reasoning should be sufficiently exposed and explained or as Barrat et al. (2011; Ketokivi et al, 2014:238) says: *“A common critique of case research..., is that they fall prey to self-fulfilling prophecies.”*

2.5.4. Linking RQ with case type

Ketokivi et al. (2014) proposes to use a case research decision tree that aids the researcher to accommodate the research question in the ideal type of case study. The following figure shows the decision tree as developed by Ketoviki et al. (2014).

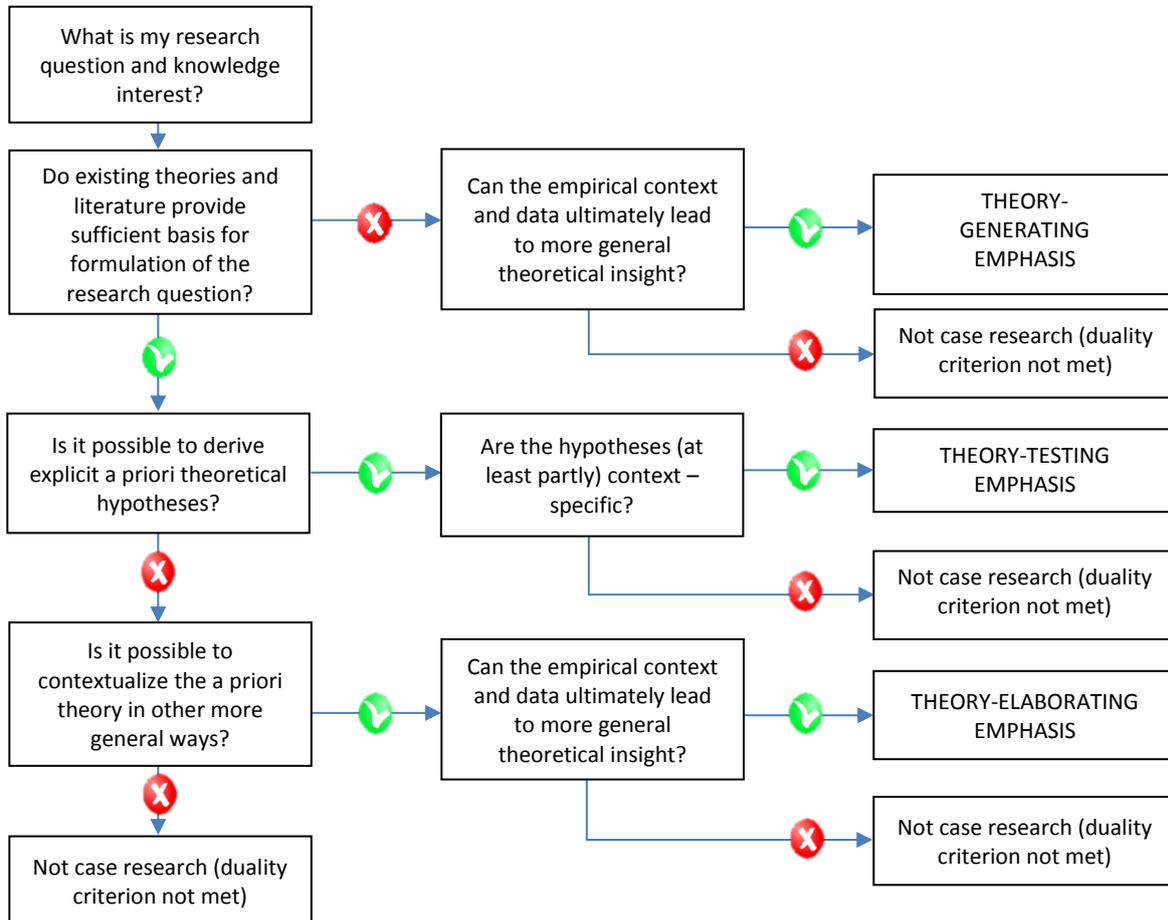


Figure 24: Case research decision tree
Source: Ketokivi et al, 2014

In order to conduct a careful selection, the subject of the case study needs to be determined. The researcher needs to have sufficient knowledge about the subject and is interested in a certain aspect or theory. The case needs to be an example of the theory or contain a possible answer on the research question. Consequently, the objective of the case study needs to be clearly elaborated.

There are different objectives why a researcher chooses to use a case study as a framework. Stake (2005) and Thomas (2016) make the distinction between intrinsic and instrumental objectives. The first category proceeds from the personal interest or passion of the researcher. An instrumental case study is chosen to obtain insight in a certain topic or to reach a generalisation. The instrumental case study plays a supportive role to understand something better.

The following sub-section summarizes the relevant lessons learned from the literature review so far and links them within the research.

2.5.5. Conclusion of case studies literature review

European inland navigation is still quite a niche in academic research and IWT innovation is even a relatively smaller field of research. There is therefore not a common research approach in this specific field or an academic consensus concerning the methodological framework.

The selected cases are thought to be most similar in the sense that they all are considered to be IWT innovations. The objectives and the type of the innovation, can also fundamentally differ. This is taken in consideration in the final cross-case analysis.

The findings from the multiple case study literature help to construct the research design and select cases in an elaborate way. Following the case research decision tree of Ketoviki et al. (2014), the multiple case study in this research has rather a theory – elaborating emphasis and nurtures more “a logic of discovery” than “a logic of validation” as Fisher and Aguinis (2017) explain as *the process of conceptualizing and executing empirical research using pre-existing conceptual ideas or a preliminary model as a basis for developing new theoretical insights by contrasting, specifying, or structuring theoretical constructs and relations to account for and explain empirical observations.*

Existing theories and literature are expected to provide a sufficient basis for formulation of the research question. Definitions are found to explain and elaborate further on the research question and the sub-questions. Finally, the empirical context and data ultimately lead to a more general theoretical insight following a path as described by Ketoviki:

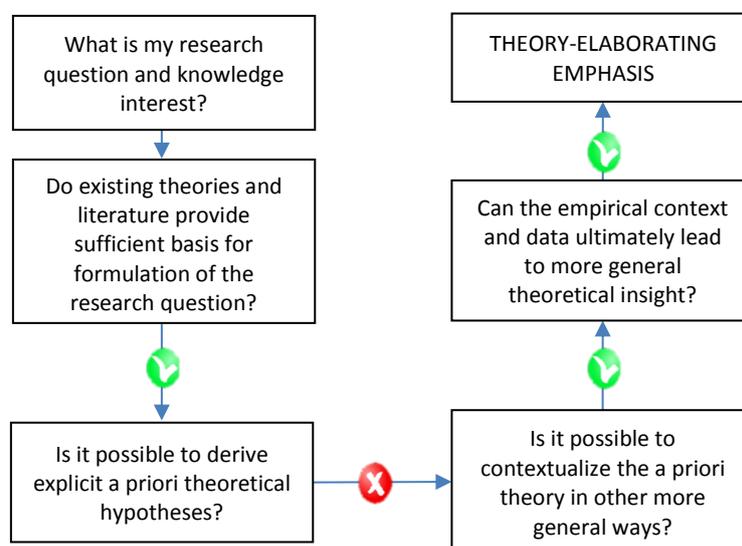


Figure 25: Type of multiple case study
Source: bases on Ketokivi et al, 2014

Although useful to situate the small-sample case study in this research, Ketoviki et al. (2014) does not provide a robust schematic for all aspects. For instance, depending on the question, there is the possibility for explicit a priori theoretical hypotheses which are (at least partly) context-specific. One might argue that in case of applying the system innovation analysis, it could be the hypothesis that infrastructure and funding are the main failure factors that prevent innovation success in certain cases. This would lead then to theory-testing emphasis. However in this research no hypotheses are tested and the theory-elaborating emphasis is understood to be mainly related to the theory that the selected methods can help answering the research questions. The theory-elaborating emphasis in this research relates more specifically to the following:

1. The developed institutional setting of PEINP offers a framework to develop a method for policy analysis which allows to answer the second part of the RQ.
2. There are analytical methods in literature that can be used to analyse failure factors and are fitted for innovation in IWT such as the SIA and (S)CBA.
3. Welfare economics offer a framework to develop a method that takes in account external costs from an end-user perspective.

However further detailed development in reference to theory-elaborating emphasis is not envisaged in this research.

This multiple case study has both intrinsic and instrumental objectives as Stake (2005) and Thomas (2016) call it. It is a mixture between personal interest and the quest for more knowledge of the topic. As Barrat et al. (2011; Ketokivi et al, 2014:238) suggest, the applied methods (including the case selection process) within this (multiple) case study, are transparent and the process of reasoning is sufficiently exposed and explained.

The caveats about case selection and context are taken into account and are answered by a developed ranking system in the methodological framework in Chapter 4. All steps are explained in a transparent way and possible bias in the input phase of the selection process is identified. Challenges of cross-cultural settings and time differences are expected to be more manageable within the research³⁵ by selecting a narrower geographical scope of the Rhine countries and Belgium, and to focus on current and present innovations. The representativeness of the findings of this chosen approach, despite the relatively small number of only five cases, relates to the generalisation issues as brought forward by MacIntyre (1985) and Thomas (2016). Despite their theory of probabilistic generalisation, this research approach is ought to be replicable and can be applied on a larger N. The choice of a relatively small sample of cases was made to gain in-depth knowledge and to test if the developed methodological approach leads to answering the RQ.

There is no academic consensus about using or even selecting case studies and several typologies co-exist. Selection of cases is vulnerable for context, bias and other interference that could lead to expected outcomes. There are still many challenges and open questions in how to select cases, to analyse them and to generalise the results. Literature provides several typologies and identifies limitations within this approach, but most authors agree to define a case study not as an analytical tool or method, but rather as a framework whereby several analytical tools can be used in both qualitative and quantitative ways.

The literature review of the case-studies provides a sufficient basis to conduct the further case analyses and to commence the next Chapter concerning the institutional setting of the pan-European inland navigation policy. This Chapter presents the detailed framework for the development of the policy analysis tool which provides insight in the policy transformation within the sector during the past decade.

³⁵ There are differences between the fleet of the Rhine and the Danube because of historical reasons which also reflect in the market structure (e.g. less SME's) and the culture on-board (e.g. less families that live on the vessel). Regulation still differs between Danube and Rhine regime despite the development of the European internal market (although this research shows that European IWT policy is in a transition phase)

3. Institutional Setting of (Pan-)European inland navigation policy

To set the scene of the development of the policy analysis tool for IWT policy, this Chapter explains the complex institutional setting of the multilevel policy model of IWT in (pan-) Europe. It is necessary to understand the current institutional framework that could support or even limit an innovation in IWT. This Chapter provides the setting for the development of an analytical tool that can be added to the developed integrated approach on IWT innovation. This Chapter does not intend to give an inventory of existing literature.

First, the European framework for inland navigation policy is briefly compared between 2004 (EFIN, 2004) until 2019. The EFIN report is partially updated according to identified later developments. Second, IWT policy actors are further defined together with their interdependent relations and how they conduct policy within a complex multilevel policy framework with, as this Chapter shows, a pan-European dimension which is referred to as pan-European Inland Navigation Policy or PEINP. After identifying some relevant institutions, the actions of the public IWT actors are discussed. Finally, the PEINP is viewed according its costs and benefits for the first time according to the identified scarce available literature on this specific topic. Elements of NIE, the theory of transaction costs and European integration are applied on the different (pan-)European IWT policy (PEINP) levels.

3.1. (Pan-)European policy framework for IWT

The EFIN report (European Framework for Inland Navigation, 2004) evaluated some shortcomings of the (Pan-) European inland navigation policy. Some of them are still relevant today:

- Low political impact (major investments, economic aid, social policy, weaker lobby than in other modes, lack of professionalization of sector representatives,);
- Incomplete opening of markets (EC, Mannheim Convention, Belgrade Convention, third countries): *Deregulation is quite well advanced. However in order to have favourable effects, EFIN expressed the need for a regulatory authority that guarantees balanced and fair competition to avoid the risk leading to unbridled competition, relative decline of freight, harmful effects on social conditions, safety, quality and capacity of financing for fleet modernization (EFIN, 2004);*
- Lack of unity in technical and legal regulations applicable to inland navigation (lack of standards, CMNI, CLNI...etc.);
- Poor human resources situation (lack of experts and means, but concentration at level of river commissions; lack of professionalization and structural weaknesses in sectoral organizations);
- Dispersed responsibility and lack of cohesion in the exercise of competence;
- Need for a more strategic approach;
- Insufficient adaptation of structures to the characteristics of an increasingly integrated European market for water transport.

Concerning private law, the EFIN report describes the lack of European unification regarding legal standards (civil law, contract law, tort law, etc.) and refers to the status of several conventions such as the *La Convention de Budapest relative au contrat de transport de Marchandises en Navigation Intérieure* (CMNI) and the *Convention on the Limitation of Liability in Inland Navigation* (CLNI). In 2005, the CMNI came in to force. CMNI is applicable to any contract of carriage in the international inland waterway transport, if at least one of the ports is in a CMNI state (state that ratified the convention). According to Kroos (2011)³⁶, the CMNI has succeeded in creating a uniform regime for European cross-border IWT, but it has no compulsory feature such as the CMR (road haulage contract regime) which makes it relatively easy to avoid and which does not solve the issue concerning legal uncertainty as

³⁶ Kroos, I. (2011), Het CMNI: Een eenheidsloze unificatie, Universiteit Antwerpen, master thesis, Antwerpen, 108p.

expected. The lack of mandatory nature of the convention does not unify the rights and duties of the various parties of an IWT contract, nor does it unify in practice the exoneration possibilities and liabilities.

The EFIN critique concerning the poor human resources also needs to be revised. The sector organizations are lobbying for support to modernize and to professionalize and are working more closely together (as explained) than described in the EFIN report on all policy levels.

Finally, the search for appropriate tools to support IWT remains delicate in a free market economy, with less possible forms of intervention, but even those which are possible, not always seem to follow a common economic strategy or policy. Despite the lack of real market policy, the two NAIADES programs of the EC were important steps in the alignment and development of IWT policy and strategy in different fields and issues. The following sub-section explains the relevant public actors that have influence on PEINP from different levels of policy.

3.2. Policy actors

As mentioned in Rouboutsos (2013), public actors inside the multi-dimensional innovation system can be found at different levels of public policy. The current inland navigation institutional framework is here described by addressing the relevant policy actors and what kind of policy tools they might have to stimulate or resist an innovation in IWT. At local level these are the ports that are often linked to municipalities or cities. As the level increases, the policy scope follows. After the ports, the provinces (different names amongst the EU member states) are described through the lens as framed by the literature review. The third actor or level relates to the regional and national levels of policy. Most of the fiscal incentives such as tax reductions are at this level. Fourth, the existence of several river commissions in Europe that usually have older founding treaties than higher levels of policy which gives them degrees of freedom to make their own policy, are explained as intergovernmental institutions that implement (and in some cases enforce) regulations on police, technical and crew requirements, rules on social security, training and skills, and even river law. Fifth, is the European Union that can regulate, standardize and provide funding to support or resist an innovation, but as shown, the EU has no competence to implement fiscal policy. Finally, a less known and explored IWT policy level is the UNECE. Since 2000 this level has become more important for IWT when the European treaties on dangerous goods (such as the ADN and ADND) became integrated or pan-Europeanised on this level. The entire IWT tanker fleet of the pan-European continent had to invest in double-hull vessels because of this treaty. The pan-European scope refers to the member states of the UNECE which are higher in number than the EU Member States.

3.2.1. Local level: Ports and municipalities

The first regulatory players that are closest to the inland navigation are usually the municipal port authorities which focus on a local or national agenda. Most ports have an authority that manages the port infrastructure, provides services, levies port dues and technical-nautical service charges, and can develop a policy towards innovation. For example, the emission sensitive price setting of the port dues for inland navigation by major ports is one example how a port can influence the diffusion of alternative fuels. Several important European ports are investigating or have implemented discounts for lower emission vessels or even penalties for forbidden “dirty” vessels (e.g. Port of Rotterdam).

Ports can present themselves as a partner or collaborator of the innovator during the different phases of innovation development. Their role in the innovation network can differ from providing expertise, adjusting port regulation, implementing the innovation or needed infrastructure, to even developing an innovation. Ports can also choose not to participate in an innovation network, or they can find an innovation to be less valuable for them or their environment. Their scope is limited to the port area which makes collaboration with other ports to tackle typical port issues with a cross-border feature. Port authorities try to balance the interests of several port stakeholders such as industry, parties in

logistics, added value services, labour unions and transport firms with the interest of the local municipality and are ideally a neutral actor between those stakeholders. Although, ports such as the Port of Antwerp have a level of policy autonomy, they do not escape the political rational as found in every phase of the policy cycle on higher levels of policy. They also must comply to higher regulation (from higher levels of policy). Ports do not have a real public policy, but they are an important public actor in IWT related policies and of course in IWT innovation policy. At port level, cross-border cooperation can also emerge, such as the merger between the ports of Flushing, Terneuzen and Ghent into the North Sea Port. Ports are also organised at the European level with organisations such as the European Sea Ports Organisation (ESPO) and the European Federation of Inland Ports (EFIP) who defend the interest of their members.

3.2.2. Province/Département/Canton/Regierungsbezirke

The second closest level relates to the province (the Netherlands, Belgium), *Regierungsbezirke* (Germany), or *Département* (France). Particularly in the Netherlands, provinces take the lead in several topics such as degassing bans in North Brabant and South Holland or the implementation of shore power supply. Provinces can also conduct research and experiments concerning automated vessels such as the Province of Western Flanders. They are often partner in infrastructural masterplans or sometimes even give subsidies for IWT. Only four regions in Germany have kept this government layer or regional mid-level local government (Baden-Württemberg, Bavaria, Hesse and North Rhine-Westphalia) but for the ones that remain, no policy concerning inland navigation was identified. Several French Departments have significant IWT such as Moselle, Meurthe-et-Moselle, Bas-Rhin, Haut-Rhin and Bouches-du-Rhône and have the power to make relevant policy decisions for the local IWT. Furthermore, the French departments play an important role in the financial framework behind the Seine-Nord Canal. This level can take initiatives to start innovation projects and even play a leading role. In Flanders they are also important in managing calamities that have a larger scope than only one municipality. The regions are explained in the next paragraph together with the national level.

3.2.3. Regional and national levels

The third identified level consists of the regional or national waterway managers as well as inland navigation policy officers and usually have ministers. National authorities have international representation at higher levels of policy and are still a significant and decisive actor in European policy. Although the European level gained more influence the past decades in IWT policy, Member States still have more tools to foster an innovation policy such as fiscal incentives which the EU does not possess. They also can lead innovations or use public procurement and other instruments to stimulate the diffusion of an innovation.

Before going deeper into the European level, it is important to note that several multilateral or bilateral cooperation agreements between national and regional actors also influence certain aspects of IWT policy. Examples are cooperation between the Flemish Region and France for the Seine-Nord Canal or cooperation between Dutch and Flemish waterway managers in addressing cross-bordering environmental issues or building new IWT infrastructure (e.g. River Information Services such as Visuris³⁷). Not only port authorities, but also waterway infrastructure managers and experts organize themselves in international platforms such as PIANC, the Permanent International Association of Navigation Congresses.

3.2.4. River Commissions

Specific to inland navigation policy is the phenomenon of the river commissions. Most of Europe's transboundary rivers have their own inland navigation authority and are called river commissions. The most known river regulators in Europe are the Central Commission for the Navigation of the Rhine

³⁷ <https://www.visuris.be/>

(CCNR) and the Danube Commission (DC). Moreover, smaller river commissions exist such as the Moselle Commission, the International Commission for the Protection of the Elbe River (IKSE-MKOL), the International Sava River Basin Commission (ISRBC) and the International Scheldt Commission.

The mentioned river commissions are not to be confused with separate international commissions for river protection which exist on the Danube (ICPDR), the Rhine (ICPR) or even the Scheldt (ISC). These commissions focus mainly on environmental policy to improve water quality and flooding management, but they have no real focus on the socio-economic dimension of inland navigation. In some cases, the environmental protection themes are combined with IWT topics in the same commission (e.g. IKSE-MKOL and ISRBC).

Because of historical and political reasons (Vienna, 1815; Mannheim, 1868), the Rhine developed a dedicated regime through the supranational Central Commission for Navigation for the Rhine (CCNR). The Danube Commission (DC) emerged in 1948 after the conference of Belgrade and became political and physical linked with the Rhine after the fall of communism and the opening of the Rhine-Main-Danube Canal (1992).

The members of the CCNR are the Netherlands, Germany, Belgium, France, and Switzerland next to several observing members. The members of the DC are Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, Ukraine, Russia and Moldova. The DC has also observer members which are currently Turkey, Macedonia, Greece, Cyprus and Montenegro. There is a distinction between observing and full membership. Whereas a full membership implies voting rights and even a form of veto power, observing members only give advice and cooperate operationally. Luxemburg and the Czech Republic are riparian MS of respectively the Mosel Commission (includes France and Germany) and the IKSE-MKOL (includes Germany). The main reason why some countries are a member of a river commission, although they are not a riparian state, is because of historical and often political reasons (e.g. Belgium and the CCNR).

The CCNR is the oldest, active international organization and has responsibilities for regulations in areas such as police, inspection, technical vessel requirements, transport of dangerous goods (until ADN on UNECE level) and crew requirements for the Rhine. The CCNR is also responsible for the annual EU funded market observation reports which has developed a larger scope than only the Rhine since the past decade. With Switzerland being a full CCNR Member State and the Republic of Moldova, Ukraine, the Republic of Serbia and the Russian federation belonging to the Danube Commission, these commissions are not limited by the borders of the EU. Almost every European inland navigation country is influenced in one way or another by these river commissions.

The CCNR, the Moselle Commission (MC) and the International Sava River Basin Commission (ISRBC) are, in contrast with the UNECE which is discussed in 3.2.6, able to impose legally binding decisions immediately after unanimity of all their MS. The DC, on the other hand, issues decisions and recommendations which are not legally binding, and which need to be implemented first through transposition into national legislation (UNECE, 2011a: pp:48). Enforcement and monitoring of the implementation of regulation is done on the national level.

To become a member of a river commission it is not required to be an actual riparian country (e.g. the Russian Federation, Belgium and DC- candidate members France and Turkey). Moreover, as the institutional framework is shifting with the emergence of CESNI, the Danube Commission is modernizing and enlarging its number of members.

The River Commissions and the waterway managers are identified as public actors that have a team of experts, experience, network and knowhow, with a daily focus solely on the inland navigation sector. On the other discussed levels such as port authorities, regional and national ministries do not have similar departments or even divisions that have a comparable focus. These public actors divide their attention between several modes of transport. It becomes already clear that the river commissions and the European Commission are the main actors behind the co-existence of dual regimes in the (pan-) European navigation. River commissions lack important competences such as public funding or other

socio-economic policies on supply and demand of the innovation. Most of their work is limited to regulation and creating standards which also includes mutual recognition as explained later in this Chapter. The following paragraph explains and analyses the European Union as a policy actor towards inland navigation.

3.2.5. European Union

Inland navigation policy in the European Union has experienced some important institutional changes since the introduction of the scrapping regulation (EEC/1101/89, 27/04/1989) and the liberalization of the fleet directive (Council Directive 96/75/EC). Starting from the end of the nineties the system of chartering by rotation was abolished. From that moment the European inland navigation became a free market. The European Union enlarged with more Danube countries such as Hungary, Slovakia (2004), Romania, Bulgaria (2007) and Croatia (2013) which was another milestone with consequences for IWT. The only Danube countries that did not become a member (yet) are Serbia, Ukraine, Moldova and the Russian Federation. This enlargement made the scope for EU IWT policy makers larger than mainly the Rhine region and its tributaries. New MS accepted EU directives and other regulation for their inland navigation market.

The European Union can be considered as the main power behind the liberalization wave in the inland navigation market. Another initiative of the EU was the NAIADES programs (Pauli, 2016) and several funding programs as discussed in the literature review. The first edition of NAIADES, between 2006 and 2013, was focused on addressing challenges in six areas concerning infrastructure, market, fleet, jobs and skills, innovation and policy³⁸. During the preparation of the second edition of NAIADES (2011)³⁹ and the evaluation of the first policy package, the European Commission launched the whitepaper on transport, “Roadmap to a Single European Transport Area – Towards a competitive and resource-efficient transport system⁴⁰” which also puts emissions more on the agenda.

Since 2014, the EU installed a new infrastructure policy for transport with the appointment of European Coordinators for each of the nine identified core network corridors and for two horizontal priorities (European Rail Traffic Management System and Motorways of the Sea). The work plans of the eleven coordinators were approved in June 2015 and run towards 2030. The most important IWT projects (that are mentioned) are the Seine-Nord Canal (CSNE) and the Rhine/Meuse – Main – Danube axis. The policy system around the coordinators includes a support structure such as corridor fora and thematic working groups of experts. Public and private authorities, on regional, national and local levels, infrastructure managers, investors, social partners and other actors are involved.

The European Commission (2014b) identified three priority areas for action: efficiency increase of the transport system, faster deployment of low-emission alternative energy and zero-emission vehicles. The suggested funding to support the strategy of the EC refers to the Investment Plan for Europe (the Juncker’ plan), the European Structural and Investment Fund, the Connecting Europe Facility and the research programme Horizon 2020. If all transport modes would have zero emissions, the main social benefit of IWT will still be the possibility to shift volumes from the heavily congested road haulage to a congestion and virtually accident free mode of transport (time and safety benefit), giving policy makers and industry enough reasons to invest in a more sustainable IWT. In order to comply with the ambitions of the new NRMM (Non-Road Mobile Machinery) regulation of the European Commission, the IWT fleet will have to adapt. Alternative fuels, after-treatment systems and green propulsion are

³⁸ The sixth area was soon abandoned as working area. Official sources only mention five areas and consider the challenges concerning governance as a reflective part.

³⁹ <https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52013SC0324&qid=1543239289640&from=EN> 40 EC (2011), White Paper Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, Brussels, 28/03/2011, 144 final

possible solutions. Several research projects and even ships were funded with EU money so far such as Port-Liner⁴¹, LNG and Prominent.

The EU has a larger scope than river commissions and its focus grew since the eighties on IWT. Next to public funding and some important Directives as described above, they are also responsible for Directives concerning crew and technical requirements. Which co-existed for several years next to the Rhine regulation creating a de facto dual regime with some interesting differences between them but within mutual recognition.

As said, another less known policy actor has gained importance for IWT the last decades which gave IWT policy a more pan-European dimension and which is explained in the following paragraph.

3.2.6. United Nations Economic Commission for Europe

The UNECE is a regional commission for Europe and works as a subsidiary body of the Economic and Social Council, ECOSOC. The fifty-four Members are elected for a three-year term by the General Assembly of the UN. The president and the other members of the governing bureau are elected annually. ECOSOC finds its legal grounds in Chapter X of the UN-Charter which states in article 68:

“The Economic and Social Council shall set up commissions in economic and social fields and for the promotion of human rights, and such other commissions as may be required for the performance of its functions (UN, 1945).”

The UNECE has a Pan-European character and scope. A disadvantage while analysing the effects of a certain UNECE policy, lies in the soft power of its treaties and resolutions. Unlike the European Union, the UNECE is not able to enforce legislation. The 56 MS of the UNECE exceed the geographical scope of contemporary Europe and include Canada, the USA, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan and Western Asia (Israel). At the start, the UNECE included all participants in the reconstruction of post-war Europe. After the disintegration of the USSR, Yugoslavia and the acceptance of Israel the number of MS increased from 34 to 56.

To facilitate Pan-European transportation in general, the UNECE tries to establish one single Pan-European regime or set of rules in several fields together with the river commissions. For example, in the past there were three different regimes for the formal demands of a transportation contract on issues such as liability, bill of lading, general average and so on; the Mannheim Convention (1868), the ‘Acquis Communautaire’ of the EU and the Belgrade treaty (1948). As the Berlin Wall fell and inland navigation became more international, the sense of urgency grew for one single Pan-European regime.

After several failed attempts, the CMNI treaty (*Convention de Budapest relative au contrat de transport de Marchandises en Navigation Intérieure*), inspired by the ‘due diligence clause’ of the Hague Visby Rules, was established as a set of rules for transportation contracts on the inland waterways, defining the liability of those who deliver goods to a ship, who transport them and who receive them. This treaty was agreed on by the UNECE together with the DC and CCNR in Budapest on 3 October 2000. In 2001 and 2002, it was signed by all officials. A special article in the CMNI treaty (Art.34) stated that the treaty would enter into force, and therefore partly avoid a possible long ratification process, three months after five signees ratified the treaty or made it clear to the depositary state not to make any reservations as to ratification, acceptance or approval, which it did in 2005. The CMNI applies to all inland navigation contracts when unloading and loading takes place in two different treaty states and where at least one treaty state is a party to this convention.

⁴¹ There were no European examples of electrified freight transport in IWT identified and it was unfortunately not possible, despite email correspondence, to receive usable data from the *Guangzhou Shipyard International Company Limited* for their claimed launch of an electric barge (suggested to transport coals for power plants) in November 2017. The only identified project in Europe for electrical freight transport in IWT was Port-Liner, but their concept changed quite recently into dual fuel with hydrogen because of the claim that infrastructure managers did not want to invest in on-shore battery containers.

Another example of a Pan-European action is the ADN treaty or the *European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways*. The ADN entered into force on 29 February 2008 and replaced the different regimes relating to dangerous goods IWT and became mostly known in the sector for the double-hull conversion of the tanker fleet. The ADN aims at:

- ensuring a high level of safety of international carriage of dangerous goods by inland waterways;
- contributing effectively to the protection of the environment, by preventing any pollution resulting from accidents or incidents during such carriage;
- facilitating transport operations and promoting international trade in dangerous goods.

The ADN treaty was adopted on 26 May 2000 in a joint effort between the CCNR and the UNECE and opened for signature for all UNECE MS whose territory contains inland waterways, other than those forming a coastal route, which are described by the AGN treaty (European Agreement on Main Inland Waterways of International Importance, UNECE, 1996) or as described in article 10 of the treaty. The ADN treaty came into force as soon as seven MS accepted, accessed or ratified it which was in 2011. For now, it is important to know that the UNECE does not have similar policy competences as the European Union or its Member States. It completely depends on the willingness of states to ratify resolutions and to transpose other agreements in their legislation. The UNECE does not impose any enforcement. There is also no public funding mechanism for IWT. The last few years another public actor emerged under the name CESNI and which is discussed in the following paragraph.

3.3. Current developments

Since 2015 a new policy framework came in operation (CESNI, a European committee for drawing up common standards in the field of inland navigation, *Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure*) between the CCNR and the EU. Within this framework the European Commission works closely together with the CCNR on common standards for crew regulation and technical requirements (ES-TRIN⁴²). Since 2019 two more CESNI committees emerged which aimed at standards for river information services and electronic devices. Automation and digitalisation of the sector are put on the agenda of these committees. CESNI enlarges the scope and unifies the dual regimes in the European IWT through collaboration. CESNI (crew and technical requirements) created one regime which is relevant for technological, operational and managerial innovation on the European inland waterways.

The problem of differences between EC and CCNR technical regulation is addressed by CESNI PT, which is the branch of the CESNI committee that develops and updates the new technical standards for IWT inside the EU regulatory framework in a joint institutional undertaking with the CCNR. One of the results of the CESNI PT are the mentioned ES-TRIN standards which also refer to the NRMM legislation. Discussing the standardization of emission limits lies out of the scope of CESNI and remains within the NRMM regulation of the European Commission.

It is yet too early to conclude if the creation of CESNI had a positive impact on innovation uptake such as alternative fuels by harmonizing regulation, but it is the aim of CESNI to complete the internal market for IWT by levelling the set of regulations for all actors inside one regime instead of several.

3.4. Overview of members at pan-European levels

Several governmental organizations are involved in policy making for the transportation sector and are part of the complex network of supra- and national policy making. The river commissions (RC), the UNECE, the European Commission (EC) and bilateral and multilateral cooperation between MSs and in some cases non-MSs, regional and local governments, and the port authorities.

⁴² European Standard laying down Technical Requirements for Inland Navigation vessels

Table 15 gives an overview of membership in the above-mentioned international organizations and bodies:

	UNECE	EU	CCNR	DC	ISRBC	MC		UNECE	EU	CCNR	DC	ISRBC	MC
Austria	X	X		X			Luxembourg	X	X				X
Belarus	X						Moldova	X			X		
Belgium	X	X	X				Netherlands	X	X	X			
Bosnia and Herzegovina	X				X		Poland	X	X				
Bulgaria	X	X		X			Romania	X	X		X		
Croatia	X	X		X	X		Russian Federation	X			X		
Czech Republic	X	X					Serbia	X			X	X	
Finland	X	X					Slovakia	X	X		X		
France	X	X	X			X	Slovenia	X	X			X	
Germany	X	X	X	X		X	Switzerland	X		X			
Hungary	X	X		X			Ukraine	X			X		
Ireland	X	X					United Kingdom	X	X				
Italy	X	X					United States of America	X					
Lithuania	X	X											

Table 15: Full membership in inland navigation policy institutions
Source: updated from UNECE, 2011a

3.5. Policy network

It becomes clear already that there is no real centralised pan-European inland navigation policy with its own executive. The policy power is fragmented between several institutions, regional and national governments which in several occasions led to conflicting regulation and scattered opinions in different areas of the multileveled policy arena or as Doni described already in 1965:

“Eine der wesentlichsten Aufgaben europäischer Binnenschiffverkehrsverkehrspolitik ist deshalb die Zusammenführung dieser noch widerstreitenden Strömungen zu einem gemeinsamen Ergebnis (Doni, W., 1965:91-125).⁴³“

Since Doni several things have changed but inland navigation policy and its institutional landscape is still fragmented amongst several institutions with their own historical backgrounds and traditions. The institutional landscape of Pan-European Inland Navigation Policy (PEINP) has been subject to several studies, papers and Ministerial Declarations in the recent past. Some might advocate for a substantial change of this landscape in creating one single European institution, while others stress the need for continued harmonization of technical and legal rules in the existing policy framework.

Figure 26 shows the relationship between the policy level and how actors depend on each other.

⁴³ One of the most essential tasks of European inland waterway transport policy is therefore to bring together these still conflicting currents into a common outcome

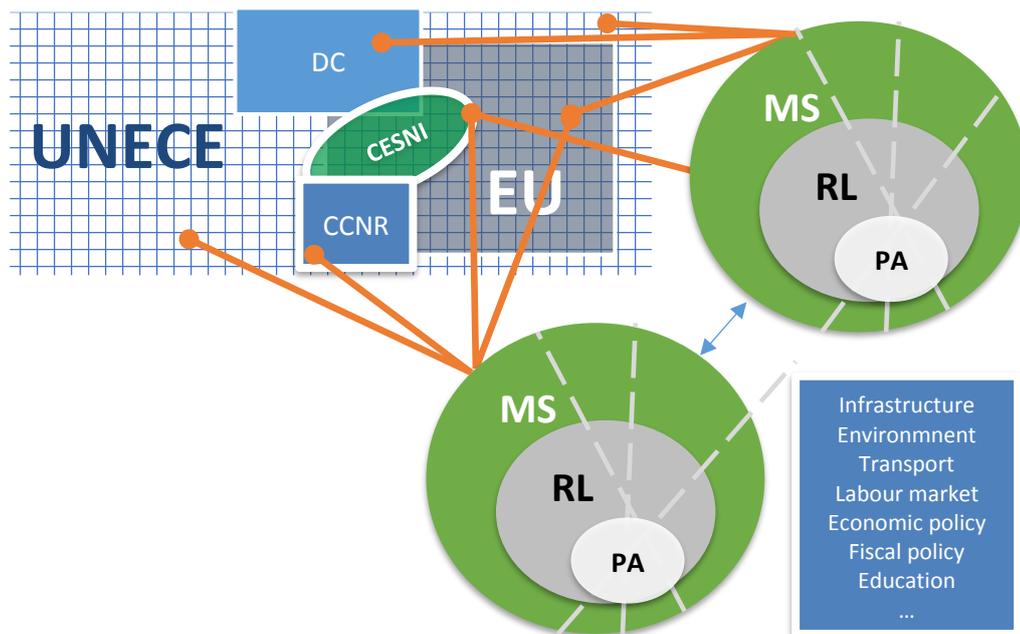


Figure 26: Institutional actors of the Pan-European IWT policy framework
 Source: own creation. PA: port authority; RL: Regional and local governments; MS: Member States

The schematic overview of the Pan-European IWT policy framework) reveals a complex multilevel, multidimensional and multi-layered policy model as explained.

What are the possible reasons why the Pan-European institutional policy setting of inland navigation is fragmented in an institutional macro-sociological context of European integration? The distinction can be made between reasons of composition, history and institutionalism:

1. **Composition:** In all identified river commissions the consensus model is being applied, making every member a powerful veto player. Some of members of the river commissions have no EU membership. It can be considered as a rational behaviour of these actors not to choose to change their rightful claim of controlling their own part of the river. If the European Union would become more responsible for the Danube or the Rhine, this could possibly give non-EU MS a weaker negotiation position.
2. **Historical:** River Commissions have developed their own political culture, working languages, values and views on their rivers and offer a multigenerational network of inland navigation experts with an institutional archive and highly specialized knowledge.⁴⁴
3. **Institutionalism:** Institutions are known to resist radical changes. Using Williamson's classification of institutional dimensions (Williamson, 1985 in Marsden and May, 2006: 774), the institutional structure of the Pan-European Inland Navigation Policy (PEINP) can be divided into informal and formal, policy institutions and actions of actors in the decision environment. These institutions are further explained in the next paragraphs.

3.5.1. Formal institutions

Formal institutions relate to institutions such as statutes, constitutional provisions, certificates, laws or regulations. Regulations such as the RRN (Regulations for Rhine Navigation personnel), RVIR (Rhine Vessel Inspection Regulations), RPR (Police Regulations for the Navigation of the Rhine), CLNI (Strasbourg Convention of 2012 on the Limitation of Liability in Inland Navigation), CDNI (Convention

⁴⁴ The CCNR finds its origin in 1815 (Vienna Congress) and 1868 (Mannheim Convention). The DC has its origin in 1948 with the Belgrade Convention and had several predecessor commissions (European Commission of the Danube 1856-1938 and International Danube Commission 1918-1938). It developed mainly behind the Iron Curtain.

on the Collection, Deposit and Reception of Waste occurring in the Course of Navigation Inland and on the Rhine), CASC (regulation of social security of crew members)⁴⁵, CMNI (Budapest Convention on the Contract for the Carriage of Goods by Inland Waterway), all are formal and international institutions that often co-exist with comparable formal institutions of the EU or the UNECE (e.g. CEVNI⁴⁶, ADN).

3.5.2. Informal institutions

Values, norms, practices, customs, traditions within informal group dynamism, differs between the different policy actors. E.g. the policy arena in the EU has 28 MS with a diversity in customs, practices and culture. Trying to reform institutions, even informal ones, can result in institutional resistance. Mostly Member States with a special interest in inland waterways, take actions regarding to IWT policy in the EU while other MS without any significant IWT show a tendency in opting out on proposed IWT Directives.

3.5.3. Policy institutions

Policy institutions relate to rules of conduct, government operational guidelines and the organizational framework. After the EFIN rapport (a new regulatory framework for the inland navigation in Europe, 2004) and the NAIADES programs, efforts have been made in reorganizing the institutional framework. Nevertheless, a new river commission emerged in 2005 with the establishment of the International Sava River Basin Commission (ISRBC) comprising members of the former Socialist Federal Republic of Yugoslavia. Two out of four ISRBC members joined the EU, which made this RC an extra partner inside the already complex PEINP structure.

The EU IWT policy process consists more of coordinating and steering between river commissions and national/regional policy actors, to find common ground.

The DC and the ISRBC are comparable (with juridical caution) with UNECE Resolutions in respective of their nonbinding nature. As the ILO-study (de Leeuw et al., 2013:13; International Labour organization of the UN) points out concerning the regulatory framework of living and working conditions in IWT of the UNECE-MS, there is no real hierarchy among these frameworks, but overlapping exists. For instance, the EU and the CCNR have concluded an administrative arrangement relating to a cooperation framework (e.g. Market Observation). Similarly, a cooperation framework has also existed between the CCNR and the Moselle Commission (Luxembourg, Germany, France) since 2014, stating that both commissions would have an observer status without voting power at each other's meetings. The CCNR exchanges information concerning any working programs (market analyses and police regulation) following the cooperation between the CCNR, the EU, UNECE and the Danube Commission, and concerning the common adoption of the RAINWAT – agreement (Guidelines of radio usage; Regional Arrangement on the Radio-communication Service for Inland Waterways).

The Danube Commission also has agreements of cooperation with the European Commission. The focus of these agreements lies on the waterway infrastructure. Other elements concern the elaboration of technical standards for navigation, infrastructure maintenance and navigability status assessment on the Danube River, contribution to the elaboration of technical standards for inland waterway vessels and the market observation. The CCNR and the DC also reached policy institutions such as the mutual recognition of the boat masters' and radar certificates and service record books.

⁴⁵ CASC stands for the central administration of social security for Rhine boatmen but was originally the result of an ILO conference in 1949 (International Labour Organization, tripartite platform between workers, employers and governments on the international level). It was the first multi-lateral European instrument for social security that instituted a system for coordinating social security legislation among the countries concerned with the interests of Rhine boatmen, who represent a special class of migrant workers (CCNR, 2016, retrieved online).

⁴⁶ the UNECE worked on a fifth edition of the CEVNI which is strongly comparable with the RPR of the CCNR. The RPR has been used by the DC as a basis for its elaboration on the "basic Provisions relating to Navigation on the Danube" (ILO, 2013:49).

3.5.4. Actions of actors

Policy actors and their actions are interdependent and influence each other's behaviour in the policy making process. Adding to the complex network, is the important role of stakeholders (shipping agents, skippers/ship owners, customers, financial institutions, verification agencies, labour unions, experts and lobbyists), media, environmentalists and others that influence the policy making system as well. This complex network results in a multidimensional (pan-) European inland navigation policy (PEINP) as well in horizontal as in vertical perspective. Horizontally, other policy domains such as environmental, social, competition policies and others can intervene in a direct or indirect manner and cause conflicting policies. Inside the PEINP, the inland navigation policy and policies for other transport modes have a similar interdependence. In most MS inland navigation policy is a part of a more general transport policy. Interdependence in this case is explained as the mutual dependency not only between policy levels and policy domains, but also between MS through multi- and bilateral agreements.

Actors that are not yet fully explained yet are the sector organizations such as the European Barge Union⁴⁷ (EBU), the European Transport workers Federation⁴⁸ (ETF) and the European Skippers Organization⁴⁹ (ESO). Although they have a European dimension, they are still a platform of mostly Rhine oriented national member organizations. Over the past years, EBU and ESO worked closely together around nautical-technical issues inside a structural Nautical-Technical Committee and started to collaborate on issues such as infrastructure, jobs, skills and education. Recently, they started to work together in a common IWT platform on a more structural way. However socio-economic issues still can have different views and beliefs between both organizations⁵⁰.

The policy actions in inland navigation can be understood in three dimensions. First, policy that is aimed at crew members (education, examination, training, certificates, qualifications...). Secondly, policy that is aimed at vessels (technical requirements, technology, innovation, emissions, energy...). Finally, policy aimed at the main European waterways and their environment; the Rhine and Danube (good navigation status, rivers speak, infrastructure...). IWT regulation can distinguish among rules of public law (technical and safety regulations) and private law (regime of legal obligations and liability).

So far, the multilevel policy scene is set with a pan-European dimension with the emergence of the UNECE as IWT actor and is viewed through the perspective of the NIE. Other more recent developments (CESNI) are next to the new collaboration of several sector organisations and river commissions and their interdependence in both horizontal and vertical way, identified and provides the framework for adding transaction costs to each level.

3.6. Towards a definition of PEINP

Based on the conducted descriptive analysis of the current policy network of the PEINP in this research, its institutional actors and a brief review of the EFIN report of 2004, the PEINP can be described as follows: *"a multi-layered multileveled policy model with growing actor interdependencies and legal scope aiming at a level playing field for IWT in accordance with safety, environmental, social, legal and technical standards and regulations."*

⁴⁷ The EBU, which represents national organizations of shippers, charterers and some larger ship-owners, also has only two members out of 11 which are from Romania and Czech Republic.

⁴⁸ In the ETF executive committee, almost 40 people come from Western-European countries (including Greece, Switzerland and Norway). Only 15 come from Eastern-European countries, where six of them represent a Danube country. On the Management Committee of the ETF, only two members out of ten are not from the West. Only a small part of these representatives are working around inland navigation.

⁴⁹ The ESO represents the national ship-owner/operator organizations, only one member organization does not originate from a CCNR Member State (ZPAS, Polish Inland Ship-owners Association).

⁵⁰ For example, where the ESO urged for anti-crisis policy measures in 2013 to solve problems in price setting, EBU rather responded by defending the free market. Inside the European organizations different views are still possible. During the skipper strikes in the Flemish Region in 2013, Flemish skipper organizations accused Dutch operators of unfair competition.

This definition describes a fragile institutional balance. The nineties' decade can roughly be described as a period of institutional conflicts and failed harmonization attempts, the lack of cooperative co-existence of different regimes and the new emerging active EU-policy for IWT. During the nulls, the harmonization policy was replaced by a different approach which resulted in an (sometimes) uneasy institutional peace with cooperation, mutual recognitions, RIS development, the integration of more Danube countries, the growing role of the UNECE (e.g. ADN), the EFIN findings, the first NAIADES program and the creation of a multi-institutional market observation report.

Today, the IWT sector witnesses:

- More policy coordination between institutional actors;
- A legal system of delegated acts which connects regulation of the EU with river commissions or other institutions (such as CESNI);
- An open window of opportunity to change regulation concerning crew, technical requirements and emissions;
- Regrouping of lobbying sector organizations and their professionalizing.

What are the costs and benefits of this policy system and how can it benefit IWT innovation? Could an answer on this question, lead to the development of a policy analysis which could help answering the second part of the RQ? The following sub-section tries to develop a framework to identify (transaction) costs and benefits of PEINP.

3.7.Costs and benefits of PEINP

The ultimate goals of this part are to identify the costs and benefits of PEINP which can be applied on an IWT innovation case. After analysing the different IWT policy levels and public actors that are relevant for an IWT innovation policy, the presence of several transaction costs become clear such as enforcement, compliance costs and asymmetrical information costs.

Following assumptions are made: Costs and benefits can be observed and identified at all policy levels. In different policy phases, benefits and costs are assumed to differ from each other, especially when multiple policy levels are involved to address the same topic.

Second, policy institutions use factors from the economy which implies an opportunity cost on society's welfare. These factors establish a certain policy and are not being used for other opportunities.

A final assumption is more specific and relates to the developed view on compliance costs. In this research the distinction is made between internal and external compliance costs from the perspective of the public actor. Internal compliance refers to the need of legal coherence of an action with other actions of the same policy actor. External compliance refers to compliance of an action of the public actor with actions of other public actors that are on a higher or equal level of power.

Administration, translation, publicity, employment, housing and transport costs are typical overhead costs which can be found in every organisation, and thus also public actors. However transaction costs go further than only costs related to overhead. The theoretically developed costs and benefits are brought in accordance with the phases of the policy cycle as shown in Table 16.

Most policy evaluation costs are included in the information costs that are made to retrieve information on past policy to create new policy. Enforcement costs depend on monitoring costs of the policy. If monitoring shows that operators refuse to comply with new regulation, more enforcement could be needed: by juridical procedures, fines, inspections, etc. During the outcome phase of policy, enforcement costs are possibly made if actors do not comply to the resulting policy. Furthermore, during other phases, enforcement costs can be identified.

	Input: demands and support, defining an issue	Agenda/selection of issues	Decision making	Implementation	Outcome/evaluation/feedback
Costs					
Information	Expert meetings, conferences, interest groups activities, research (academic and consultancy) Higher if asymmetrical information	Research support for deliberation, Nautical, technical economic and juridical advice, Budget information, Suggested solutions	Information for meetings of officials Choosing the "right solution"	Information about implementation	Surveys, Effect analyses, Monitoring policy, Information for evaluation purposes
Administrative	Secretary work Organizing meetings Reports and preparation of meetings	Secretary work Listing the alternatives Reports and preparation of meetings	Organizing meetings Secretary work Reports and preparation of meetings	Communication with and retrieving information from stakeholders	Gathering statistics, Organizing meetings Secretary work Reports and preparation of meetings
Translation	Reports and preparation of meetings, Interpreters	Agenda, interpreters	Translating policy papers and decisions, Interpreters	Translating official documents towards MS	Translating evaluation activities and documents
Communication	Publishing meeting reports	Publishing agenda	Communicating decisions	Publishing guidelines for implementation	Evaluation results, reviews
Employment	Civil servants, representatives, officials, experts				
Housing	Meetings and conferences at different locations, hotels				
Transport	Traveling abroad: signing charters, depositing signatures Moving official documents and working staff External costs				
Enforcement	Demanding statistical data input, transparency Enforce if necessary and possible by police, courts, fines				
Compliance (internal)	Consistent with equal legislation Precedence of legislation Competences check				
Project	Investment of the chosen policy/project (subsidies, infrastructure)				
Opportunity	Use of scarce government means for policy development and implementation and not the alternative				
Benefits					
Quality	Valid information and knowledge, reducing asymmetrical information problem Learning curve through pool of experts and consultation; private and public stakeholders		Scope of implementation influences the benefit Evaluation capacity Learning curve Output of insight and information to market Credibility of policy		
Synergy	Bringing experts regularly together can cause sustainable synergies in research and other inputs Exchange of best practices between MS				
Social	If changes already occur in expectation of the developed policy, this can already give social benefits.		Redistribution of welfare, infrastructure, health and environment, Safety...etc.		

Table 16: Policy costs and benefits in a policy cycle

Source: own creation, adding transaction costs to the policy cycle. (policy cycle by Crabb et al. 2012; Lasswell, 1956)

Policy makers must comply internally with other legislation from policy levels according to the precedence principle. In a multileveled and multi-layered policy model it is not uncommon that institutions meet each other in public courts. The higher the complexity of the institutional setting, the higher the internal compliance costs of policy. All the identified costs are included, normally, in the budget of administrations and other regulation sources. The following parts explain these developed costs and benefits as attributed to the stages of policy more.

3.7.1. Policy costs

As explained in the literature review the economic transaction cost theory (Coase, 1937, 1984; North, 1992; Ostrom, 1990) provides the basis of this approach together with the findings of Pelkmans (2006).

A. Policy credibility and asymmetrical information costs

Policy institutions are contractual partners towards stakeholders and society whereas politicians primarily have a contract with their constituency. If promises and deals are not kept, the credibility of policy becomes problematic and threatens the dynamism of the involved stakeholders which can lead to government failure and to innovation failure. The phenomenon of asymmetrical information which is described in the transaction cost literature, can lead to moral hazard and adverse selection.

Asymmetrical information costs lie in every phase of policy, but they work in both directions. The innovator does not always have an incentive to be completely honest or transparent towards the policy partner and can decide to withhold vital information (from a welfare perspective) that could weaken the business case. The policy institution does not always have the time, means and capacity to get all the information of the innovation. Sometimes, policy has more information which it keeps confidential in order not to influence a desired outcome. Asymmetrical information can lead to higher costs in every policy cycle phase but if repeated too many times, the partner will develop a weaker negotiation reputation and will pay more in the long run, jeopardizing future deals. The cost of the private asymmetrical information can be threatening for the innovation market uptake. The development of an innovation within the innovation network relies on trust, as most social relations do in order to succeed. A high uncertainty caused by asymmetrical information could be a significant cost.

B. Enforcement costs

Policy enforcement has an impact on the innovator. If the innovation does not comply with the regulation, the innovator or its customer could be fined. A lack of enforcement can lead to unfair competition were competitors do not comply with regulation which indirectly punishes those that do comply.

The level of policy explains partially if the policy outcome will be easily enforced. Not every level has monitoring or enforcement capacities and often relies entirely on the MS or other policy actors within the multilevel policy model to implement a given policy. Policy in this case is broadly defined and comprises resolutions, regulation, standards, directives, delegated acts and other law instruments. And, when enforcement costs are considered too high, the incentive to comply decreases.

Enforcement does not only consider private partners, but also between public actors where Member States need to comply to supranational agreements such as regulation. Enforcement costs as developed in this research relate to the costs of river police, Rhine courts and the Court of Justice of the European Union.

C. Compliance costs

Compliance costs, as mentioned before, have a public and private dimension. From an innovator point of view, compliance means that the innovation should be complying with existing legislation. Not every innovator has the means to convince regulators to change regulation if compliance to existing regulation could jeopardize the innovation, or the ability to understand the PEINP sufficiently to know who to address and how to proceed. These costs are compliance costs and are also the main reason of existence of professional lobby groups.

An innovator can also be a lobbyist that has to convince policy makers to foster the development of the innovation by adapting regulation, providing infrastructure, giving subsidies or other support. The innovator can also ask to be left alone and free to innovate. In this case the policy is asked to do nothing. Innovators, like any other lobbyist, could be involved in every phase of the policy cycle if the innovation needs policy. At a certain point during the innovation development, talking or collaborating with the government can be unavoidable.

D. Transitional costs

Policy that supports an innovation competes indirectly against traditional existing products and services, leading to transitional social costs. All phases in the policy cycle can lead to this kind of changes in the market. Those who anticipate early on future regulation or subsidies, change their behaviour before the actual policy implementation and pay transitional costs. Consequently, the market can be disturbed by expected policy without factual policy implementation. In some cases, this is intentional and part of the policy strategy to provoke this anticipative behaviour.

Policy that provides inadequate outdated standards or other failed policy, can also provoke anticipative behaviour. Innovators could choose other markets to explore and take their potential benefits with them. And also, adverse selection of an innovation through regulation and standards, can indirectly eliminate any incentive for other perhaps even better alternatives⁵¹. These transitional costs are mostly captured by losses in producer and consumer welfare and are neglected, to avoid being double-counted in the analysis.

3.7.2. Policy benefits

It is assumed that the inherent goal of the policy cycle and its outcome, is to change or improve society. The benefits of a multilevel policy where public and private actors cooperate generates certain process benefits. These potential benefits relate to policy quality and synergy next to the more outspoken social benefits that depend on the outcome of a policy. The causality between a given policy and observed social change or other targeted benefits, is not always clear and often difficult to prove.

A. Synergy benefit

Bringing experts, stakeholders and policy makers together in a policy structure on a regular basis, leads to the mutual benefit of sharing knowledge. It delivers a framework where actors can learn from experiences in order to improve the quality of the developed policy and to create spin-offs which could lead to more innovation, also outside the policy arena.

The policy model is not only a multidimensional and multi-layered meeting room between public and private players focusing on an issue inside the policy cycle, but it often gives an opportunity to participants to build sustainable relationships and to learn from each other. Synergy benefits increase the knowledge pool with the public actor. It offers economies of scale and depends strongly on the scope of the policy level. In this regard, the knowledge pool depends on the quality and quantity of the input from accessible knowledge networks and on the gate-keeping output. The latter refers to individuals or institutions that are responsible to collect, process and publish the input of experts. During this process, also the political rational has an influence. Size is not everything and defining or measuring policy quality is subjected to political debate and bias.

What it certainly does not mean, is that a higher level with potentially a larger network, would deliver a better policy quality. The quality of the policy outcome is discussed in the following part.

B. Quality benefits

The higher the policy level, the more stakeholders and MS could be invited to share information and to learn from each other. Best- practices can be exchanged and policy could be improved during all phases of the cycle. Of course, the quantity of involved stakeholders is not sufficient to improve quality. The degree of professionalization and specialization, and the accessibility of the arena to experts and real innovators are vital to improve the quality of policy.

⁵¹ The implementation of double-hull which had a social benefit of a modernized and safer tanker fleet, disturbed the second hand market of single-hulls and several ships ended as a wreckage on the coast of Nigeria and Ghana. Other hull innovation had no real incentive to evolve in the tanker fleet and external costs or rather negative benefits are transferred to pollution costs in Africa.

The accessibility of relevant stakeholders during all phases of the policy cycle can also improve policy which also influences the synergy benefit as explained above. The performance indicators concerning policy implementation, evaluation capacity and others, are hypothetically allocated inside the public budget while accessibility to policy is experienced by external actors.

Policy can require homologation tests of the innovation (e.g. LNG engines, automated devices) and provide a derogation period where the innovator can derogate from existing rules with an official permission while complying to a comparable or improved safety level. Both policy actions can stop an innovation or improve the quality by demanding extra features. In this case it is assumed that inspectors have sufficient information, knowledge and capacities to evaluate the innovation.

C. Measuring policy benefits and willingness-to-pay

To measure benefits of a policy, beneficiaries can be asked how much they are willing to pay for the policy (WTP). Another method is to determine the WTP by using production data if policy would lead to an increase of production of the supported product or service multiplied by the market price.

The willingness to pay for a policy can also be reflected from a behavioural point of view on the political support by voters suggesting that if voters resent a policy, they can vote out the incumbent. In case of inland navigation, the sectoral interest has hardly any impact on general elections in most countries. However in countries where it is perceived by the average voter that inland waterways are a part of the solution of road haulage, not supporting this mode can cost votes, but again, even when this is a fact, the impact on elections is hardly outspoken. The willingness to pay for an innovation policy in inland navigation depends rather on the expected return of investment and/or social benefits, and on the strength of lobbying during the policy cycle phases in different arenas to get a topic on the political agenda when necessary.

3.7.3. Policy beneficiaries and losers

There are different costs and benefits that can be identified of each policy on an international, Pan-European or European Union level when dealing with cross-border externalities. The following example can help to understand cross-border externalities: Imagine a river that has two riparian states. The riparian state on the left bank has more water bound industry and thus more benefits to organize maintenance of the river. The riparian state on the right bank does not benefit as much to organize the same maintenance. If both do not engage in maintenance of the shared river, inland navigation will not be possible anymore and the left bank state will lose. This is an example of a cross-border externality that can be solved by a higher level that helps compensating the loser and makes sure that the river stays navigable at both sides. It is important for an innovation and for any policy to identify the group or individuals that benefit or lose from the innovation or policy. In this case, policy and innovation have comparable aspects. Both are targeting improvements. It is necessary to identify possible resistance and ways of compensation early in the policy cycle. If resistance is too high, policy or the innovation can fail. This part is an addition to sub-section 2.4.3 concerning the distribution of welfare.

A. Policy beneficiaries

The main beneficiaries of an IWT innovation policy are in the first place the suppliers of the innovation whose purpose is to sell as many products or services as possible. Other beneficiaries are the innovation customer and the society. The vessel owner/operator has a return on investment through a better management, technology (e.g. more safety, fuel efficiency) or other gains of organizational efficiency introduced by the innovation. Society experiences social benefits or a reduction in social costs, in order to legitimize the policy changes to support a given innovation. Society benefits if the innovation has a social benefit such as redistribution of wealth, cleaner air, safer transport or others.

B. Losers of policy

When policy decides to support a certain innovation, certain groups or individuals could lose despite the social and private benefits. For example, in case of alternative fuels, an innovation policy supporting producers and engine builders of alternative fuels with a subsidy, will benefit an innovation champion but the producers and engine builders of traditional fuel will sell less if the innovation becomes successful. The main losers are the incumbent dominant market actors that lose their position because of the successful innovation.

At all levels in the policy cycle, the question of social redistribution towards welfare losers can be addressed. Not all levels have competences to develop an active policy concerning the latter. During the policy stages, information and agenda-setting, firms and individuals could change their behaviour in expectation of social compensations. For example, if firms expect that policy would enforce more strict environmental regulations, they could already start investing before the policy is implemented or expect social compensation (e.g. subsidies for a cleaner engine). The higher level of policy, the more individuals could show this behaviour. The disadvantage of a higher-level compensation, is the higher complexity and it seems that especially smaller firms do not find their way easily to these levels. Even if losers of a policy or an innovation are compensated by subsidies, another potential problem emerges. Those who do not receive a subsidy are disadvantaged in the market towards a subsidized competitor.

Table 17 summarizes the identified transaction costs and benefits of PEINP according to institutional level and shows an interesting way to view policy in different dimensions. It links all IWT public actors with their transaction costs and benefits if any. This table can be enlarged if international players such as IMO or IALA are added, but they are kept out of the overview for now.

3.7.4. Policy costs and benefits according to institutional level

Different levels or institutions in the multileveled policy model of pan-European IWT are described and summarized in perspective of their transaction costs and benefits in the following table. These are generalized features and represent a simplification of the reality on every identified policy level that is relevant to IWT. Especially the relationships between the mentioned public actors are important as they add up to a real PEINP.

C-B					
Institutions	Transitional social cost	Enforcement cost	Compliance cost	Quality benefits	Synergy benefits
Port	No economic IWT-policy	Administration controls policy, juridical enforcement possible	Existing regulation and precedence of higher and European law	Frequent meetings with operators, port experts, local preferences, closest contact with part of IWT sector, including customers, but limited scope	Low, but less formal and possibly more dynamic/ responsive than other levels
Province/ Bezirke/ Department/ Canton	No economic IWT-policy	Juridical		Supporting training centres, infrastructure, knowledge centre, but in most cases ad hoc policy if any	Low, project based
Region	Affecting regional employment and firms. In most cases limited economic IWT-policy	Juridical (in case of Belgium, inspections)		Depending on region, mostly focus on infrastructure (in Belgian case much more relevance)	Depending on regional importance of IWT – sector, most regions low benefit
National	Affecting national employment & firms. Possible economic IWT – policy	River police, juridical, inspections, monitoring costs		National knowledge network institutions, data gathering, evaluation capacity	Depending on national importance of IWT – sector, most countries low benefit
Bilateral/ multilateral	Effects on involved countries. Possible economic IWT-policy	Depending on bilateral agreement, MS enforcement	Compliance within state structures, partner(s) and existing regulation and precedence of higher and European law	Bilateral knowledge exchange, cross-border initiatives	Depends on members of agreement, IWT-importance of waterway in scope enlarges benefit
River Commission	Effects on involved countries. No economic IWT-policy	Juridical, enforcement through MS	Compliance with River Commission convention and agreements with other institutions, existing regulation and precedence of higher and European law	Multilateral knowledge exchange, professional unimodal expertise network, data gathering, cross-border initiatives, hardly evaluation capacity	Highly specialized network with possible synergies and sustainable relations between institutions
European Commission	All MS. Possible economic IWT – policy (only supportive, no taxes)	Juridical, enforcement through MS, possible to give EU – sanctions to firms and MS	Compliance with Acquis Communautaire	Multilateral knowledge exchange, cross-border initiatives, evaluation capacity, data gathering, but not all MS are interested in IWT – policy	Interest in IWT depends on policy agenda of European Commission, less frequent meeting place, but higher scope of synergy possible
UNECE	All MS, largest scope but weakest enforcement of all levels, no economic IWT-policy	Good will of states, ratification process	Compliance with existing UNECE resolutions and conventions and agreements with other institutions	Multilateral knowledge exchange, not all MS are interested	Possibly strong for ADN, larger scope

Table 17: Costs and benefits of multileveled PEINP

As a theoretical example, the PEINP tool can also be applied on the system of mutual recognition (MR) as a whole (not according the policy cycle) as shown in Table 18.

Transaction costs	
Information	<ul style="list-style-type: none"> • MR is often invisible for actors • Grey areas because MR is often based on case law • No real 'legal text book' available
Compliance	<ul style="list-style-type: none"> • National regulation still exists with own particularities • Verification by European institutions or other MS or organizations who test national regulation on conditions of MR
Other transactions	<ul style="list-style-type: none"> • Monitoring of MR requires high resources, in practice not real monitoring • If MS refuse MR system, there is hardly any arbitrage • Guaranteeing rights of enterprises is difficult
Benefits	
Regulation	<ul style="list-style-type: none"> • National autonomy is protected by objectives concerning safety, health, environment and consumer protection • Emphasis on objectives, not on technical details
Strategic	<ul style="list-style-type: none"> • Improvement of free traffic of persons and services if credible • The MS remain responsible for costs of overregulating or policy failure which stimulates cost management on national level • Basis for regulation and institutional competition between MS (improvement of national policy by bench marking) • Internal market without additional or replacing regulation
Welfare	<ul style="list-style-type: none"> • Stimulates competition and growth • Influences quality of different policies (if bench marked)

Table 18: Costs and benefits of mutual recognition
 Source: based on Pelkmans (2006)

3.8. Conclusion of PEINP

This Chapter provides a descriptive analytical narrative to explore, identify and explain the PEINP which gives a basis and setting for the further development of the suggested policy analysis tool in this research. It also gives a part of the answer, although descriptive, qualitative and theoretical, on the final part of the RQ concerning policy and on the following sub-question:

What is IWT innovation policy, how is it organized and which role plays IWT innovation policy?

By using the theory of transaction costs, together with findings from European Integration theory, it was possible to identify IWT policy levels, their interdependent relations and to link the public actors with their public transaction costs. PEINP was defined in this Chapter as *“a multi-layered multileveled policy model with growing actor interdependencies and legal scope aiming at levelling the playing field for IWT in accordance with safety, environmental, social, legal and technical standards and*

regulations.” This definition can now be attached to the definition that emerged from the literature review concerning policy. This results in following definition of PEINP related to innovation:

All combined actions undertaken by a multi-layered multileveled policy model with growing actor interdependencies (both public as private) and legal scope that aim at levelling the playing field for IWT in accordance with safety, environmental, social, legal and technical standards and regulations with the objective to stimulate, facilitate, participate and / or even lead or enforce innovations towards success (or failure in case of an unwanted innovation) and to improve the innovation system in both produced quantity as quality while following a cyclic policy path and using instruments that could target both demand and supply of innovation.

Quantification of the identified transaction costs in all separate policy cycle phases, levels and areas of PEINP in this research seems challenging or even unfeasible. At this moment the developed tool is mostly descriptive because of the lack of data to quantify transaction costs which indirectly invites policy makers to collect distinctive and detailed PEINP cost data concerning public expenditures on IWT policy and make them transparent available.

The next Chapter concerning the methodological framework starts with a detailed description on how cases were selected and how the in-depth interviews were conducted during the research. The third part is about the actual methodological development of all used tools such as the SIA, CBA, PEINPA and how they can be related through a cross-case analysis.

4. Methodological framework

In this Chapter the methodological framework is developed. It starts with the description of the case selection process. Afterwards, the Chapter proceeds with explaining the role of the conducted in-depth interviews which are, unfortunately, largely kept confidential as agreed with the respondents. The applied analysis are explained in sub-section 4.3 including the cross-case analysis.

4.1. Case selection

Although there are different ways to select cases, a more pragmatic and customized approach is developed. Context and familiarity with potential cases is hereby decisive.

Through informal and formal meetings with several stakeholders and experts, several brainstorm sessions⁵², administrators and academic peers, next to extensive desk research, literature review and early exploratory in-depth interviews, a list of several possible innovations is drafted. During this stage the research time frame and a careful a priori estimation of available material for each potential case (where possible) is taken into account. Table 19 shows the result of all identified innovations in IWT. They are divided and ranked according to following developed parameters:

- Interviews: Was the innovation mentioned in the first group of exploratory interviews? The following scoring is used: 0 = not mentioned, 1 = mentioned, 2 = often mentioned; 3 = most mentioned;
- Innovation stage: Development stages are scored. The higher the development, the more knowledge could be available. 0 concept; 1 initiation; 2 development; 3 implemented. Innovations which are implemented score higher than those who are still conceptual;
- Literature available: Is there sufficient research material available to perform a case analysis?⁵³ 0 = assumed not to be available; 1 = assumed to be sufficient;
- Network: Is the network of case-related experts available and accessible? If no experts and innovators were identified, the innovation scores 0 as selection condition;
- Research scope: Is the case research feasible within given time constraints and is the case within the geographical scope of the research?
- PEINP dimension: Does the case has implications for pan-European policy? 0 = no; 1 = yes. This criterion relates to the scope of research. Does the innovation require changes in pan-European policy to be successful or is it an issue on the PEINP agenda during one or more phases within the policy cycle?
- Policy innovation: The choice has been made to focus on private innovations. When the innovation is clearly policy driven, the score is -1.

The next step during this selection process is to determine the number of cases. As the literature review concerning case studies shows, a large N-sample can have a higher representativeness of the larger population, but a smaller sample allows more detailed insight. In order to understand this largely unexplored field of European IWT innovation, more detailed in-depth case studies are preferred with a limited number of cases which were thought to be feasible in the given time frame of the case study part of the research between 2017 and 2019. A previous period of research was between 2007 and 2011 where mainly research was conducted concerning IWT policy and general transport statistics.

As the literature review shows, there is no scientific consensus on how to select research cases, but in order to allow other researchers to replicate this research on other cases, it is important to explain every step, including the case selection process, in a transparent and detailed way. The resulting long list had sufficient innovations to allow a further distinction between clusters of IWT innovations such

⁵² A complete list of respondents and contributing experts is to be found in the annexes.

⁵³ At this stage, the parameter information was for most listed innovations an assumption and in retrospect after the research did not quite fit tall listed cases such as the automated inland vessel. Future research should take this in account.

as environmental, ICT, operational, small waterways, ship design and policy. Alternative fuels, Selective Catalytic Reduction (SCR) and diesel Particulate Filter (DPF) are clustered as *environmental* innovations. Another cluster relates to innovation that has the intention to reactivate the *small waterways*. The cluster *ICT* refers to on-board information technology innovation. The cluster *policy* contains purely innovation that is implemented by policy⁵⁴. There are mixtures such as River Information Services (ICT and policy) where the key technologies are policy driven as mainly public actors were the main innovators behind it. The developed category *operational* refers to technological innovation that is used to improve the on-board operations such as loading and unloading, and water ballast (e.g. heeling pump). As explained in the literature review other typologies exist, but these clusters were specifically developed during the research to fit this long list.

The strength of this more pragmatic approach of selection relies partially on the quality of the direct input from brainstorming and from experts. A potential danger of a case selection process refers to possible bias in the input phase and which is significantly avoided by using the developed ranking technique on the long list. Indeed, the context behind the selection process interferes and could steer towards an expected research outcome.

A significant part of the selection was done during a research internship between 2017 and 2018 on the premises of the Central Commission for the Navigation of the Rhine in Strasbourg (France). In the same period the commissioners and country delegates of the CCNR discussed alternative fuels and automation during their committees. Most of the formal and informal interviews were done within this context. It was possible on the margin of these sessions to meet engine builders, LNG experts, sector organisations (EBU and ESO), the European Commission, Danube Commission and UNECE (guest-representatives during CESNI), waterway managers and port authorities⁵⁵. Through this network LNG consumers are interviewed such as Jaegers, Danser Group and Somtrans. A similar window of opportunity was true for automation.

Some innovations were discovered as participant-observer during previous years as IWT policy officer for the regional Flemish government where I had the opportunity to participate and observe as Belgian representative in meetings with the European Union and the CCNR during the removal of the bottleneck of LNG-D between 2014 and 2017; during the first CESNI meetings for Qualification of personnel; and during a research internship at the CCNR when the discussion started concerning the automated vessel. Finally, I also had the opportunity to participate in high level EU working groups concerning the financial framework of IWT during NAIADES II, next to regional various assignments for the Flemish government. These experiences triggered my passion for IWT policy and had an influence on the case selection in judging if there is a PEINP dimension, if it is a policy innovation or to estimate if case related literature would be available prior to the actual case study.

The selection process resulted in following cases of which the applied innovation typologies are explained at the beginning of every case analysis and are based on the literature review:

1. Automated and unmanned vessel (AV): mainly private, technological, organisational, managerial and cultural innovation that allows automated sailing towards unmanned and autonomous.
2. Liquid natural gas: private, technological, organisational, managerial and cultural innovation, although driven by policy: the vessel is equipped with an LNG engines and cryogenic tank.
3. e-Barge Chartering: private, technological, organisational, managerial and cultural innovation that aims at improving the business of chartering a vessel by offering an easier and cheaper way to charter a vessel through a digital online platform.
4. Small Barge Convoy (SBC): public, technological, organisational, managerial and cultural innovation that aims at the reactivation of the small waterways by introducing a new concept of convoy with self-propelled dump barges.

⁵⁴ During one of the interviews the convention of Mannheim of 1868 was mentioned as an important IWT innovation.

⁵⁵ The actors are explained in Chapter 3 concerning the institutional setting.

Innovation	interviews	Innovation stage	Literature available	Available network	Scope of research	PEINP dimension	Policy innovation	Scoring	Cluster
Gas engines (LNG)	3	3	1	1	1	1	0	10	Environmental
Automated and unmanned vessel (AV)	3	1	1	1	1	1	0	8	Ship design / ICT
e-barge chartering (e-BC)	3	3	0	1	1	0	0	8	ICT
Small barge convoy (Watertruck+)	3	2	1	1	1	0	-1	7	Small waterways / ship design
Pallet Shuttle Barge (PSB)	1	3	1	1	1	0	0	7	Small waterways / ship design
SCR + DPF	1	3	1	0	1	1	0	7	Environmental
Double hulls	1	3	1	1	1	1	-1	7	Ship design
River Information Services	1	3	1	1	1	1	-1	7	ICT / policy
Liberalisation of the sector	1	3	1	1	1	1	-1	7	Policy
Containerisation	1	3	1	1	0	1	0	7	Ship design / operational
GTL fuel	1	2	1	1	1	1	0	7	Environmental
Fuel water injection	1	2	1	1	1	1	0	7	Environmental
Scheldehuid/Y shaped hull	0	3	1	1	1	1	0	7	Ship design
Hybrid propulsion	0	3	1	1	1	1	0	7	Environmental
Act of Mannheim	1	3	1	1	0	1	-1	6	Policy
Magnetic (un)mooring	1	2	1	1	1	0	0	6	Ship design
Crane technology	0	3	1	1	1	0	0	6	Operational
z-drive	0	3	1	1	1	0	0	6	Engine design
1500 m3 Heeling Pump	0	3	1	1	1	0	0	6	Operational
Coupled barges	0	3	1	0	1	1	0	6	Ship design / operational
Full electric	1	1	0	1	1	1	0	5	Environmental
Barge RO-RO hybrid	0	2	1	1	1	0	0	5	Environmental
Optical Character Recognition	0	3	1	1	0	0	0	5	ICT
Methanol	0	2	0	1	1	1	0	5	Environmental
modal shift scans	0	3	1	1	0	0	-1	4	ICT
BCTN Barge slots	0	2	1	1	0	0	0	4	ICT
Accident casuistry system	0	0	1	1	1	1	-1	3	Policy
eIWT	0	0	1	1	1	1	-1	3	ICT
Synchromodality	0	0	0	1	0	1	0	2	ICT
Q-Barge	0	0	0	0	1	0	0	1	Ship design

Table 19: Identified and selected innovation cases in European IWT

4.2. In-depth interviews

The in-depth interviews played an important role in the selection process and throughout the research. The main targets of the interviews were the following:

- Exploring interesting cases in different innovation phases;
- Gaining real-time insight in the innovation cycle (where is the mentioned innovation located in its innovation path)
- Actor and network identification (who are the people behind it?);
- Identifying possible barriers to lead to innovation success.

Relatively early in the research a questionnaire for in-depth-interviews aiming at experts, customer/operators, researchers, policy makers and innovation champions was made. The list of possible respondents grew longer during the research. Several actors were identified that play a significant role in the innovation in inland navigation. The identification considered the background of the actor (research/policy/practice and/or public/private) and the actor level (international/ national/ regional/local). Thanks to the large network of TPR, the CCNR and different stakeholder organizations (ESO, EBU, EUROMOT, ETF, AQUAPOL, IVR, EDINNA, EICB), it was possible to find enough volunteers to have a diverse and sufficient sample to explore several innovations and possible cases for this research.

4.2.1. Questionnaire

The questionnaire used during the in-depth-interviews, started with some general ice-breaking questions that gave more input on the profile of the respondent. The questions are explained by the following table:

Factors	Target	Question
Innovation	Explore	What are the first innovations that come to mind in the inland waterways?
Success factors	Identify factors	How does an innovation become successful?
Failure factors	Identify factors	What could be the reasons that not everybody innovates? What do you think are the main barriers holding innovation down? What causes failure?
Cost and benefits	(S)CBA	How much does the innovation cost? Costs for development/investment (only when relevant respondent)? What are the (social) benefits?
Actors	Identify network	Who are the innovation actors in general or in mentioned innovations? And why? Who benefits of the mentioned innovation(s) and why?
Policy making	Acts of Policy	What can policy do to support the innovation?
	Policy level	Which policy maker(s) can an innovator address?
Consumers view	Outlook on innovation path	If you are a skipper with an old ship in what kind of innovation could you invest?
		How does the IWT vessel of the future looks like?

Table 20: Questionnaire and relevance to research

During the interviews it became clear that some questions were too general such as the questions concerning the vessel owner view. Moreover, the policy making questions were even for some policy experts not that easy to answer. Sometimes examples had to be given by the interviewer to explain the question. By doing so, there is a risk for bias in the input. Another source for potential bias was that several interviews were taken at the premises of the CCNR at the margin of official meetings with their own agendas and issues. It is suggested for future research to pay more attention to this and to

work with different questionnaires adjusted to the profile of the respondent and in different places. Nevertheless, the quality of the interviews grew parallel with the quantity. The results, although confidential and not further coded in a thorough interview analysis, are considered to be sufficient for the exploration and identification of innovation factors, policy actions and levels. Not much cost-data was retrieved because of market sensitiveness and confidentiality.

4.2.2.Respondents

The 46 interviewees come from the Netherlands (15), Germany (11), Belgium (10), France (6), UK (3) and Hungary (1). The respondents can be divided across public (21) and private actors (26). They have different profiles divided among four identified groups:

- Innovators: main driving personalities behind the selected cases, developers or innovation consumers (vessel owners);
- Direct stakeholders: representatives of IWT branch organisations, labour unions, shippers and other members of industry;
- Experts from verification agencies, research institutions, inspection and insurance agencies;
- European policy makers.

Some interviews are performed through telephone and videoconference, although real life encounters were preferred. Most interviews are recorded, and the respondent was free to oppose to recording on every moment during the interview. The interview recordings (digital MP3) are treated and processed in a confidential way. Some interviews are written down accordingly if preferred not to be recorded. The interviewees had the opportunity to validate their input during the research through an expert meeting while presenting preliminary findings. In annex all the respondents are listed next to case related contributors.

4.3.Methodology of applied analyses

To answer the research questions, following methods of analysis were chosen from literature review and further developed:

1. Systems of innovation analysis (SIA)
2. Cost-benefits analysis (CBA)
3. Pan-European Inland Navigation Policy Analysis (PEINPA)

First, SIA is applied to all selected cases. This analysis is rather qualitative and does not need extensive datasets. Most inputs come from interviews and desk research. The SIA is considered to be a powerful typology and exploration tool. It is important to understand that the SIA shows if a CBA and PEINPA need to be performed. When cost data is kept confidential an CBA is not applied. When the analysis of institutional factors reveals that there is no real Pan-European policy dimension, the PEINPA is also not applied. Second, the CBA includes a feasibility or cash flow analysis that is applied on the selected cases where relevant or possible (available cost data). The CBA is here considered as a quantitative method and is an analytical tool that shows if an investment, in this case an innovation, has a positive business case or not for the private investor and in this approach, it includes the impact of external costs. Finally, the PEINPA looks on the institutional level of inland navigation innovation policy and its impacts. The approach of the latter is derived from literature concerning new institutionalism, transaction cost theory, European multilevel policy and considers the institutional setting as it is. The ongoing institutional process of Europeanisation and in some cases Pan-Europeanisation is taken into account were visible. All three methods are combined in a framework to answer the research question.

4.3.1. System of Innovation Analysis

As pointed out in the literature review, the summarized typologies (Arduino et al., 2011; Roumboutsos, 2013; and Sys et al. 2016) are applied on the selected cases as introduction. Every case analysis starts with a description of the innovation while linking it with the typologies. The innovation is situated in every time of its development (initiation, development and implementation) and analysed accordingly.

As also explained in the literature review, the SIA helps to identify failure and success factors which are variables (X_1) that are needed to reach a desired outcome (Y) or a successful innovation. These variables refer to the failure or success conditions of the innovation during the development phases. A basic hypothesis is that the cases have a similar innovation pattern and pathway or that X_1 of innovation case 1 can also be found in the other innovation cases. X_1 refers to variables such as:

- **Infrastructure:** The physical infrastructure that actors need for functioning, including science and technology infrastructure, such as waterways, fuelling and bunker facilities; locks; terminals, refineries, quays, moorings, ...etc.;
- **Hard institutions:** Regulatory framework and general legal system such as to be found in regulations of the CCNR and the European Union. It also relates to contracts, including company law, employment contracts, and legal rules concerning patents;
- **Soft institutions:** Social institutions such as political-economic, business, entrepreneurial, and cultural influences and values which shape the context in which innovation takes place and the objectives of public policy. These will include, inter alia, firms' willingness to cooperate on innovation; the level of risk aversion in the society, and the overall commitment of government and private parties to support innovation. In this analysis subsidies are soft institutions;
- **Networks:** Interactions in networks are very important to the promotion and adoption of innovation. Networks are strong or weak and have positive and negative effects on innovation. These can also be too strong or too weak. Linkages are needed between the network actors to make sufficient use of complementarities, interactive learning, and to generate new ideas;
- **Capacities:** Firms need to be capable to learn rapidly and effectively.
- **Lock-in effects:** Firms can be locked into existing technologies/patterns and miss ability to adapt;
- **Market demand:** The demand among potential users;
- **Competition (innovation):** The extent of competition for the innovation case.

The matrix approach links the variables with actors such as waterway managers, port authorities, industry, vessel owners, financial institutions and others. This approach is applied on each case and during every development phase (initiation, development and implementation). It provides more insight why an innovation is not (yet) pulled by or pushed on the market. At the end of the individual case analyses, a cross-case analysis will investigate if patterns can be recognised. This pattern recognition is effectuated through a context analysis. To perform this context analysis, the innovation cases are grouped by context (or end scope) and studied with respect to the involved actors. Hence, the conditions in the innovation system that need to be present in order to successfully implement an innovation are identified and analysed. This approach and the pattern recognition help in determining which institutions and at which stage of the innovation process were relevant to enhance efficiency and avoid over- or underspending of resources.

The influence of variables during the innovation process such as soft-institutional issues (politics, cultural values and social aspects) and hard institutional issues (rules and regulations) can be an important determinant during the initiation phase, while infrastructure can possibly play a key role during both the development and implementation of the innovation. Another aspect is the nature of the innovation, in other words whether it is "open" (exchanges knowledge with the external environment) or "closed" (knowledge remains within the business or group of businesses). An open innovation could invite more external debate and other research which could lead to an improvement of the innovative product or process before it becomes commercialized. Early identification of bottlenecks of failure factors can also be the result of an open innovation. With a closed innovation

the firm chooses to keep the knowledge inside. The rationale behind the innovation, often technical knowledge, is of competitive value. In order to find out if an innovation is open or closed, or respond to any other typology, extended desk research and in-depth interviews with the innovator, (existing or potential) customers and other actors are crucial.

The latter also applies to the SIA matrix which is scored by findings coming from the interviews and desk research. Interactions within the SIA matrix, as explained in the following sub-section, can have a negative or positive effect on the innovation evolution. The failure and success factors are presented graphically by black and grey areas (Table 21) in the matrix and are described in every case analysis. The matrix can be used during various discrete phases following the consideration that an innovation process is evolutionary. It can be applied on the phases of initiation (demonstration phase), development (preparing for market and getting regulation in place) and implementation (commercialization of innovation) of the innovation where relevant for each case. If essential actors or institutions are missing, the innovation will probably fail.

Actors Institutions	Demand: VOs, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
	Infrastructure			
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 21: Example of Systems Innovation matrix (initiation phase of the pallet shuttle barge)

Source: Verbergh et al.(2019), based on Vanelslander et al. (2016), Aronietis (2013) and InnoSuTra (2011) D6, p.41-44

VO= vessel owner: most vessel owners in the Rhine fleet also live on their vessel and operate as captain

Legend: grey: factors are in place; black: factors are not available and could lead to failure

The innovation actors in IWT innovation are the following:

- At the demand side of the innovation: the end consumers of the innovation such as the vessel owner / operators, freight charterers or industry with own vessels.
- At the demand side of the IWT service: the shippers that demand IWT service to transport their freight can be of vital influence for the success of the innovation. A shipper that opposes the innovation or does not have complementary infrastructure (e.g. automated docking if needed for an unmanned vessel) will choose another vessel without the innovation on-board.
- Third parties' lobbyists, manufacturers, consultants and sector organizations not only include the supply side of the innovation (e.g. engine builders for LNG), it also refers to the important support of lobbyists and the sector itself. Opposition by sector organisations and lobbyists, could lead to social resistance or even political actions against the innovation and vice versa.
- Knowledge institutes, funding, standardization bodies, verification agencies, regulators: Without knowledge or further development, the innovation will probably fail. In case of IWT, verification agencies can be added to this category as they are essential in approving the vessel to meet safety standards. Funding needs financial institutions (private and/or public) to be aligned. Standardization bodies need to be willing to adjust or provide necessary standards to allow the innovation to be implemented and to safe-guard a generally accepted level of quality on the market.

The SIA can point out if a CBA is feasible which means if sufficient cost data can be found. The qualitative approach not only helps to identify the possibility of an CBA, it also can provide information of the benefits of the innovation. The CBA framework approach as applied in this research is discussed in the following sub-section.

4.3.2. Cost-Benefit Analysis framework

With this analytical and more quantitative framework, the cases are appraised as an investment decision in order to assess the welfare change attributable to it. The analysis monetarizes costs and benefits of a project or policy. In this approach, the calculations are done from the standpoint of a private innovation consumer, while taking into account the external costs on the level of the enterprise. A detailed micro-economic vessel model is developed that resembles a real IWT enterprise with one vessel. The basic approach includes, indeed, a shipping cash flow model and the external costs are then calculated based on the vessel model. The applied analysis differs from a complete SCBA from a societal perspective although the external costs are considered. Therefore, in the case studies, a CBA is applied with elements of SCBA but only from the perspective of the vessel owner. However this approach can be an important element to quantify a complete SCBA which would include cost and benefit data of the innovator in developing the innovation which is not always possible to obtain. The SCBA generally looks at costs and benefits on a more aggregated level of society, while this CBA is more detailed on the level of the firm.

Complete SCBAs also include the identification of losers and beneficiaries following the diffusion of the innovation or its potential. The applied CBA in this research gives limited attention to the social welfare distribution and only briefly mentions when losers are identified. It is therefore called a CBA with elements from the SCBA framework (external costs).

For the application of the CBA, two vessel models are developed on the level of the firm of a vessel owner. The CBA is applied on the case of the automated (unmanned) vessel and the second on the LNG-diesel dual fuel vessel (LNG-D). In the first case, since the innovation is still in the initiation phase and that available cost data is limited, several assumptions are taken into account. The second case offers a significant and relevant literature coming from diverse projects and studies. The LNG-D dual fuel engine is already at the implementation stage, which offers more cost data and literature. In order to compare cross-case results if possible, a similar CBA approach is applied on both cases. The external costs are then calculated in relation to the developed vessel model which provides information on fuel consumption and performance of the vessel. A CBA was not applied on the last two cases because of case related limitations (data or relevance) that was revealed by the SIA. A similar CBA can be applied on them in future research, but with a different vessel model for the Small Barge Convoy. The e-BC is implemented in CBA - scenarios of the AV.

First, the innovation costs and benefits are identified through interviews and desk research. Wherever gaps are found, carefully considered assumptions are provided and decisions are made where possible. In order to conduct the CBA from a vessel owners' perspective, the following considerations are made:

- The vessel owner is the consumer of the innovation. Within this perspective, less attention is given to research and development costs or type-approval costs on the side of the innovation manufacturer or innovation champion. Nevertheless, it gives more insight in the reasons why an innovation experiences market uptake or not. Does the investment bring benefits to the IWT firm?
- A vessel and its relevant dimensions are chosen and fixed. The vessel size and length have an impact on several costs, such as fuel costs. Moreover, the number of crew members depends on the vessel size as required by relevant regulation. The vessel model is designed according a vessel of 110m long, which was most frequently built in the past decade in the European IWT. The vessel has its own engine and propulsion. The main difference between the two cases is the transported cargo. Almost all (potential) LNG consumers have inland tankers. In the case of the automated vessel, the assumption is made that dangerous goods (mostly tankers) would probably be the last type of freight that would be fully automated and unmanned transported. Therefore, a dry bulk cargo vessel has been selected to serve for this analysis.
- The lifespan of the vessel is an important indicator. The vessel is designed to be operational for a relatively long period of time. This lifespan is an important component of the analysis. In the applied analysis, the vessel is in both cases newly-build but the life-span differs.

- The capital value is calculated with and without the innovation (null-scenario or conventional reference case). Therefore, both a conventional as an innovative vessel are developed and analysed in order to compare the results.
- Both vessel designs (conventional and innovative) are fictitious, however based on existing data, desk research and/or several assumptions.
- The sailing profile and the assumed fuel consumption differ between cases.
- The tanker market of mostly dangerous goods is quite different from the market of dry bulk. An application on the IWT market of containers probably generates different results.
- The distinction between private and external costs is made for every case next to the earlier explained distinction between industrial-economics and welfare-economics perspectives.
- A similar structure of costs and benefits is developed for both cases and for both the conventional and innovative vessel design. The value of the identified costs and benefits depends on case particularities. The following costs, benefits and other relevant components (e.g. lifespan) are used:
 - Revenue: the private revenue of every vessel in operation is calculated on an annual basis and forecast, using real-time data (freight data) where possible. Furthermore, the variation of water depth is taken into account in calculating the forecasted revenue during the lifespan of the vessel.
 - The capital value of both vessels with and without the innovation is calculated on real-life data.
 - The residual value which is in both cases the assumed scrapping value of each vessel at the end of the lifespan.
 - The annual maintenance and repair cost are also different between the cases
 - Port and fairway dues: these costs differ between the cases and could perhaps stimulate the innovation or not.
 - Insurance costs: the annual payment of insurance premiums is based on the capital value but insuring an automated vessel without crew is assumed to be relatively cheaper
 - Financial cost: the interest of a loan that is annually paid and which decreases towards the end of the payback period.
 - Chartering provision: is paid by the vessel owner to the intermediary freight charterer as a commission on the freight transport assignment.
 - Crew cost: in both cases, these costs are significant and especially important for the case of the automated unmanned vessel.
 - Administration and communication: these costs are more explained in the automated unmanned vessel but are also taken into account in the LNG case.
 - Technical compliance: These costs relate to vessel inspections, obliged shipyard visits and technically required upgrades because of new regulation.
 - Fuel costs: In order to calculate the differences between the price for LNG and diesel, a special indicator is developed within this research taking into account the world spot market, bunkering and distribution, and the caloric value of both LNG and diesel. Moreover, a new forecast was needed to be developed. For the automated unmanned vessel, the fuel cost calculation is less detailed.
 - Taxation: in the last two cases annual taxation is estimated and taken into account.
 - Case-specific costs and benefits: in case of the LNG vessel, several subsidies were granted to support the innovation. The annual service cost of the shore control centre is case-specific for the automated unmanned vessel and irrelevant for the vessel with an LNG dual fuel engine.
 - Value of time: This is only relevant for the automated unmanned vessel where the implementation of automated systems results in a time benefit.
 - The differences in costs and benefits between both CBAs will have to be taken into account when comparing the results of both case studies.
 - The external costs for both cases are examined but can show differences in relevance for each case. Only infrastructure, emission and climate costs are important for the LNG dual fuel engine, whereas accidents, congestion and the potential impact on labour are added for the automated unmanned vessel.

- It is possible to transform costs into benefits and vice versa by changing the symbol, but in this research, costs contain all effects of the investment that require welfare resources.
- The cash flow of the annual vessel operations is taken in consideration⁵⁶ in the case analyses and the distinction is made between enterprise and equity.
- The scenario built up in each CBA can differ, because of the particularities of each case.
- The discount factor is similar in both cases.

For somebody outside an innovation network, getting reliable data about the basic cost categories is quite challenging. To obtain more detailed information about the mentioned costs, one requires full access to a project or business case with the necessary transparency. Innovation costs are usually confidential to keep first-mover advantages, to avoid copying easy riders or to keep possible resistance less informed. This did not present a problem in the last two selected cases.

A. Calculation of the Net Present Value and Internal rate of return

The European Commissions' guidelines refer to economic performance indicators such as net present value (NPV), the economic or internal rate of return (ERR, but here it is called the IRR) and Benefit-Cost ratio (B/C ratio). A positive economic return shows the society is better off with the project; the expected benefits on society justify the opportunity cost of the investment (EC, 2015a: 18).

The discount rate in the economic analysis of investment projects reflects the view on how future benefits and costs should be valued against present ones. The following formula shows the Net Present Value (NPV) which is merely the algebraic difference between discounted benefits (B) and costs (C) of cash flow with a discount rate d as they proceed over a period (i):

$$NPV (i) = \sum_{t=0}^{Ti} \frac{B_i t - C_i t}{(1 + d)^t}$$

The index of the annual costs and benefits in constant prices is showed by t . The project or policy adds value if the NPV is positive (benefits outweigh the costs). If the result is negative, the project or policy should be rejected (Eijgenraam, et al., 2000). The NPV can be a Pareto correction, whereas losers are compensated by the winners.

The IRR refers to a discount rate that results in an NPV that is zero and shows if an investment is attractive for the investor, which means that the IRR must be higher than what the investor wants for his or her investment⁵⁷. The formula is as follows:

$$0 = NPV = \sum_{t=1}^T \frac{C_t}{(1 + IRR)^t} - C_0$$

Where:

C_t = Net cash inflow during period t

C_0 = Total initial investment costs

IRR = Internal rate of return

t = number of time periods

⁵⁶ According to the European Commissions' *Guide to Cost-Benefit Analysis of Investment Projects, Economic appraisal tool or Cohesion Policy* (2015), the data that has to be considered refer to the incremental cash disbursements encountered in the single accounting periods (usually years) to acquire the various types of assets consistent with the time-plan for implementation.

⁵⁷ An interesting overview of financial metrics is explained on <https://www.investopedia.com/terms/i/irr.asp>

B. Weighted average costs of capital

Two perspectives are used regarding the NPV. The enterprise perspective (Higgins, 2007) goes a step further than the private equity perspective and takes in account both equity and debt. Not only the cumulative free cash flow is analysed, but also the interest costs and the yearly payback of the loan. The IRR of private equity is compared with a discounting factor of 10%, which expresses the opportunity costs of the invested private equity. The IRR of the private equity together with debt is compared to the weighted average cost of capital (WACC). For all given scenarios, the WACC is 5.35%. The WACC is calculated as follows:

$$WACC = \frac{(1 - TAX) \cdot D \cdot C_i + C_e \cdot E}{D + E}$$

WACC = weighted average costs of capital in percentage

TAX = tax rate (25.5%)

D = total debt in EUR

E = equity in EUR

C_i = interest costs (4,5%)

C_e = equity costs (10%)

C. Cash flow analysis

For the cash flow analysis, the internal rate of return (IRR) is calculated next to the net present value (NPV). Furthermore, the benefit/cost ratio (B/C) is given which divides all the recurrent benefits during the lifespan of the project by all costs. The B/C ratio shows the relation between benefits and costs of the innovation. When the ratio is higher than 1, the innovation is expected to be a positive business case. When it is lesser than 1, the costs outweigh the benefits. In the cash flow analysis, the benefits relate to the revenue and the costs include fixed and variable costs. The first two concepts are discussed in the following part.

The CBA includes a cash flow analysis of the vessel. The calculation of the cash flow is shown by the following table.

Earnings	1
Operational costs	2
Insurance	3
Overhead	4
EBITDA	5 = 1 - 2 - 3 - 4
Depreciation ⁵⁸	6
Operational result	7 = 5 - 6
Interest costs	8
Result before tax	9 = 7 - 8
Tax	10
Results after tax	11 = 9 - 10
Cash flow	12 = 11 + 6
Payback loan	13
Free cash flow	14 = 12 - 13

Table 22: Calculation of the free cash flow⁵⁹
Source: van Hassel (2011a)

⁵⁸ In a SCBA depreciation and taxes are not considered. For the CBA from the private VO perspective as developed in this research, depreciation and taxes are taken into account.

⁵⁹ Cash generated by a firm by its activities, minus the cost of capital expenditures.

4.3.3. Pan-European Inland Navigation Policy analysis

This developed Pan-European Inland Navigation Policy analysis (PEINPA) has as main target to provide more insight in the factor of hard and soft institutions in the SIA by examining the levels of policy, its actors, interdependent relations and its policy tools. It takes in account transaction costs where possible such as compliance and enforcement costs. It takes in account possible innovation policy measures for every level such as public funding.

In this research, it is assumed that not only the type of policy (subsidies, do-nothing, fiscal incentives, leading innovation, procurement, etc.) has an influence on innovation, but also the policy level and the interdependent relations in every phase of the policy cycle. The level could determine the scope of the policy and offers a policy arena with multilevel policy networks and possible funding with each their own costs and benefits. To keep the method simple for testing purposes within this research, the phases of the policy cycle are not used. Furthermore, it seems not feasible at this point of initiation of this tool to test the entire theory as described in sub-section 3.7.

The costs and benefits of each policy level are expressed by following formula:

$$B_i - C_i > z$$

With B_i as the societal benefits from the policy level and z as the threshold to argument and legitimize the choice of the policy level or institution and with i referring to the policy level. This exercise is mostly qualitative and theoretical. Further research and accessible data can possibly quantify this component and test it on other cases. Basically, the analysis applied on the Pan-European policy could consider following costs when given:

- Costs:
 - Practical overhead: administration, studies, meetings, travelling, salaries, translation costs (on the total scope of policy, expected to be relatively small but still mentionable)
 - Compliance: internal (internal acquis and other policy regulation); external (e.g. compliance with Mannheim Convention and MS regulation)
 - Information costs: price of asymmetrical information on a higher policy level can be higher than paying for the 'right' information. When policy is closer to the sector, information costs are lower, but less information can be available;
 - Enforcement costs: costs related to updated service instructions, court law and police;
 - Monitoring costs: market observation and analyses but with time and important spatial differences between policy levels;
 - Policy tool costs: e.g. subsidies, funding and tax cuts;
 - Transitional social cost: preparing for expected policy change

- Benefits:
 - Quality improvement: economies of scale towards cross-border externalities; single Market scope with freedom of services and persons; value of time benefit compared with harmonisation; level playing field for enterprises
 - Synergy benefits: learning capacity;

The transaction costs are normally covered by the state expenditures and there are limitations for PEINPA. On the policy levels that are involved, precise cost data for IWT policy is often not to be found. Civil servants that work in the field of inland navigation are usually involved in different IWT policies. On some levels they are also involved in other transport or environmental policies. The financial framework of the identified pan-European public actors does not show the entire expenditures as working groups include members, experts or other representatives that are paid by other public actors. This makes it more difficult to quantify the costs. Administrations are also found not to be that eager to collect detailed cost data according to the policies they create or share them. This remark relates more

to the internal overhead costs of the public actor and when compared with the total expenditures for a certain policy, these costs become more relative.

4.3.4. Cross-case analysis

Starke (2013) defines cross-case analysis as “the systematic investigation of qualitative similarities and differences of values on theoretically relevant variables across several cases.” Starke does not mention quantitative findings which makes sense for this research. For instance, the quantitative results of both CBAs relate to different investments in different innovations. The variables that he refers to are taken into account for every applied method and are regarded as variables that give a certain outcome or not.

After the case analysis the developed tri-method approach is broken down and compared through its components were relevant. The independent and dependent variables, patterns and other findings are compared between the cases. Although the small-sample multiple case studies analyses only 4 cases concerning innovation in the (pan-) European inland navigation, there are quite some differences to be expected. The cases are completely different innovations in technology, objective and even submarket/business (dry, liquid, fixed and unfixed contracts) within the market of IWT.

The different typologies seek if any similarities and differences exist and how findings can be generalised while corresponding with the development phases of each innovation (initiation, development or implementation). It is rather problematic to compare one innovation in the initiation period with another innovation in the implementation period.

Concerning the results of the cash flow analysis of the CBAs, the NPVs can only be limited cross-case compared with the general understanding that it is about two non-competing innovations while considering the limitations caused by the identified particularities of each case study. Comparison is therefore rather theoretical between the findings of the cash flow analysis of those two cases. It does not mean that when an investment in the automated vessel would have a higher NPV than the LNG-D vessel, that the owner should invest in the first innovation.

Furthermore, case differences are also significant. The majority of IWT firms in the European fleet are SMEs with only one or two vessels and where the vessel owner also lives and works on the vessel. Being active in dry or liquid bulk suggests sunk costs. Captains for example have invested in specialized training to transport dangerous liquids and therefore a switch to dry bulk could not be that evident. Nevertheless, a real investment decision between the two innovations, could emerge in enterprises that have multiple vessels in both dry and liquid bulk. These differences become clear in the actual case studies.

All three of the applied methods seem compatible and show overlapping. This is tested by applying the analyses on the cases. The following overlaps are discussed during the cross-case analysis:

- SIA-PEINPA: the SIA helps to identify the regulatory factor such as hard and soft institutions and infrastructural factors of which port authorities and waterway managers can be held accountable for. The SIA explores the case to see if a PEINPA can be applied.
- CBA – PEINPA: the CBA of the vessel model analyses external costs to show if an innovation can be positive for society. The PEINP analysis tries to identify any transaction costs of the PEINP that stimulates the innovation and looks at the impact of policy instruments (e.g. compliance costs) on the CBA of the vessel model.

Now that all used concepts and developed methodological framework tools are explained, the multiple case study can finally start with a first case in the next Chapter. This Chapter goes deeper in the development of the fully automated and unmanned inland vessel.

5. Analysis of the automated and unmanned inland vessel

This Chapter presents the research findings of the current status of automated vessels in the inland navigation. Three analyses were tested on this case focusing on barriers that could prevent market uptake (SIA), the developed CBA that takes external costs in account within a SCBA framework and on the institutional framework of automation in the inland navigation (PEINPA).

The case analysis starts with a literature review in order to situate the innovation. Afterwards, the actual analysis is introduced and performed.

5.1. Case related literature

No specific academic literature is found for automated vessels in the inland navigation, but automation in other modes has become in recent years a global emerging industry. This inspired a number of researchers (Fagnant, Kockelman, 2015; Kretschmann et al, 2015) to examine automation and to conduct several research projects which were or are still being conducted (e.g. MUNIN project⁶⁰, AAWA and Yara Birkeland). Most of these authors originate from robotics literature and are here rephrased to fit inland vessels.

5.1.1. Definitions of automation and autonomous

Today there is a global contamination in definitions with inconsistent usage of the words ‘autonomous’ and ‘automated’. Several definitions are possible to define autonomous a fully-automated vessels. Most of them originate from robotics literature and are here rephrased to fit vessels.

An ‘autonomous’ vessel is in this research considered as a vessel that can decide for itself without human intervention while ‘automation’ still requires human decision making or monitoring and intervention. Several authors have defined automation and autonomous according different stages of development with autonomous being the final stage. Autonomous suggests here a developed form of artificial intelligence, while automation still needs human monitoring to solve extraordinary events where programming is perhaps not adequate and where the human creativity is still far more superior than any AI that is developed so far.

As ‘autonomous’ requires a certain degree of artificial intelligence, the term ‘automation’ is preferred in this research, with the following definition: *the process of a growing variety of organizational, operational, and/or technological innovation initiatives, that is aimed to increase support or even to replace human tasks by a device, (or machinery) or an integrated system that in the end will be able to conduct all human tasks (continuously and unconditionally) and is programmed to accomplish (partially or fully) a growing number of functions that were previously, or conceivably could be, only carried out (partially or fully) by a human.*

Table 23 gives an overview on several other definitions as identified from literature. The distinction is made between autonomous and automated vessels. Furthermore, the 10-level definition of Sheridan and Verplank (1978) is added whereby a computer evolves into a self-governing decision maker.

⁶⁰ MUNIN project, Maritime Unmanned Navigation through Intelligence in Networks, is co-funded by the EU ran from 2012 until 2016. For more information <http://www.unmanned-ship.org>

Autonomous vessels	Rephrased or quoted from
<i>The vessel</i> “should be able to carry out its actions and to refine or modify the task and its own behaviour according to the current goal and execution context of its task”	Alami et al. (1998)
“ Autonomy refers to systems capable of operating in the real-world environment without any form of external control for extended periods of time.”	Bekey (2005)
“An Unmanned System ’s own ability of sensing, perceiving, analysing, communicating, planning, decision making, and acting, to achieve goals as assigned by its human operator(s) through designed <i>Human vessel interaction</i> ;” “The condition or quality of being self-governing.”	Huang H-M. (2004)
“ Autonomy : agents operate without the direct intervention of humans or others and have some kind of control over their actions and internal states.”	Wooldridge M and Jennings NR. (1995)
Automated vessels	Quoted from
“Device or systems that accomplishes (partially or fully) a function that was previously, or conceivably could be, carried out (partially or fully) by a human operator”	Parasuraman R, Sheridan TB, Wickens CD (2000)
Automation	Quoted from
<ol style="list-style-type: none"> 1. The computer offers no assistance; the human must take all decisions and actions before turning the job over to the computer to implement 2.The computer helps in determining the options; the human must take all decisions and actions. 3.The computer helps determine the options and suggests one which human need not follow, 4. Computer selects options and human may or may not do it, 5.computer selects action and implements it if human approves 6. Computer selects action, informs human in plenty of time to stop it,7. Computer does whole job and necessarily tells human what it did 8. Computer does whole job and tells human what it did only if human explicitly asks, 9. Computer does whole job and tells human what it did and the computer decides he should be told. 10. Computer does whole job if it decides it should be done, and if so tells human, if computer decides he should be told 	Levels of Decision-Making Automation by Sheridan TB; and Verplank WL. (1978), Human and computer control of undersea teleoperators and Man-Machine Systems

Table 23: Definitions for autonomous and automated vessels

Source: based on Jenay M. Beer, Arthur D. Fisk, and Wendy A. Rogers. (2014) Toward a framework for levels of robot autonomy in human-robot interaction. J. Hum. -Robot Interact. 3, 2 (July 2014), 74-99

A definition for automation needs to explain different levels of automation which can be found in the classification table of Lloyd’s Register (2016) of ship autonomy levels as shown in Table 24. It is a shorter version of Sheridan et al. applied on vessels in maritime.

Level of autonomy	Description
AL 0) Manual – no automation function.	All action and decision making are performed manually – i.e. a human controls all actions on ship level.
AL 1) On-ship decision support	All actions on ship level are taken by a human operator, but a decision support tool can present options or otherwise influence the actions chosen
AL 2) On and off-ship decision support	All actions on the ship level taken by human operator on board the vessel, but decision support tool can present options or otherwise influence the actions chosen.
AL 3) ‘Active’ human in the loop	Decisions and actions on the ship level are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride them. Data may be provided by systems on or off the ship.
AL 4) Human on the loop – operator/supervisory	Decisions and actions are performed autonomously with human supervision. High impact decisions are implemented in a way to give human operators the opportunity to intercede and over-ride them.
AL 5) high automation	Unsupervised or rarely supervised operation where decisions are made and actioned by the system
AL 6) Full automation	Unsupervised operation where decisions are made and actioned by the system

Table 24: Classification table of ship autonomy levels

Source: Lloyd’s Register (2016) Cyber-enabled ships, ShipRight procedure – autonomous ships, first edition, July 2016, A Lloyd’s Register guidance document, p.2

Based on the reviewed definitions, a schematic is now elaborated for IWT. Table 25 is based on the identified stages of the conceptual autonomous vessel as described in the MUNIN project and shows a comparable evolution as the classification by Lloyd’s Register.

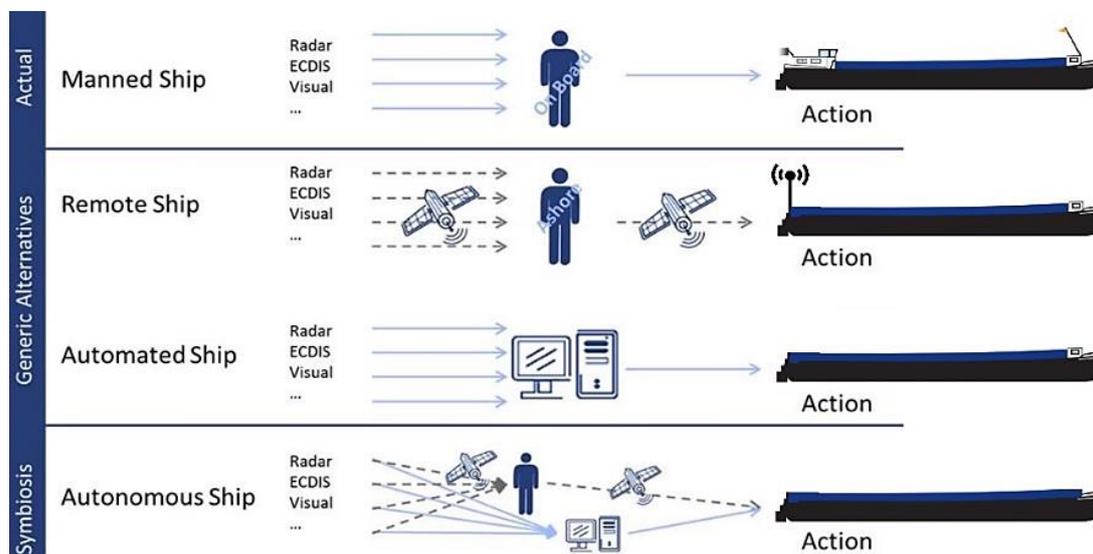


Table 25: Autonomy stages of an inland AV

Source: own adaptation⁶¹ of the schematic of MUNIN (2015)

⁶¹ The image is adjusted from the original. The vessel image was modified and the accommodation area decreased. Partially ignoring the, although very relevant, comments of Den Boogaard (2016). In the stage of remote and automated ship, the wheelhouse (to intervene in the system) is located in front of the vessel as are the accommodation for the intervening crew. In the stage of an autonomous vessel and if proven safe, the wheelhouse disappears.

According to Van Den Boogaard et al. (2016; in Wróbel et al., 2018:335), the suggested stages of autonomy do not work in one direction. Because of safety uncertainties, especially in the initial phase, it is necessary that the system must be capable of operating in multiple levels without reducing the overall safety performance. Moreover, if remote control fails, an unmanned ship needs reliable emergency procedures to dock automatically and in a safe way. At that moment of system failure, the ship needs to be automated or even autonomous.

Another study is the Finnish Advanced Autonomous Waterborne Applications Initiative (AAWA) concerning the development of a remote and autonomous ship in collaboration with Rolls-Royce, bringing together universities, ship designers, equipment manufacturers and classification societies to explore economic, legal, social, regulatory and technological factors. The definitions are derived from the levels of autonomy as described by Sheridan (1978) which is a 10-point scale categorizing higher levels of automation as representing increased autonomy, and lower levels as decreased autonomy (as quoted from Beer et al., 2014).

A completely automated operating system (AOS) must perform all tasks on board of the vessel such as navigation, propulsion, applying anchor winches or adjusting the height of the wheelhouse (if any). This definition does not mention mooring and unmooring, loading and unloading or other dynamic navigation tasks. The specific context wherein the automated vessel (AV) is active, relates to certain navigational circumstances such as traffic intensity, passing locks, navigation in convoy or in platoon.

The context also relates to the digital infrastructure such as the network type and capacity for the data transmission. The sailing area as referred to in the table, relates to the navigational status and weather conditions, river current and other external (rather fully unpredictable) variables where the AV must retrieve vital information and adjust its course to maintain the safety level. The AV also must be able to communicate with other vessels and their operators as with shore infrastructure (bridge and lock masters, terminal dispatches...).

The pan-European fleet can currently be situated at the end of level 1. There is no such thing (yet) as an automated or autonomous vessel, only a redundancy of mostly non-integrated automated systems that aim at supporting one or more human tasks but that need much more development in order to replace an entire crew. Nevertheless, the development of a first generation of AVs, seems yet feasible from a technological perspective with developments such as: the mandatory use of AIS (automatic identification system) and other river information services; devices (auto-pilot); developments in automated bridge gauge scanning (e.g. BridgeScout), route plotting systems (e.g. Track pilot); water depth scanners (e.g. Covadem); autodocking (e.g. intelligent Dock Locking System); advanced 3D radars (e.g. Lidar); and other relevant innovations.

The more data is being gathered concerning ships' behaviour and navigational skills (machine learning), the more the actual navigation and propulsion becomes automated. Software programs are already on the market to give suggestions for the ideal speed (e.g. ecological sailing) and route plotting, but the helmsman still decides. In this case, it is important to distinguish among the different automated ship systems (subcomponents and robotics included) and not only among the automation levels.

The CCNR draft resolution (Rhine Police Regulation, document 18-32, 2018)⁶² describes a proposal to define automated navigation as is inspired by the levels of automation as described earlier (MUNIN, Lloyd's register) and links the dynamic navigation tasks with levels of automation but it does not mention 'autonomous'. The proposed definition as developed by the Rhine Police regulation is presented in Table 26.

⁶² CCNR, 2018, "Geautomatiseerd varen, Ontwerpbesluit inzake de definitie van de automatiseringsniveaus in de binnenvaart", document RP18_32, translated from Dutch, Strasbourg, 7p.

Stage		Description	Navigation (manoeuvres, propulsion,...)	Sailing area monitor & interaction	Fall-back performance of dynamic navigation tasks	Remote controlled
Human performs most dynamic navigation tasks	0	No automation the full-time performance by the human boat master of all aspects of the dynamic navigation tasks, even when enhanced by warning or intervention systems (e.g. navigation with support of radar installation)				No
	1	Steering assistance The application of an autopilot within a specific context while using certain information of the sailing area where the operator still decides and performs all other aspects of the dynamic navigation tasks. (e.g. Track pilot: plotting system along predetermined route lines)				
	2	Partially automated The application of an automated operating system (AOS) for the navigation and the propulsion within a specific context with the use of certain information of the sailing area where the operator still decides and performs all other aspects of the dynamic navigation tasks.				Subject to context specific execution, remote control is possible (vessel command, monitoring of and response to environment or fallback performance). Influence on crew requirements (number or qualification)
AOS performs all dynamic navigation tasks if activated	3	Conditional automation the continuous application of an AOS for all dynamic navigation tasks within a specific context, including collision avoidance, if a skipper will respond to a request to intervene, to system failures and gives an adequate response.				
	4	High automation the continuous application of an AOS for all dynamic navigation tasks within a specific context, including fall-back measures, without assuming that a skipper will respond to a request to intervene (e.g. the AOS is not able to pass a lock without human intervention)				
	5	Full automation = Autonomous the continuous and unconditional application of an AOS for all dynamic navigation tasks, including fall-back measures, without assuming that the skipper will respond to a request to intervene				

Table 26: Levels of automation as proposed juridical definition for IWT
Source: based on CCNR, 2018 (some parts are rephrased)

To build an elaborated definition for automation in IWT within this research, the following systems are described:

- *Automated Wheelhouse System (AWS)* with subsystems such as an Advanced Sensor System (depth, weather, current, wind, smell, alarms, inspection, full vision (day and night), Lidar, surface scanners and under water sonar), navigation software, electronic charts, propulsion control with ecological power use, interface for human intervention, communication with vessels, shore, crew (if any) and others, ship monitoring. The AWS is the core of the AV.
- *Automated Engine Room (AER)*: conventional crews still perform tasks in the engine room. As engines become more advanced, less maintenance and repair would be needed. Repair and maintenance can also be outsourced to ad hoc human crews or can be solved by robotics.
- *Shore Control Centre (SCC)*: an SCC can control one or more vessels in operation. An SCC can belong to the government such as the waterway manager or to a private company that employs captains or boat masters together with engineers. The external captains in the SCC can be in control of the entire voyage, only during a part of the voyage or in latter phase only in case of system malfunctioning. The Human-Machine-Interface, the workload, situation awareness, liability, data size, connection reliability and security, quality of data, connection speed and even the design of the SCC are some of the remaining challenges that invite further research.
- *Automated Docking Systems (ADS)*: there are several products already on the market and they can be on-shore and/or on-board using magnetic or vacuum mooring technology.
- *Automated Bunkering System (ABS)*: a conventional vessel bunkers water and gasoil. Without a crew, water is still needed for stabilization (or other technology). In case of electric vessels, there are already examples of charging batteries through induction by an on-shore docking station.
- *Automated Cargo Management (ACM)*: cargo management is already heavily digitalized, and the human decisions not necessarily have to be made on-board. The ACM is mentioned as an important challenge concerning cargo liability during the voyage and includes monitoring of the loading procedures and the safe execution of stowage plans, which normally is the function of a captain on-board.

Every component is considered to have sufficient inter-compatibility to provide a smooth integrated Automated Operation System (AOS) of all automated systems and robotic devices on the (unmanned) automated vessel (AV). For every component mentioned, a separate innovation research can be done. Every device or (sub)system is an innovation on its own which also follows the levels of automation. As long as all components are not fully automated or even autonomous, and proven reliable and safe, a freight vessel cannot be truly unmanned.

Now that the concepts and the difference between autonomous and automated are defined, relevant cost-benefit literature concerning automated vessels is reviewed in the next part. Unfortunately, no cost-benefit literature was identified concerning an automated inland vessel. Only maritime examples were identified which provide a basis to see which kind of costs and benefits there are to be found, but with caution. A CBA for an automated ocean vessel is quite different than on an inland vessel. The differences will be further explained in the following parts.

5.1.2. Maritime AV Costs & benefits from literature

Kretschmann et al. (2015) performed for the MUNIN study an ex-ante cost-benefit analysis based on a maritime shipping cash-flow model for a conceptual new-built remote – controlled automated and unmanned dry bulk vessel. In a baseline scenario, the expected present value (EPV) is estimated at 7 million USD more (over 25 years) than a conventional dry bulk vessel (CV). The study showed a theoretically positive business case. Costs could be saved because of a higher efficiency of land-based

services in port and by the suggested Shore Control Centre (SCC), next to a reduction in fuel consumption, emissions and in crew costs.⁶³

Although the MUNIN study is only conceptual for now, the findings could be relevant for inland navigation. Some of the issues raised, should also be addressed for the development of the concept of an unmanned inland navigation vessel, such as:

- Safety and security issues, reduction or human error related accidents by autonomous systems and data security against cyber-attacks;
- Legal and liability concerns, regulation on manning and technical requirements: the attribution of liability (ship master duties) could be blurry and crew on-board is mandatory;
- ICT infrastructure, ship-shore and ship-ship communication, safety devices, security on board, reliable integrated ship (large) data networks;
- Bridge functionalities, manoeuvre systems, requiring advanced sensors and remote-control systems;
- Autonomous propulsion systems and procedures with advanced remote engine monitoring and maintenance systems;
- Procedures to interact with other vessels, search and rescue operations, vessel traffic services;
- Extra reduction of fuel and increase of loading capacity by removing living quarters next to an advanced energy efficiency system and reducing the size of the engine room;
- Need for e-policy to replace paper documents and international data-sharing.

The following parts contain costs and benefits from the MUNIN project but are based on a maritime example. During the actual case analysis of the automated inland vessel, the significant differences between maritime and IWT are carefully taken into account.

The voyage costs (related to fuel and port calls) are variable as described by MUNIN. Due to high volatility of fuel costs, several scenarios are examined for different prices of crude oil and marine fuel (MDO and HFO). The port call is estimated at an average of USD 100,000 or 16.3% of the maritime voyage costs. The capital expenditures (CAPEX) are the assumed discounted value of all payments related to the buying and selling of the conventional ship or 21% of the total cost.

Furthermore, MUNIN calculates the operating expenses (OPEX), with distinction of voyage costs and CAPEX for 25 years without taking into account the possible difference of revenue between the reference vessel and the MUNIN concept. For the NPV, the discount rate is set at 8%. The average crew cost accounts for 45% of OPEX and is estimated to be USD 735,840 for a crew of 20 for each year. Consumables on board are estimated at 14.3% of OPEX. On average, 12.7% of OPEX is estimated for repair and maintenance. 15.2% is estimated for insurance costs. The general cost (administration, management, flag state, communication, etc.) is 12.8% of the annual OPEX. The periodic maintenance in a dry dock is set at a 100% of the average annual OPEX for every 60 months.

Without automated berthing, mooring, (un)loading systems, it is still necessary for a crew to come on board for each port call which increases the total voyage costs, which is estimated by assuming the port call cost as 20% higher. The OPEX of the MUNIN concept is lower than the conventional reference carrier, if the costs for the SCC and port services are lower than the crew costs. In case of the capital costs, there is a reduction if the prices of the necessary technology and advanced integrated systems are lower than the price to build crew accommodation and a conventional wheelhouse. Further reduction of OPEX is possible by removing crew support systems such as energy use for ventilation, laundry, lighting, kitchen, leisure time and others. This leads to an estimated reduction of up to 40% of the consumed energy. The MUNIN project removes a 20-head crew from the vessel and claims to achieve a fuel reduction of 40% combined with a lighter design. Indeed, by removing the crew, less electricity is needed which is power by conventional gen-sets on-board. The SCC has an estimated

⁶³ The quantitative analyses resulting in the CBA can be found at <http://www.unmanned-ship.org/munin/wp-content/uploads/2015/10/MUNIN-D9-3-Quantitative-assessment-CML-final.pdf>

annual recurrent cost of USD 874,960 and a one-time cost of USD 2,131,800 (prices of 2016) for the situation room, software, hardware and other office equipment (MUNIN, 2015: p.21-55).

Another development is the Norwegian Yara Birkeland by Kongsberg. This project aims at building self-driving ship control systems for Maritime Autonomous Surface Ships – MASS / unmanned ships. This 3,200-dwt vessel will have a length of 80 meters that will sail fully electric with an estimated CAPEX of USD 49 million (vessel and on-shore equipment, prices of 2017). The fertilizer-transporting vessel will have a capacity for 120 TEU and a depth of 12 meters. The ship is announced to be operational in 2020, although this deadline already has been shifted backwards.

To solve the mooring problem for an unmanned vessel, several possibilities are identified which are on the market already (e.g. Cavotec, Wärtsillä, Trelleborg). The system of the Dutch Trelleborg (AutoMoor T40) costs EUR 450,000 (prices of 2018) for each unit which includes software, delivery, product training and commissioning. For dangerous goods transport an additional EUR 50,000 for each unit should be added. An annual software subscription costs approximately EUR 2,500 for each unit. The life-span is claimed to be between 20 and 25 years if service and maintenance is carried out in accordance with the Trelleborg's recommended schedule (Zanderigo, 2018). According to Zanderigo the prices are similar for an inland vessel.

A social benefit of automation of vessels is assumed to be an increased safety by removing the human error or a decrease in accident costs. However as Wróbel et al. (2018) claim, more data (accident data) must be required in order to reduce the uncertainties concerning the assumed safety benefit. The latter is the case for maritime, but even in the maritime sector, it is easier to find more accident data than in inland navigation sector which will be explored during the case analysis (Chapter 5). Safety benefits originate from knowledge that is gained from actual operations and accident investigation (Wróbel, 2018).

Not all authors are thus convinced that automation will have a positive impact on the safety of maritime shipping. The methodological approach of Wróbel et al. is interesting as they use a method to analyse safety in case of a lack of sufficient quantitative or qualitative data, which is called "System-Theoretic Process Analysis". This method is rooted in the System-Theoretic Accident Model and Process of Leveson (2011) and is applied in some innovative domains, including the maritime sector."

Problems can occur and in the case of remotely-controlled unmanned automated or autonomous vessels, the needed interaction will have to rely on stable communication links, distant situation awareness with necessary decision tools to replace crew members' expertise and the inability to operate manually immediately. Although Wróbel et al. mention that ship design must be extensively rethought with numerous scanners and devices, possible auxiliary supportive innovation in the field of robotics is not taken into account in the analysis. Knowing that most accidents occur because of human error, it can be assumed that further automation could make also inland navigation safer. Another example to support this assumption is fire safety. Most fires are caused in the kitchen or by other human activity. And if a fire occurs on an unmanned vessel, systems could easily be designed to extinguish fires by emptying all air in the surroundings without the risk for life.

Furthermore, the mental condition of supervising humans in an SCC or a decreased crew to one person on-board as a caretaker, could also decrease safety. Caretaking or merely remote supervision on automated processes can lead to boredom, skill degradation and loss of situational awareness (Porathe et al., 2015; in Wróbel et al., 2018). In case of one crew member, the lack of social contact during weeks can also have an impact on the mental condition. Following the reasoning of Wróbel et al., the linkage or relationship between the vessel and the operator gives perhaps more incentive to look for solutions in dangerous situations compared to the case of an alienated shore operator without any (emotionally) linkage with the vessel. This is certainly the case for the inland navigation, where the love for the vessel can go far.

To return to the suggested method of the System-Theoretic Process Analysis (STPA), in case of a lack of sufficient data to apply a traditional safety assessment, "a hazard mitigation can be chosen as a

surrogate for a likelihood.” The potential of the design to reduce or eliminate danger has a direct impact on the probability or likelihood of an accident occurring. The reduction or mitigation of danger can be determined before the selection of the system design. The design could aim at reducing the damage if an accident occurs; reducing the probability the danger causes an accident or that even the danger emerges; and at eliminating possible danger coming from its design. Every control function or system can be scored on a suggested danger mitigation scale according the aims of the design. The decisions that designers will make are essential to create fully automated and autonomous vessels that not only comply with existing safety standards but even offer a social benefit of increased safety.

At the management level, several essential competences are required that also include the interaction with other actors such as shippers, charterers, river police and infrastructural operators. The AV should be able to respond to real-time situations and to a dynamic largely unpredictable environment. Changes in depth, current, wind, behaviour of other (possibly manned or conventional) vessels and even smell could present potentially dangerous situations for ship, cargo and human life (when colliding manned vessels).

5.1.3. Conclusion of AV literature review

The literature review defined important concepts for the case analysis. The automated inland vessel can be defined as follows:

The fully automated and unmanned inland vessel (AV) is a vessel with a completely automated operating system (AOS) which performs all tasks on board such as navigation and propulsion; integrates all scanners, devices and areas such as the automated engine room, automated docking stations, the on-board bunkering system, automated cargo management system, and communication with a shore control centre (SCC), locks, bridges, ports, terminals, other ships and authorities.

Although in a maritime context, some of the mentioned costs and benefits by Kretschmann et al. (2015) can be of inspiration for the CBA of the AV case study. Certainly, the SCC costs and the mooring devices can be considered similar with an inland navigation concept. Potential benefits such as the decrease in accident costs and fuel cost (and therefore emissions and greenhouse gases) need to be scrutinized if they apply on IWT. Some of the issues that are raised could also be relevant for the inland AV such as legal and liability concerns, regulation on manning and technical requirements, the existing ICT infrastructure and the need for more e-policy. Especially for the SIA and the PEINPA, these mentioned issues could be relevant.

5.2. Setting of the analysis of the AV

Following the typology of Arduino et al. (2011), Rouboutsos (2013) and Sys et al. (2016), the innovation of a fully automated and unmanned vessel is considered to be a technological, managerial, organizational, cultural – market change, which is currently situated in the beginning of the initiation stage. It is assumed to become a radical change to the market, but for the moment it is rather systemic as it integrates multiple independent innovations that work together to improve the overall system performance. However it is currently not successful (yet). There is an international network of private firms developing this open innovation and its components. Moreover, public actors are supporting the innovation.

Table 27 shows the AV according the applied typologies.

Type of innovation	I TECHNOLOGICAL	II TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - BUSINESS CHANGE	III TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	IV MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	V POLICY INITIATIVES (MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE)
Implementation level	Initiation		Development		Implementation
Degree of Innovation	Incremental	Modular		Systemic	Radical
Level of Success	Success		Failure		Not Available

Table 27: Features of the fully automated and unmanned inland vessel
Source: applied typology derived from Arduino et al. (2011), Roumboutsos (2013) and Sys et al. (2016)

Numerous companies are involved in developing the first fully automated and unmanned freight transporting vessel, both in maritime and inland navigation (Seafar, Rolls-Royce, Wilhelmson, KONGSBERG, ...etc.). The question whether a completely automated vessel will be a disruptive game changer as some believe, or rather an incremental innovation, is still debatable at this stage. It has the potential to be disruptive in the entire supply chain as all transport modes are discovering their automation potential. In this case analysis the innovation is considered to have the potential to be disruptive or radical towards the IWT market. However as explained, in the current period of development, the innovation fits rather the definition of a systemic innovation.

The technology is assumed to have a potential impact on vessel safety, trip planning, fuel efficiency and even freight capacity (e.g. the removal of living quarters and wheelhouse adds extra transport capacity on board).

There is a global technology push with rapid improvements and developments of sensors, data – processing, cloud computing and artificial intelligence in almost every sector which could fasten the innovation path in the entire transportation sector. Second, the inland navigation and the maritime sector, including policy makers worldwide are very interested in all kinds of projects and research concerning automation in transport which creates an interesting and global window of opportunity.

In the Flemish region, not only the waterway manager is conducting experiments, but also the Port of Antwerp is testing a fully automated sounding boat for depth measurement. Another example is the *Roboat* in Amsterdam, next to several maritime experiments in Norway (e.g. Yara Birkeland). During the research, it seemed that the automation of vessels (in broad sense) was in the middle of a global race where several companies and public actors were trying to be the first to develop fully automated vessels. In order to fully understand automation, all processes that are conducted manually on board of an average vessel need to be analysed and these processes should be given an automated or autonomous answer (or not).

The SIA in the following part investigates the barriers of fully automated vessels adoption and implementation from a consumer and regulatory perspective.

5.3.SIA of the AV

The SIA in this case highlights the barriers that could keep the innovation uptake at bay. The innovation that is highlighted in this analysis is an automated vessel. The SIA helps to define these concepts further (e.g. which level of automation is feasible and what are the barriers). The focus in this analysis is on fully automated navigation backed by a shore control centre.

The results are collected from literature review, interviews with innovators and expert panels. This case study is ex ante because automated IWT vessels are yet to be designed or are in a small-scale experimental phase. Several innovators were identified that have started test phases and are rolling out the first experiments for automated IWT and maritime transport in the Rhine countries, Belgium, Norway and other countries. However this list is probably not exhaustive and can change rapidly.

5.3.1. Current situation

Most of the current CCNR fleet is situated on the first level of automation as explained during the literature review at the beginning of this case study. Some more advanced vessels have equipment that measure engine parameters, and which could be linked with applications for smart phones and tablets, but in all cases, human response is still required.

The step towards full automation and unmanned vessels requires a (new) vessel design, adjusted regulation and infrastructure (both digital and physical). The human intervention could be limited to maintenance and to situations where the equipment cannot perform without human help (without robotics and infrastructure adjustments, mooring and loading still need human intervention). It is important to understand that the latter refers to a fully unmanned vessel with an AOS and not only a full automated wheelhouse system (AWS).

The experiments that are currently being conducted could provide more information on how an AOS will behave in several situations. The focus of the first wave of developments is more on automated navigation than on other automated processes as described in the case related literature review. Gradually, and as the innovation and its auxiliary innovations (e.g. automated docking) improve, the role of the crew will be more and more limited to necessary emergency intervention during system failures and for caretaking tasks until the vessel becomes fully unmanned.

5.3.2. Initiation period

The main identified stimuli or triggers behind this innovation process are the competition with other modes (self-driving trucks and trains), technological breakthroughs, the relatively high and increasing salary cost, claimed safety benefit, low supply on the labour market of sufficient and qualified crew and the further optimizing and digitalizing of the supply chain.

The main innovators are research institutions and innovative enterprises which have established in some cases an international network with authorities and industries. The experiments that are being conducted in Norway, the Netherlands, Belgium and Germany, both for maritime as for inland navigation and the growing global attention offer a possible window of opportunity.

Several interesting projects, experiments and other developments are announced, currently running or already delivered as on-the-shelf products in this field:

- *De Tuimelaar*: an automated unmanned survey vessel for depth measurement in the Port of Antwerp. The firm Seafar, together with other partners, is currently conducting a small-scale experiment with an automated boat (called the *Tuimelaar*) which is fully equipped with scanners and essential devices and is remote – controlled from an SCC. The boat can perform unmanned activities in the test area but still needs human support because of regulation and practical issues (e.g. mooring);
- *LAESSI or Leit- und Assistenzsysteme zur Erhöhung der Sicherheit der Schifffahrt auf Inlandwasserstraßen*⁶⁴. The *MS Jenny* was used as demonstration ship to test four support systems: the bridge

⁶⁴ Guidance and assistance systems for increasing the safety of navigation on inland waterways. The LAESSI project was funded by the German Federal Ministry for Economy, Affairs and Energy in cooperation with the in-innovative navigation GmbH, research institute DRL (Deutsches Zentrum für Luft- und Raumfahrt e.V.) and Alberding GmbH. More information on <https://www.innovative-navigation.de/en/allgemein-en/impressive-final-presentation-of-the-collaborative-research-project-laessi/>

collision warning system alerts the skipper as soon as there is a problem with the bridge crossing; the mooring assistant displays the measured and calculated distances to the quay wall or to other ships, thus, assisting the skipper in demanding manoeuvres; the automatic track control relieves the skipper of the trip by keeping the ship on a previously defined route; an indicator permanently displays all movements of the ship, the rudder position and the speed of the propeller. LAESSI provided several insights but no PSDs were developed;

- *Novimar*: automated platooning vessel train, NOVel Iwt and MARitime transport concepts, where a wireless platooning vessel train concept links several vessels and is navigated by a lead vessel which can be remote-controlled⁶⁵;
- *Roboat*: unmanned package delivery and public transport concept in Amsterdam;
- *Self-driving boat*: partnership between Shipping Factory and Xomnia with the aim of developing an algorithmic approach by machine learning and minimum hardware components;
- “*Autonom varen in de Westhoek*” or autonomous sailing in West-Flanders: small experiment of unmanned sailing⁶⁶ which ended in the first pilot of the automated and remote controlled Watertruck+
- *Automated docking*: several companies such as Wärtsilä, Cavotec, Mampaey and Trelleborgh are selling automated mooring devices such as vacuum or magnetic based robotic arms or as in Norway combined with a wireless power charge system;
- Underwater hull cleaners such as the *Hull Bug* (Robotic Hull Bio-inspired Underwater Grooming tool) and *I-keel crab*⁶⁷ are currently on the market for maritime vessels.⁶⁸. These systems do not replace tasks of existing crews, rather those of inspectors and divers or repairmen at a dry dock.

As commercial IWT vessels dock significantly more often than seagoing vessels (at locks, waiting time for bridges, loading, unloading, rations and change of crew), replacing these activities by on-shore ad hoc crews would be an organizational challenge at a cost. Automated docking in all situations is needed to replace these tasks and to make AVs possible. As waterway managers are installing automated, remote-controlled and unmanned locks and bridges, and as the reality of other mooring infrastructure (old poles in the water, unequal quay walls) is insufficient to allow the first generations of on-board automated docking stations, AVs cannot be yet operational in all circumstances.

Beyond inland navigation, since the nineties, automated systems are implemented in space such as the Zarya, which was the first module of the International Space Station to be launched and which flew for almost two years fully automated. Another development is Waymo (subsidiary of Google’s parent company, Alphabet Inc). On November 7, 2017, Waymo announced that it had begun testing driverless cars without a safety driver at the driver position. Google had begun testing the self-driving car project in 2009. Others such as Tesla already installed self-driving options in their vehicles and are enhancing further the autopilot. In railways, the first fully automated rail journey was performed by Rio Tinto in Australia transporting iron ore⁶⁹. And of course, there are earlier mentioned experiments or research in maritime by Rolls-Royce and others. The developments coming from military applications of drone technology are also expected to be further commercialized in the coming years. Ignoring developments in other modes and even the broader field of robotics could impose lock-in effects which

⁶⁵ <https://novimar.eu/>

⁶⁶ For the project “Autonom varen in de Westhoek” regional (Vlaamse Waterweg), POM West-Vlaanderen and European actors invest EUR 622,994 to develop an automated (even autonomous) barge for the small canals and waterways. <https://www.vlaamsewaterweg.be/autonom-varen-de-westhoek>

⁶⁷ <http://www.keelcrab.com/en/>

⁶⁸ The build-up of organisms on a ship’s hull (bio-fouling) could reduce the vessel speed by 10%, leading to 40% more fuel use; the mobile underwater robots are able to remove this during operations of the vessel as claimed by the company. Lowe (et al., 2016) identified 6 autonomous or semi-autonomous hull cleaning robots that are already on the market and are being developed since 2010. Lowe C., Curran A., O’Connor B., King E. (2016), Analysing the Current Market of Hull Cleaning Robots; WPI, USCG, Worcester Polytechnic institute, https://web.wpi.edu/Pubs/E-project/Available/E-project-121416-161958/unrestricted/USCG_Final_2016.pdf

⁶⁹ Retrieved from http://www.riotinto.com/media/media-releases-237_23264.aspx; <https://en.wikipedia.org/wiki/Zarya>; <https://waymo.com/>;

could ultimately lead to innovation failure for the IWT automation. Moreover, if inland navigation does not evolve towards more automation and must compete with transport modes that become more advanced, the position in the mode split of IWT could weaken.

Another important evolution is the further automation of the entire supply chain. From a logistical perspective with developments such as digital ledger systems (e.g. blockchain) where every piece of the chain shares relevant information with other pieces within a distributed network of computers, components (in this case transport modes) that are not linked because of a lack of innovation, could become rejected or obsolete. Digitalized documents such as a bill of lading can be sent by the ships' AOS to the next distribution centre, refinery, sea vessels after transshipment or other logistics partners within the supply chain through the ledger system. Regarding blockchain, the Port of Rotterdam started in 2017 with 'Blocklab', to develop applications in this sense. Automated supply chain parts could be essential as the AOS could provide information easier and faster. They also could perform more optimally than conventional human systems. In other words, if all modes and points of sending and delivery of cargo (ports, distribution centre, logistics hubs, floating stockage), become automated and operational perhaps within a digital ledger system, except for inland navigation, customers could shift to other modes. An outdated inland navigation sector with paper documents and relatively high crew costs, could become a disintegrated part of the automated supply chain, while other modes become more advanced (more optimized and perhaps unmanned). The social cost concerning congestion and road accidents could then increase.

3D printing can also be considered as an auxiliary innovative support for the AV. Whenever a spare part is needed, the ship will not necessarily need to stop at a shipyard if there is enough space for a 3D printer on board and if the caretaker or the robotic equivalent can do the necessary reparations, installations or replacements. Another solution would be drones with spare parts that leave from a distribution centre or a ship yard nearby. This evolution or supportive innovation is not taken into account in the analysis and goes beyond the scope of this research. However it is worth mentioning the additional potential that could be brought by such auxiliary innovation. Although sounding more like science fiction than science, the technological feasibility and the rapid evolutions in auxiliary innovations such as 3D printing and robotics can happen much faster than predicted or perhaps not at all (e.g. if barriers are not removed).

Robotic products that are spinoffs from NASA's efforts or from advanced army drone technology such as magnetic crawling robotic devices that clean hulls, inspect narrow spaces, paint (including removal), coat, weld, etc. are coming on the market. Most of these devices are remote-controlled now but, as artificial intelligence is more and more linked with such kind of devices, they could evolve into real autonomous systems. For example, the firm *Sea Machines Robotics*⁷⁰ already offers *Intelligent Control Hubs* with flexible Sensor Integration, interfaces and control devices covering auto-navigation, machine awareness, payload control, remote communication links and other automated tasks.

A fully automated operation system for unmanned vessels is not developed yet but as research and technological advances move very rapidly, several the human tasks could already be automated by existing technology. It will be a matter of mainly time and money before the first fully automated and unmanned IWT vessels (or with the possibility to be unmanned) become active in all segments of the IWT market.

Several components for the next level are being initiated through research and pilots and are becoming more advanced. Navigational tasks are being translated into algorithms by machine learning through several experiments and these developments are moving very rapidly. It becomes clear that automation is not only one device, but rather an integrated set of advanced subcomponents and devices that function in a synchronized, reliable and safe way. As each part has its own development status and background, it becomes more complicated to create a fully-integrated AOS on-board of an AV. Furthermore, a fully unmanned vessel without on-board crew to intervene, depends on further

⁷⁰ <https://sea-machines.com/>

robotic developments which need to be tailor-fitted for IWT and on infrastructure adjustments. The need for robotics can be replaced by (or outsourced to) ad hoc human crews with sufficient knowledge of the uniqueness of every unstandardized IWT vessel if the new fleet of AVs is not standardized.

So far, the initiation period is analysed in a descriptive way. Now these early findings are further investigated by applying the SIA Matrix on the initiation period of the AV in the next part.

5.3.3.SIA Matrix of the AV

The SIA matrix is applied on an automated and unmanned vessel. The shaded areas represent the areas in which system failure or success factors could be observed and the actors that are related to causing and/or potentially solving these failures during the initiation phase. It provides insights as to why an innovation is not (yet) pulled by or pushed on the market (market uptake) and shows the failure factors for a fully automated and unmanned vessel which is in the initiation phase with small scale pilot projects. Table 28 shows the identified failure factors in a SIA matrix for the AV during the initiation period.

Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties’ lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Institutions				
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 28: Systems Innovation matrix of the initiation phase of a fully automated and unmanned vessels
 Source: based on Aronietis (2013); Legend: black shaded cells represent identified failure factors. Grey shaded figures show identified success factors.

The matrix approach links the actors with innovation factors such as market (uptake), infrastructure, hard and soft institutions (regulation, cultural, values and believes), capabilities (external knowledge and financing) and network aspects (influence of actors) as further identified by the detailed analysis. These factors are linked with each identified actor within the innovation network. The waterway manager or private terminal operator needs to look for a solution together with private actors for the mooring problem. The actor “shippers/forwarders” need to be able to have enough infrastructure (digital and physical) to receive the AV and to perform operations. This is currently missing in the initiation phase, but as the technology is being developed, solutions will have to be found. Large vessel owners need the capability to invest in the innovation, but they should also be able to work with high tech innovation such as the AV. Training is required but the definition of training and required skills still must be developed. This is also the case for shippers and forwarders. Regulation is still missing, but funding is available and knowledge institutes, verification agencies and standardization bodies are aligned in the development. Referring to regulation, legal issues concerning liability, crew and technical requirements need to be solved. Governments and port authorities provide funding and organize or facilitate pilots. The Netherlands and the Flemish region decided to transform their waterways into one transnational experimental zone for innovation in IWT (except the international rivers) only demanding compliance to existing regulation and with official permit of the waterway manager. Norway, the Russian Federation, China and Japan claim to do comparable actions.

The demand for a regulatory framework at European level with legal definitions is also emerging with proposals and debates on the levels of the CCNR and UNECE. The European Commission has shown special interest by accepting funding schemes for several automation programs and developments in

all transport modes. Policy makers can play an important role in granting derogations⁷¹ and adjusting regulation to further develop and implement this innovation. If automated vessels must comply with existing crew regulation according to their exploitation mode (A1, A2 or B), the business case behind this innovation will fail.

The infrastructure for a knowledge network of institutions is identified at a global level. Hard institutions and lack of mooring infrastructure are important barriers for the AV but do not prevent the development and implementation of small survey vessels or other pilots. On the side of lobbyists and manufacturers, several players are identified with a strong network with different institutions. The branch organizations do not show any resistance, although this could be the case in later stages of development. Companies such as Seafar and the Shipping Factory are identified as innovative companies with the capability to initiate pilots and conduct research which is crucial for further development.

5.3.4. Innovation conditions of the AV

In this part the failure factors concerning infrastructure, institutions and interactions are investigated more detailed and explains more the findings of the SIA matrix as presented in part 5.3.3.

A. Infrastructural conditions

An AOS that only performs navigation tasks (with crew on board) does not need any fundamental changes in physical structure. The system should be able to identify the existing infrastructure (including signalizations) and perform accordingly in a safe and reliable fashion. In this scenario, only the wheelhouse could be unmanned.

In case of a truly unmanned vessel, infrastructure probably needs to be adjusted, although not all innovators agree with this. Existing conventional bollards can then be added by automated docking stations that are built inside the lock walls, at terminals, at waiting points (e.g. waiting at bridges that close during the night), and which are dynamically adjustable for every water depth and could be used in all-weather circumstances. On-shore pipeline or tank interfaces for bunkering, also will need attention. Perhaps a revision and upgrade are needed in order to attend unmanned freight vessels (both liquids as dry bulk, containers, project cargo, etc.). Bunkering facilities⁷² should then be reconsidered and redesigned for automated use. The communication infrastructure should make it possible to safely communicate with unmanned vessels. Most described tasks (and in expectation of a slow changing infrastructure) will make a crew still needed on board of most ships in the upcoming years.

However as modifications (if needed) on the infrastructural side progress, more trajectories will possibly witness unmanned vessels. The infrastructure technology to support unmanned vessels already seems feasible but still needs to mature and comes with a significant cost (e.g. the quayside equipment for the Yara Birkeland is estimated at USD 20 million⁷³).

The digital structure could be even more challenging because the need for big data exchange and data security. A remote-controlled vessel could be vulnerable for hacking. Private and public actors should

⁷¹ which means that an innovator is allowed to temporary benefit from an exemption from the existing regulation to prove with sufficient monitoring and expertise that the innovation maintains at least the safety level as required by regulation. After the period of derogation, the policy maker can decide to allow the innovation by adjusting the regulation. (e.g. inland navigation fuel was not allowed to have a flashpoint of -162°C). The derogation procedure looks for the 'right' balance between maintaining a high safety level (monitoring, testing time, evaluation, hazard studies,...) and the evolution of the innovation (productivity targets, business case).

⁷² The described problem of bunkering is based on a vessel running on fossil fuel. Electrified vessels can avoid this issue and do not need human interference.

⁷³ <https://www.marineinsight.com/shipping-news/gard-evolves-insuring-sailing-ships-autonomous-ships/>

be aware of this issue in building a reliable and secured digital infrastructure⁷⁴. However this issue goes further than inland navigation only, while it refers to the digital infrastructure of the entire economy. In every sector, the problem to secure data and to ensure continuous data synchronization in real-time occurs and poses a global challenge everywhere.

The issue of piracy exists in the maritime transport, but this is not the case for European inland navigation. Although the use of expensive robotic systems and the value of the cargo, could require a sufficient level of security against theft or even vandalism. On an unmanned vessel, these security issues will require secure data connections and presumable follow-ups by human or robotic interaction.

Automated docking systems (ADS) can be on board the ship or on shore. Automated dock devices for locks are already operational at the St. Lawrence Seaway.⁷⁵ The first-generation systems were tested in 2010. From the 622 tests, 149 lockages failed or showed a success rate of 76% (Nolet, 2012). Recent investments for the Eisenhower and Snell locks are already the fourth generation of mooring devices. This kind of innovation looks already very promising but still must mature. Moreover, the maritime design must be tailor-fitted for inland navigation. Automated mooring can also be done with devices installed on the vessel. The TMS Valburgh with the iDL from Mampaey is an example of an on-board installation which is claimed to moor within ten minutes. Regarding the mooring system of the TMS Valburgh from Covatec, no prices were given, but similar on-board units from Trelleborg Marine Systems cost EUR 450,000 for each unit and need additional updates and maintenance costs next to adjustments in ship design. For ADN vessels, prices are EUR 50,000 more for every on-board docking station.

The quays, lock walls and other mooring locations are not always equipped to allow automated mooring with on-board devices (those that are on the market). In 1998, the first vacuum-based auto-mooring system was introduced by a New Zealand company, called “Mooring Systems Limited”, with the first “IronSailer Series I” on the rail passenger ferry “Aratere” in Spain⁷⁶.

Other examples can be found in Melbourne, Dover, Salalah (Oman), Devonport (Australia), Picton (New Zealand) and Helsinki (Finland)⁷⁷, which are already operational for maritime vessels. For ferries, a system is installed at the ferry port of Den Helder in the Netherlands that uses a similar technology of auto-mooring system with vacuum naps.

The company Wärtsilä introduced, together with Cavotec, Norled, Innovasjon Norge, Fjellstrand, Haugaland Kraft and Apply TB, an automated docking station that also could power charge a vessel. In 2018, the hybrid ro-ro passenger ferry, the ‘MF Folgefonn’ (85 meters), which services Jektevik-Hodnanes in Norway, was successfully tested with this on-shore wireless power charging and docking system. This type of vessel has predictable routes and loads, known patterns and predictable data within two fixed points of origin and destination. The project costed in total NOK 27.8 million (Singstad, 2017).

⁷⁴ The developments within the RIS environment (e.g. RIS COMEX), the current upmake of the evaluation of RIS Directive 2005/44 by the European Commission, the formation of CESNI TI, together with RIS expert groups are considered vital to tackle this issue.

⁷⁵ In May 2015 this technology was recognized by the OECD. On the US side of the Seaway, the Eisenhower and the Snell locks are also being equipped by such devices. A total of USD 9,971,000 for both locks is allocated from the budget of the U.S. Saint Lawrence Seaway Development Corporation. One unit of the fourth generation is estimated on USD 830,917 and has two vacuum docking devices. U.S. Department of transportation (2017), Budget estimates, fiscal year 2017, Saint Lawrence Seaway development corporation, submitted for the use of the committees on appropriations, 98p., <https://cms.dot.gov/sites/dot.gov/files/docs/SLSDC-FY-2017-CJ.pdf>

⁷⁶ <http://www.cavotec.com.ua/download/cat9/AMS.pdf>

⁷⁷ The installation of the on-shore units in Helsinki costed in 2016 approximately EUR 2.5 million for six units with 400 kN of holding power for every unit. <http://megastar.tallink.com/the-west-terminal-2-will-have-the-first-automated-ship-docking-system-in-the-nordic-region/>

Automated mooring systems are claimed to reduce fuel consumption and improve air quality because of the efficiency benefit compared with traditional mooring which needs the necessary manoeuvring to moor. Another possible benefit is accident risk reduction. The use of ropes or wires can be dangerous and could lead to severe injuries. Another system is a grip-based auto-mooring that consists of a vertical guiding system attached to a bollard⁷⁸. Most of the systems that are being tested and even commercially available need adjustments on the infrastructure side.

Focusing on one type of mooring technology and making it a standard to adjust the entire infrastructure, increases the opportunity costs (sunk cost). When the implementation is finally there, other and better systems could be available. It could also be that the chosen technology becomes already obsolete at the time of implementation and that the incentive to look for better systems without necessary infrastructural changes is decreased by making one type as the new standard. In case of rapidly changing development in the world of robotics and automation, it will be also difficult to keep pace with realistic standards and requirements.

Automated fenders, mooring, loading and unloading, need infrastructural adjustments, but automation itself brings other issues that eventually could lead to failure of this type of innovation. In an article of *The Pilot* in 2006, John Baker wrote that even if rather expensive automated devices are available on-shore, the issue of liability could be the reason not to use it. If something goes wrong, the berth operator could become responsible⁷⁹ and not the crew on-board.

For inland navigation, automated mooring, loading and fender devices are in most cases only feasible if shore installations are provided. For truly unmanned vessels, these are essential requirements for a level 4 or 5 innovation to succeed. These on-shore devices should be able to adjust height according to the loading status of the vessel (vessel depth).

Not only the waterway managers have to adjust their infrastructure: private customers could also install compatible docking and loading systems in order to receive automated and unmanned vessels. If waterway managers and other market players do not make the necessary adjustments to receive fully automated and unmanned vessels, the innovation will probably fail. A vessel with automated navigation and with crew for operational tasks on board, will not need any physical infrastructure adjustments. A safe and reliable digital infrastructure remains essential in all levels of automation.

Next to infrastructural issues, existing institutions and organisations could pose problems for the innovation. This is investigated in the next part.

B. Institutional Conditions

The influence of variables during the innovation process such as soft institutional conditions (politics, cultural values and social aspects) and hard institutional conditions (rules and regulations) can also be a determinant for the diffusion of the innovation.

B.1. Hard rules

As in maritime transport, several IWT regulations need to be addressed in order to make the development of automated navigation possible. Legal definitions and other regulatory aspects must be addressed by all actors in the multileveled policy structure of the (pan-) European inland navigation and perhaps be adjusted or developed into a complete new set of rules (e.g. drone laws if an AV is not considered as a vessel). A scenario where regional or national states define automated vessels and draw up regulations, can be problematic for an international sector such as inland navigation. It would drive the costs of this innovation up because of additional compliance costs for each regime.

⁷⁸ http://www.ttsgroup.com/Global/Product%20sheets/Auto-mooring_4page.pdf?epslanguage=en

⁷⁹ Baker, J. (2006), Automatic mooring Systems, *The Pilot*, July 2006, no. 286, AR Adams & Sons (Printers) Ltd, Dour Street, Dover, Kent CT16 1EW, <http://www.pilotmag.co.uk/wp-content/uploads/2008/07/pilotmag-286-final.pdf>, 16 pages

The following table shows the different levels of policy and the relevant regulations that could have an impact on the levels of automation.

Institution	Technical requirements	Private law issues (VO & other commercial partners)	Other rules (criminal, public law... etc.)
National		e.g. Belgian law of river chartering (Wet op de binnenbevrachting °1936)	Labour provisions
River Commissions	RVIR	CLNI	RPR (police)
CESNI	ES-TRIN		CESNI/QP
EU	Ship safety directives & regulations, crew requirements		
UNECE	ADN (in case of automated dangerous goods transport); CEVNI	CMNI	CEVNI (police)

Table 29: Layers of relevant affected IWT crewing and technical legislation
Source: own compilation

Policy such as regulation and existing standards, is expected by the interviewed innovators to be a bottleneck to unroll automated and perhaps unmanned vessels on the international waterways, since it could take years before regulation is adjusted by all relevant policy actors and then even not necessarily in one common regime.

Existing technical regulation requires for manned barges to have on-board equipment such as a mariphone (marine VHF radio), machinery and installations needed for lights, sounds and optical signs, domestic litter reservoirs, reservoirs for oil containing cleaning textile, small chemical waste (liquid and solid), other greasy ship’s waste and a slop tank. Three steel ropes are mandatory to be on board according to the Rhine regulation as are portable and non-portable fire extinguishers and installations, lifebuoys and lifejackets. Most freight ships in IWT are mandatory to also have a dinghy on board. Furthermore, a ship must be built, designed and equipped in such a way that humans can work safely and move freely. It can be questioned if an AV needs all of this. The list of technical requirements goes longer, but it should be clear that installing a complete AOS on an AV that could fully replace the crew, makes eventually a number of mandatory technical requirements obsolete. In some cases, this can give additional space for cargo if approved by regulators. An unmanned vessel does not need a dinghy, drinking water, heating or household waste disposal units.

The AOS should receive real-time information of all relevant elements that existing scanners and human senses can monitor, interpret and translate directly in necessary actions. The question remains if the new generation of scanners can see objects that appear suddenly in the water and are merely on the surface (e.g. ship or a container that is sinking, very small boats, drowning human, etc.).

Administration requires an amount of transaction costs. The way waterway managers and other administrative units deliver their service is still quite archaic. In many cases, the crew is still obliged to keep hard copies of service booklets, loading and vessel documents at offices at a lock, a terminal or refinery. Moreover, the contracts between the customer and vessel owner still often demand paperwork in hard copy. Government is evolving, but in a much slower pace. A lack of sufficient level of e-government (e.g. online document transaction) can slow down automation of all vehicles. Another aspect is the inspection and enforcement challenges of a fully automated vessel. Inspectors need knowledge of automated vessels and other technology on board, and specialized training. Again, even for inspections there are still differences between EU MS. For example, the Netherlands demands inspections every seven years in dry dock while Belgium demands it every five years, which increases the compliance costs of the enterprise. More common rules at least between states with navigable waterways will benefit from automation, especially as the European IWT market is relatively small.

The absence of a vessel owner on board the vessel causes challenges regarding liability. In inland navigation, the captain is responsible for the cargo until unloading. If a ship is fully automated without a crew, a solution is not only necessary for some important practical issues, but also a clear liability clause is needed. A legal definition and description of competences⁸⁰ of the *external captain* at the SCC (or on-board caretaker), can help partially to meet this liability challenge. The responsibility is then divided between the caretaker or external captain, the AOS manufacturer and the owner of the on-shore installations.

B.2. Soft rules

Barriers in soft rules depend on the identified window of opportunity. Public as well as private innovators and institutions are aligned behind the objective of being the first innovator with a completely automated vessel that could be unmanned, and which is inspired by breakthroughs in other transport modes and robotic research. The soft actions within standardizing bodies (e.g. CESNI) should be kept aligned and open for derogations for the innovation to be successful. The lack of alignment in both soft as hard rules can represent additional barriers as the innovation proceeds.

Currently, there is no clear funding mechanism. Countries can provide financial support according to EU rules (such as *De Minimis* rules, EC, 2013a) next to rather limited EU funding programs (such as Horizon 2020 and CEF) for IWT. Other institutional actors such as the River Commissions do not provide financial aid. In other modes, several projects are funded such as CARTRE⁸¹, AutoMate⁸² and SCOUT⁸³ for automation of road vehicles. For inland navigation, the EU contributed EUR 7,923,951 for NOVIMAR. For LAESSI, the German government paid EUR 1.2 million. The Flemish and Dutch government started under the umbrella of PIANC the working group “Smart shipping on inland waterways” in 2018 to create a framework for the deployment of smart shipping in a safe and reliable way. “Smart shipping” refers to highly automated vessels, traffic management and infrastructure, interaction between ships and logistical parties, and interaction between vessels, regulators and inspection. The latter action is driven mainly from the perspective of a public actor that looks for ways to automate inspections, decrease traffic management costs, and achieve efficiency and effectiveness benefits in further automation of the fleet.

For the project “Autonom varen in de Westhoek” regional (*Vlaamse Waterweg*), provincial (POM West-Vlaanderen) and European actors invest EUR 622.994 to develop an automated (even autonomous) dumb barge for the small canals and waterways.

Cultural institutions comprise typical characteristics of contemporary inland navigation in Europe. However it is important to point out that because of historical reasons, there are many differences between the business structure in the fleet that is active on the Rhine and the one on the Danube. The traditional VO in the Rhine region has a more family-orientated business (mostly with family on-board), whereby accommodation is an important issue, while the Danube operator usually works for a relatively large company with several vessels, which explains why accommodation is usually less important.

The degree of commitment of a VO to its vessel, could be of importance in comparing with an external captain in a SCC. For most VOs in the Rhine fleet, the vessel is everything they have. It is their family house, job and company. The personal attachment with the vessel and the logical consequence that safety does not only concern the transported cargo, could lead to more extreme behaviour in protecting the ship than the safety incentives and level of attachment at a shore control centre. Furthermore, when reduced to an on-board caretaker, the VO could feel less attracted to work on an automated vessel with merely a fallback monitoring function. The existing VOs could find it less

⁸⁰ including training and appropriate sufficient level of ICT knowledge which could be needed in overriding the system in case of system failure

⁸¹ https://cordis.europa.eu/project/rcn/206011_en.html

⁸² <https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/automated-road-transport/automate>

⁸³ https://cordis.europa.eu/project/rcn/204978_en.html

appealing to work in a SCC. In the medium-long run, the VO or external captain will also gain less navigation experience, which lowers the quality of the work force that should be able to intervene. Hetherington et al. (2006) point out that automation still needs attention of the crew, or in case of unmanned navigation of the SCC. However automation can lead to too much reliance on machines with less monitoring and care-taking consequently and to new human weaknesses, amplifying existing ones (2006). Lützhöft and Dekker call this a certain kind of cognitive lackadaisicalness (2002).

More sociological and psychological research is needed to measure the possible differences in operational and safety quality from a shore operator in distant “gaming mode” and a vessel operator who is protecting his or her life, family, house, company, cargo and other belongings. Furthermore, the existing working force will have to be re-educated for other assignments in a strong automated and more complex world. Finally, as the labour shortage grows, it will be more difficult to replace the ageing crew of the Rhine fleet.

The level of conservatism can be relatively high. Existing operators and other actors will doubt safety and reliability of all the new developed technologies. In a time when automated crafts are going in to space to dock at the ISS (since the nineties), there are still those who believe that it is too difficult or even impossible to develop fully automated and even unmanned vessels for the inland waterways. Resistance and general disbelief will be important aspects to tackle for the innovation to be successful.

It is not proven that an SCC will be safer indeed. Issues such as situation unawareness, data misinterpretation, capacity overload, reliable connectivity and as mentioned the lack of emotional attachment should be examined closer from a multidisciplinary perspective (socio-medical, computer science, psychological). This invites further research and is not included in the scope of this research.

A mind switch could also be necessary on the side of the customers. It is possible that some customers will easily entrust their valuables with these kinds of “robots”. Unmanned, automated, remote – controlled or autonomous vessels will have to prove that they are trustworthy and above all safe and reliable. The question of liability, who becomes responsible for vessel, cargo and perhaps automated berthing, is a very important one. An unclear answer could lead to failure of the innovation.

Another important topic of soft rules to consider, is that a fully automated vessel could have ethical flaws. For example, in case of a calamity between other ships, an unmanned automated vessel will notice, could scan the situation and at best inform the river police, but will probably not be able to react as a manned vessel for rescue operations. Furthermore, when a small boat such as a fishing boat or a yacht suddenly crosses the trajectory of an automated vessel and evasive manoeuvres are at hand, the behaviour or choices of the automated vessel determine the outcome of such situations. This outcome or reaction of the AV could influence public opinion and increase resistance if not dealt with properly. Too high public resistance leads to failure.

C. Interaction conditions

Interaction conditions could lead to innovation failure or market uptake. If the innovator is not linked to an innovation network, chances for failure could be high. Furthermore, If the innovator is too strongly linked, vital information outside the network can stay hidden. There are hardly any interactions identified between innovators that are focused on automation in different transport modes. Innovators, as most policy makers do, tend to have a unimodal focus. Only maritime and inland navigation are often linked but this could lead to wrong conclusions and outcomes⁸⁴. IWT is a relatively small sector at the European level and most EU-countries do not have a strongly developed waterway network. On the side of the main lobby organizations of the branch of the sector, the network is also considered weak. This weakness manifests itself in the scattered opinions between the numerous

⁸⁴ An ocean going vessel is quite different from an inland navigation vessel (technological, business and market size, organizational and regulatory).

branch organizations across Europe towards different layers of policy and customers. A more efficient lobby could help to put important IWT issues higher on the policy agenda.

Although, since 2018, closer cooperation between the different organizations has become noticeable on all policy levels with the creation of the European IWT Platform between EBU and ESO. A lot of effort needs to be done to strengthen the network which could be beneficial for all innovations. This is true especially when lobby work is in direct competition with lobbyists from other transport modes to get the attention of high-level policy makers.

D. Capabilities

Innovation requires sufficient capacity during research, design, initiation, development and the implementation stages. In all stages of innovations, challenges could arise, and without sufficient capability the innovation could fail. The capability of the innovator is not only financial. Firms, especially small firms, may lack the capabilities to learn rapidly and effectively and hence may be locked into existing technologies/patterns, thus being unable to jump to new technologies/business patterns or develop an innovation themselves.

D.1. Financial

The future deployment of automated inland vessels implies high development costs, low-scale production and a lack of mass consumer availability. The initial costs are considered relatively high at this stage of initiation. A fully automated and unmanned vessel includes the development and implementation of other innovation elements such as new technologies to replace all essential processes on board to navigate, and in following phases, to (un)moor, (un)load, maintain the engine room, supervise loading while constantly adjusting on all irregular weather conditions, and different waves and tides. The reduction of personnel cost, fuel cost and safety cost are the main identified drivers to have a return on investment. Furthermore, regulation could possibly be lagging, despite the efforts of policy makers, what could influence the intended operation mode of the vessel and increase the costs even more because of the delay. When automated processes become allowed to reduce the mandatory crew size, the AV would make a more positive business case. Uncertain policy in this regard can lead to failure.

D.2. Knowledge

The innovation in this phase needs sufficient machine learning that can be achieved by gathering and sharing data, real-time field experiences and simulations of as many situations as possible. A complex innovation such as an automated vessel requires more specialized expertise for automated operations and inspections. Asymmetrical information could occur between public and private actors or even between the different subcomponent manufacturers and the integrated AOS manufacturer, which could lead to system failures in a worst-case scenario or compatibility issues. Evaluation capacity is needed during the development and later implementation phase of the innovation cycle, especially within inspection and regulatory standardization bodies.

D.3. Potential market

If the described fleet evolution continues (see introduction to the European inland navigation), the number of potential customers (existing VOs) for automated vessels is not expected to grow in the freight transport market. With only 20,000 vessels (of which 7,000 in dry cargo) in the European fleet and with every segment their needs, trajectories, size and unstandardized vessel designs, the innovation addresses only a small niche, especially in the initiation period.

5.3.5.SIA conclusion of the AV

The SIA helps to identify, explore and define the innovation case through the stages of development. The matrix approach revealed important patterns between innovation actors and failure factors.

Although several success factors are in place, the innovation still needs to tackle a number of challenges to arrive in the development period.

The typology and the descriptive analysis of the initiation period offer important first insights in this case. Next to recent developments, the involved actors within the innovation network are also identified with the SIA matrix. Case-related findings so far, are:

- Most relevant actors are (semi) large companies, ports, waterway managers and research institutions;
- The validation of the assumed safety increase and the expected decrease of lower crew costs, are key elements for a company’s business case;
- Financial possibilities are limited within the relatively small IWT market;
- The first feasible unmanned ships are expected to be rather small vessels on fixed trajectories (e.g. survey vessels, ferries... etc.) without a lock problem or other insufficient infrastructure for unmanned vessels. The possibilities for barge convoys and platooning also seem feasible in the short run;
- The AV does not replace human error, they transfer the possibility for human error to the programming input phase of development and during the update and maintenance phase of every component;
- The IWT fleet is in general at the end of level 1 in the automation scale with systems to assist in steering such as the auto-pilot and AIS;
- There is a regulation bottleneck: to solve this, several countries have decided to allow pilots and further development,
- Vessels that do not require loading or unloading procedures and which are less dependent on market demand with fixed trajectories are considered to be the first wave of potential customers if no other failure factors are present

The RQ and its sub-questions can be partially answered which is presented in Table 30. The table continues on the following page.

Sub-questions Innovation	Answer
When is the innovation successful or a failure? What are the conditions that lead to failure or to success?	The AV is not successful yet but is situated early at the initiation period. Important failure factors could be solved and are related to: Mooring problem to allow fully unmanned; Bunkering and operations; Consumers availability and capability; Cultural conservatism; lack of sufficient knowledge; Regulatory bottleneck, lack of alignment between soft and hard institutions and potential policy uncertainty; Deskilling and cognitive lackadaisicalness for SCC operators; Compatibility issues with needed devices (perhaps robotics) and scanners; Risk of looking too unimodally and the need for further developed digital and physical infrastructure
How can innovation be analysed or measured?	The SIA proves to be a powerful tool to explore, identify, categorize and qualitatively analyse the case of the AV, but it does not state if the AV is a good business case for investors as well for society. It also does not give any solutions how to remove failure factors such as the regulatory bottleneck. Too early to measure the diffusion of the innovation because the AV is situated early in the initiation phase and still needs to be further developed.
Who are the relevant actors in IWT innovation?	Actors are identified within a global network of innovating firms, knowledge institutions, public actors, verification agencies, standardization bodies, some VOs and large vessel owners, manufacturers (including ship yards), consultants, regulators and waterway managers. Charterers and industry with own vessels and shippers/ forwarders are not identified. In the following phases and to tackle the mooring problem, alignment with these actors can be needed. Most pilots are led by private innovators with the support of public funding. In some cases, the waterway manager takes the lead as a public innovator (e.g. Raven project)

Sub-question policy	Answer
<p>What is (IWT) innovation policy, how is it organized and which role plays IWT innovation policy?</p>	<p>There is no real policy yet on automation in IWT. Several public actors such as the European Commission and the CCNR have started the debate concerning a regulatory framework for automated vessels. Some regions in Europe allow pilot testing on their waterways and allow derogations. There is public funding available in several projects and studies. There are however no plans identified to adjust the public infrastructure.</p> <p>The SIA offers also exploratory insight and a first attempt to reveal the regulatory bottleneck which sets the scene for the PEINPA.</p>
<p>Which innovation policy measures are applicable to IWT?</p>	<p>River commissions can allow derogations for further testing similar to regions and MS. Bottlenecks concerning the regulation related to river police, liability issues, technical and crew requirements can be adjusted. Concerning the digital infrastructure (RIS environment) these public actors play a role in the further development of the digital infrastructure to allow secure data exchange and sufficient coverage.</p> <p>European commission: Ship safety directives & regulations, crew requirements, River Information Services, Digitalization policy, next to public funding for projects and studies.</p> <p>The national or regional level can solve private law issues, labour provisions and their waterway managers can lead innovations and adjust infrastructure. Another important role for the national actors is to lobby in the agenda-setting phase in higher levels of policy to address automation in IWT. In case of infrastructural adjustments, ports and private actors such as IWT terminals, need to be involved and aligned.</p> <p>Although, the first wave of automation seems to be focussing on dry cargo, in a later period, also tankers could be addressed. In this case the ADN of the UNECE needs to be adjusted. Furthermore, CEVNI were several countries refer to in their national legislation (e.g. Belgium) and which affects river police regulation, needs to be adjusted and aligned accordingly.</p> <p>In case of the AV: public funding, assigning testing zones. The type of funding of projects supports the collaboration between several knowledge institutes, public and private actors (e.g. Novimar) which vaguely refers to an innovation network policy situated at the level of the EC. First traces of debating relevant policies on level of River Commissions and European Commission; development of AV standards within CESNI is expected.</p> <p>No traces of fiscal incentives for R&D (only funding), other support to firms, policies for training and skills, entrepreneurship policy, pre-commercial procurement or innovation inducement prices.</p>

Table 30: SIA conclusion of the AV, answers for the RQ

The next sub-section analyses the AV as a potential business case for IWT. It also allows to identify the significance of external costs within the designed vessel model that could advocate the further development of the innovation or not from a welfare perspective.

5.4.CBA of the AV

In this analysis, it is assumed that a fully automated and unmanned vessel exists with the support of an SCC. This assumption includes several elements as the presence of training centres, the availability of needed technology, the existence of regulation, the upgrade of infrastructure and the presence of a job market for the SCC working force. The results could of course differ in other scenarios or for different types of ships. The safety benefit of an unmanned vessel as mentioned in maritime transport, is discussed for the automated IWT. Furthermore, the potential loss of conventional jobs is compared with the creation of new jobs (e.g. SCC) and the assumed growing labour supply shortage.

Furthermore, IWT and the further automation will probably be influenced by developments in the field of object detection (scanners, radars, etc.), internet of things (communication between automated instruments and machinery), communication (satellites, 5G, GPS,...), big data (safety and level of synchronization), robotics (e.g. unmooring, fuelling) with digital processes and cloud applications (sharing of big data). An important development can be block chain technology, which has gained a lot of attention worldwide also in transport, and which could integrate and optimize a complete logistics chain whereby all logistics parties have complete access to all relevant transport data and where all actors agree on all transactions. This also inflicts existing conventional vessels.

The potential social benefits as stated by MUNIN (2015) are related to safety and fuel efficiency (the latter includes a private benefit) in maritime. This analysis investigates if accident cost reduction and improved fuel efficiency are also beneficial for IWT. Another social benefit, as some might add in this regard, is the presence of a competitive inland navigation towards less sustainable modes of transport. The latter reasoning raises the concern that IWT might lose market share when all other modes become successfully automatized. A loss of market share or modal share would be indeed a social cost because of the modal shift towards road haulage depending on cross-mode elasticities. Even if road haulage becomes automated, there is no reason to believe that the social cost of road congestion will be significantly reduced. The social cost of road emissions and accidents could be reduced by automated vehicles but there is no proof yet that this will be the case.

The social costs are derived from the possible *creative destruction* of traditional inland navigation jobs such as boatmen and even operators or boat masters. However a *Schumpeterian* view also includes the creation of jobs in the longer run. More technicians will be hired, operators could work in SCCs and as regulation is not expected to change rapidly, the mandatory number of crew members, the employment in the inland navigation will not be affected immediately. As the vessel becomes fully automated, the crew members will have less transaction costs and more time to do other tasks. As navigation becomes increasingly supported by automated processes, the mandatory crew size might become more obsolete. For several years now, European inland navigation has experienced a manning problem with many job positions that remained open.

The next part explains the social costs and benefits for different actors related to the fully automated and unmanned inland vessel and how other actors such as the innovator, customers and society could benefit from the innovation. This offers a theoretical starting point for a complete SCBA, but which requires and invites further research. This starting point however helps to situate the development of a CBA that takes in account external costs from the perspective of the vessel owner by using a vessel model of an IWT enterprise.

5.4.1. Cost and benefits for different actors

This part explains how to view the costs and benefits of different actors that are involved in the innovation. The distinction is made between the innovator which develops and operates the SCC and AOS; customers who pay for the installation, digital infrastructure, maintenance and benefit from improved safety, having more time and fuel efficiency; and society which also benefits from safety (external accidents costs decrease), less congestion (because of modal shift which refers to time) and less emissions. A more competitive, safer and more fuel-efficient inland navigation can also be

considered to be a benefit. Indirectly, a mode shift could occur to inland navigation from congested roads, which indirectly increases benefits in congestion reduction and other externalities of road haulage. The costs and benefits of the actors within the innovation network will differ. Table 31 shows the structure of the main costs and benefits grouped by the different actors involved such as the company that sells the automated systems and provides the SCC, (the innovator); the VO or skipper that buys the innovation; and the rest of society (individuals). The benefits and costs can be both private and external and are presented as a potential framework for a complete SCBA.

Actor / SCBA component	BENEFIT	COST
Companies (the innovator)		
AOS development	ΔR_p	X
AOS operation		X
Service rate and price of installation		X
Customers (public and private vessel owners)		
AOS devices	ΔB_s	X
Infrastructure		X
Maintenance and repair		X
Safety		X
Time		X
Fuel Consumption and emissions		X
Society		
Safety	X	ΔC_s
Time	X	
Fuel consumption and emissions	X	

Table 31: Actors and their direct costs and benefits of automated navigation
 Source: based on Aronietis R. (2013)

As explained, this analysis is performed from a vessel owners’ perspective. In order to gain as much details as possible, a shipping cash flow model is developed that also can calculate the external costs within the vessel model which answers to the welfare-economics perspective. Another reason is that relevant costs concerning the development of the innovation were not given in the initiation stage, which made a complete SCBA not possible yet.

The following part explains a number of data challenges to assess the main claimed benefit of accident cost reduction, the reason why real innovation development cost data could not be obtained and to what extent this is solved.

5.4.2.Data challenges

As an AV does not yet exist, it is challenging to find empirical and triangulated data concerning costs and benefits. A number of assumptions and uncertainties need to be addressed to perform the analysis. First, it is challenging to find reliable accident data in inland navigation to calculate the safety benefit and to support the external cost calculation of several authors such as Ricardo AEA (2014) and Van Essen et al. (2019). Some past sources provide detailed data but with quality problems such as the Dutch SOS database. It does show that if an IWT accident occurs, it is mostly caused by human error.

Second, an automated vessel can be programmed to abide the law, does not drink, is never tired or distracted, but does that mean no accidents will ever happen again? Accidents in an automated world are unexpected, but they still can occur. The cause of the accidents can then be related to program errors or system malfunctioning. Such a system could improve the innovation by enlarging knowledge concerning accident causes to avoid old and new types of accidents.

Another data problem lies in market-sensitive cost data. Not every company responded and those who did were not willing to give a precise estimate of the money invested in research or compliance. The cost-benefit analysis in this research is based on the gathered information and on several elaborated assumptions. The market sensitivity in sharing data, can be expected because the innovation is still in an initiation phase within a global race to become the first company or country with a full operational unmanned AV.

Finally, during the desk research, a number of projects were identified, most of them with enhanced images of the future vessel design which made them look more convincing than others. Identifying real projects, filtering merely sales pitches and even hoaxes, presented a challenge and if filtering is not done properly, this could result in contaminated data.

The operation costs of the AV are in the further proceeding of the analysis estimated and based on the available data and interviews which are described in following paragraphs. The costs of the innovation are briefly examined from the perspective of the innovator but are not completely analysed because of limited available data. Secondly, the potential customers on the IWT market are identified and finally the costs and benefits from a customers' perspective are closely analysed.

The following parts also show other assumptions and limitations concerning the calculation of the costs and benefits in this case study. The first issue is the theoretical development of an SCC which could help to estimate the service fee of the AV.

5.4.3. Costs and benefits for the innovator

The main investment cost for the innovator concerns the SCC as described by Kretschmann et al. (2015). It includes five situation rooms, 45 working stations and 169 employees. It is designed to offer a service for 90 maritime vessels at the same time which are 18 vessels for each situation room. In IWT this design or required SSC size would not be the case during the initiation phase. The shore control centre could also be at the beginning of the implementation stage much smaller in reality and only contain one situation room or even one working station at a significant lower annual cost.

To offer a service to a pilot AV, this design is therefore not needed (yet) for the innovator to develop, but it offers a way to estimate the possible annual service fee for an AV which is not given, and which is assumed to be similar with maritime. Monitoring and intervening from a SCC is considered not that different between IWT and maritime. The only difference relates to the skills of the SCC crew. The overview of costs allows to estimate the cost for the SCC rate for one customer.

According to Kretschmann et al. (2015), the SCC has an estimated annual cost of EUR 787,349 (personnel, overhead costs, updates of software, maintenance) and a one-time cost of EUR 1,920,541 for the installation of the situation rooms, software, hardware and other office equipment in prices of 2015⁸⁵. Table 32 gives an overview of all identified costs of one shore control centre within a 24/7 operation. The annual break-even price without financial costs, tax and depreciation, is estimated to be EUR 117,022 on average for each customer. This amount will be compared with the estimated salary cost on the vessel and adjusted as such.

⁸⁵ The same exchange rate is used here as mentioned in Kretschmann et al. (2015, deliverable 9) of 1.11 USD for each euro in current prices of 2015.

Costs of one SCC in 24/7 operation, EUR (2015)	One-time cost	Operating Life in years	Annual costs
Situation rooms	945,946	8	
Software	689,189		
Hardware	105,405	3	
Office equipment	180,000	13	
Rent for office space			370,300
Power supply			20,382
Software subscription and support			137,838
Training costs for employers			258,829
Salaries SCC crew			9,369,369
Ad hoc crew repair & maintenance			121,875
Total	1,920,541		10,531,966

Table 32: Annual costs of five situation rooms capable for 90 vessels at the same time
Source: based on Kretschmann et al. (2015), MUNIN report, €/USD = 1.11, SCC operator is able to monitor 6 vessels

The described SCC is in this case a theoretical example with the sole purpose to derive the annual service cost for the vessel that will be developed further. When more suppliers or service providers come on the market, this service cost will probably decrease. In the first stages of development of the SCC the costs will be presumably lower as only a few vessels (pilots) will be monitored. Because the innovation is in its initiation stage, it is far too soon to assume the price elasticity of supply and demand in this case.

The following part explores the potential customer of the innovation and develops the private cost model of the vessel firm.

5.4.4. Costs and benefits for the innovative vessel owner

In this part the developed shipping cash flow model is developed. It gives an overview of the cost structure of the reference vessel of 110m in the null scenario (conventional vessel, CV) and an 'automation' scenario (fully automated unmanned vessel of level 5, AV). The costs of the AV are based on literature review, interviews and several assumptions and uncertainties.

The costs are inspired by Van Hooydonck & RebelGroup (2015) and Prominent (2018) next to own estimations for the conventional vessel. All costs are according to prices of reference year 2018 or adjusted as such (e.g. cost of the SCC, compliance, capital value... etc.). The geographical context of the dry bulk vessel is Belgium. The vessel sails under Belgian flag. The following table shows the costs of a conventional and an automated dry bulk vessel of 110m in the first year of operation.

Based on a vessel of 110m, dry cargo, mode B: S2, annual costs in EUR (current prices of 2018); reference case

	CV	AV
Capital value	2,000,000	5,900,000
Lifespan vessel	40 years	
Leverage (70% of capital value)	1,400,000	4,130,000
Payback period	15 years	
Number of crew (persons)	4	0
Maximal loading (tons)	3,000	3,300
Residual value (scrap value)	80,000	
Fixed cost	161,359	452,710
Maintenance & Repair	50,000	26,586
Insurance	28,000	67,850
Salaries (gross)	272,800	0
Technical compliance (certificates)	9,000	6,750
Administration & communication	3,000	300
Financial cost	130,359	384,560
SCC service	0	190,960
Variable cost	579,030	388,241
Charterers provisions	67,760	10,861
Fairway & port dues	15,154	19,002
Fuel costs	164,316	134,082
Total cost	740,389	840,951
Revenue	Fixed freight rate (EUR 2.15/ton, first year)	968,000
		1,086,096

Table 33: Costs of a conventional and an automated dry bulk vessel of 110m in the first year of operation.

Source: Costs are based on RebelGroup et al. (2015), cost structure as suggested by Kretschmann et al. (2015) and own estimations and interviews

The costs and revenue are detailed explained in following parts which are elements to perform the cash flow analysis of the modelled dry bulk AV.

A. Revenue

Revenue is different for every firm and depends of a number of factors inside and especially outside the firm. Within this model, the revenue is assumed. During the analysis, any changes in revenue are taken into account to measure the impact on the cash flow analysis. For the first year, the conventional VO has an estimated revenue of EUR 968,000 based on the following assumptions:

- A fixed freight rate of EUR 2.15 per tonnes within a long-term fixed contract;
- Three trips per week are fully loaded (no empty sailing);
- Freight rate is negotiated under a long-term fixed contract;
- Every trip takes ten hours on average;
- Maximum payload is 3,000 tonnes for the CV. The AV has more cargo and trips than the CV (time benefit and more cargo space) which explains the difference in assumed revenue;
- Difference in earnings between both vessels in the first year of operation is given in Table 34.

Behind the earnings estimation lies the assumption that during the lifespan demand of the AV and CV the IWT sector grows as such that freight rates stay constant. In a more complex approach, own-price and cross-price elasticity of demand would lead to more volatility of the freight rate as Beuthe et al. describe (Beuthe et al, 2001). Cross-elasticity of demand measures the shift between transport modes if one mode becomes cheaper than the other. Own-price elasticity measures the impact on demand

for IWT or for one transport mode, when the freight rate changes. If demand for IWT responds elastically on a price change, the demand for IWT will fall if prices go up and ceteris paribus.

	CV	AV
Freight rate (fixed, long term contract)	EUR 2.15/ton	
Number of trips	150	153
Payload	3,000 tonnes	3,300 tonnes
Weeks in operation each year	50	
Trips per week	3	3.06
Annual revenue (operation based)	EUR 968,000	EUR 1,086,096

Table 34: Difference in earnings between AV and CV (current prices of 2018)

B. Capital value

The capital value of the conventional vessel is estimated at EUR 2,000,000 and is based on estimations from experts. The AV is assumed to be a refitted existing vessel with the same capital value as the CV but with scanners, AWS, AOS and an on-board ADS in addition. The initial capital with the added devices of the AV is in this analysis estimated at EUR 5,900,000. The engine prices are based on the findings from literature as more explained in the LNG-D case. An average is taken for a diesel engine with CCNR II for an estimated price of EUR 220 for each kW. In this cost-benefit analysis, the reference vessel has one propeller with an installed power of 1,250 kW. The price of the main engine is therefore estimated at EUR 275,000 and is included in the capital value.

The generator set (gen-set) is assumed to have an average price of EUR 350 per kW⁸⁶ (Prominent, 2018). The gen-set generates a power of 32 kW⁸⁷ or 40 kVA with a power factor 0,8. The average price of the gen-set is EUR 11,200 which is included in the capital value. The engine system has in both cases a conventional diesel propulsion with the engine mechanically coupled to the propeller and a basic gen-set. This assumption will probably not be the case in reality because of the earlier-mentioned findings that the preferred propulsion for the automated devices would probably be electric, but for reasons of clarity, only the innovation of the automation will be analysed in this research.

C. Lifespan and payback time

The lifespan of the vessels is estimated at 40 years, which is not uncommon in the European IWT. The design life of the docking stations is according to the manufacturer 20 years. During the lifespan of the vessel, the AOS hardware (including subsystems) must be replaced (minimum once). The payback time of the loan is 15 years in the base scenario.

D. Residual Value

The residual value after the end of the lifespan of the vessel is assumed to be EUR 80,000 as scrap value according to prices of the initial year of investment. For automation systems, the residual value is estimated to be zero and the rest of the vessel has the same residual value as the CV. The residual value depends on the scrapping market price or the market of second-hand vessels. However for reasons of simplicity, the residual value is fixed in this model.

⁸⁶ As mentioned in Prominent (2018), http://www.Prominent-iwt.eu/wp-content/uploads/2018/07/18_03_13_Prominent_D2.8_D2.9_Standardized_model_and-cost_benefit_assessment_for_right-size_engines_and_hybrid_configurations.pdf

⁸⁷ According to Royal Haskoning as cited in CBRB (2010), the average diesel gen-set has a range between 10 to 50kVA or with a 75% performance and a power factor" (p.f.) of 0.8 lagging

E. Maintenance and repair

The maintenance and repair costs (M&R) are calculated according the suggested method in Prominent (2018). Day-to-day fuel-based maintenance costs are estimated at EUR 0.12/m³, power-based maintenance is estimated at an annual EUR 4.6 per kW. Engine revision is assumed to be needed every six years and it costs EUR 63 per each kW.

The other M&R costs (excl. engine-related M&R) for the AV could be included in the service agreement with the SCC that organizes the ad hoc M&R crews. This cost depends on the negotiated service contract with the SCC. The reasoning behind this is that the SCC service and installation of the automated devices aims to replace all tasks of the crew in this model. What cannot be automated (yet) of the M&R, the SCC service provider will organize with human labour. For the CV, the total M&R cost is estimated at EUR 50,000 (including the engine related maintenance). The AV is assumed to have a service contract included within the SCC service and the engine-related M&R costs are estimated at EUR 26,586 for the first year of operation. The revision costs are calculated annually but must be paid every six years. For the fuel-based cost, as mentioned in Prominent, the estimated daily cost is multiplied by 350 days of operation. The M&R of the gen-set is included in the SCC contract together with all other maintenance and repair.

F. Port and fairway dues

Based on port and fairway dues (P&F) of the port of Ghent and the Flemish Waterway manager, the annual cost for the CV is EUR 15,154 for the first year. Because of the higher investment of the automation infrastructure, every AV pays an additional EUR 2,000 annually for the usage of automated docking in locks⁸⁸. Furthermore, the waterway managers must be able to communicate and manage automated and unmanned vessels. An upgrade of the entire infrastructure is needed, together with more specialized inspections (not only for automated vessels). In this analysis, it is assumed that this additional infrastructure and inspection costs will be paid partially by the users through fairway and port dues. In the first year, the AV will pay EUR 19,002 on fairway & port dues.

The P&F values in this model are mentioned in Table 35. The port dues are given for 14 days and adjusted for one daily rate.

	Number of port calls (annual)	Daily port due in EUR/bt	Total for port dues	Fairway due in EUR/tkm	Total for fairway dues
CV	151	0.0069	EUR 3,139	0.000267	EUR 12,015
AV	154	0.0069	EUR 3,521	0.000267	EUR 15,481 (Incl. EUR 2,000 AV infra + inspection)

Table 35: Port & fairway dues of the CV and AV

Source: based on port dues of the Port of Ghent (2018) and fairway dues of the Flemish Waterway Manager (2018)

G. Insurance

Protection and Indemnity (P&I) and Hull insurance is in this analysis an annual cost of almost EUR 28,000 for the CV. For each person on board, total insurances paid by the employer are estimated at an average of EUR 1,250 for each year per employee or EUR 5,000 for the entire crew. In case of the AV, this means that a remaining 1.15% of the value of the ship, hull and P&I (without crew insurance) must be paid, which is estimated at EUR 67,850.

As automated vehicles could become safer, the annual premium is expected to decrease by 10%. Next to the higher capital value of the AV and several remaining uncertainties concerning the development of this innovation, the premium is set higher than for the CV. The lack of cyber-attack insurance which

⁸⁸ The ADS in locks is not only possible for automated vessels but also for conventional vessels. Nevertheless, the additional costs are payed according to the usage of the locks by automated vessels.

is not covered by traditional P&I and hull insurances, could explain a higher risk premium. However because of a reduction of the number of crew members, the premium for life insurances is lower. Nevertheless, the insurance cost in the first year of operation is estimated to be 60% more for the AV than for the CV.

The private safety benefit will express itself eventually in lower premiums (when proven) but is in this analysis not expected during the first years of operation.

Other insurances such as household insurance, car insurance (special premium for putting a car on-board) will, next to a part of the P&I insurance (fatal accident or injuries of crew member and life salvage), be subtracted from the total insurance cost. The P&I insurance should only cover in the case of an automated unmanned vessel the collision liabilities, loss or damage to property other than cargo, pollution, towage contract liabilities, wreck liabilities, cargo liabilities, cargo's proportion of general average or salvage, fines, legal costs and the Omnibus cover⁸⁹.

H. Financial cost

The loan is in both cases 70% of the capital value of the initial year with an interest rate of 4,5%. Within 15 years, the loan is paid back in both cases in the first scenario. The business case is built without the assumption of subsidies. Investors are assumed to be available.

I. Charterer provision

For the CV the charterer provision is assumed to be 7% of the trip revenue. The AV is tested with 7% but also with lower provision rate. It could be assumed that also chartering becomes automated with an electronic booking system that is assumed to cost 1% of the digital charterers provision. This is also tested and shows the impact of different charterer provisions on the business case.

J. Crew cost

The crew cost on the CV is calculated according the exploitation mode B for a vessel of 110 meter. The conventional vessel complies with the technical standards as set by S2 in the CCNR regulation and requires two skippers (Rhine patented), one helmsman (four years of experience) and one boatman.

According to RebelGroup et al (2015), the total costs for a Belgian SME with VO and crew on board is on average estimated at annually EUR 880,000 of which 59% are considered fixed costs and 41% variable costs. In case the VO is not the operator and the operator is a member of the personnel with full salary, the total cost increases by EUR 40,000 in this type of vessel and exploitation mode. For the CV, a total crew salary of EUR 272,800 is estimated for the first year of operation without a salary of the vessel-owner/operator (VO) included.

For the AV, the crew cost is replaced by the service cost of the SCC and ad hoc R&M on-shore crews, which is included in the total service cost of the SCC.

K. SCC service rate

The total costs of the SCC lay outside the cost structure of the user. In this scenario, the SCC belongs to a specialized company that provides services to VOs. In order to have a competitive price, the service fee for the SCC including backup, yearly maintenance and repair of devices, is assumed to be under the normal personnel cost. In this scenario, the leasing of the material and total service of the SCC reduces the personnel cost of the CV by an estimated 30% in the first year of operation. As more vessels become customer at the SCC, and other service suppliers appear on the market, these prices probably will decrease during the lifespan of the AV. In the first year of operation, the annual service cost of the SCC is estimated at EUR 190,960.

⁸⁹ "The Omnibus rule covers risks that do not fall expressly within the expressly itemized cover but which are incidental to the operation of an insured ship and which fall broadly within the scope of club cover." Cited from http://www.gard.no/web/publications/document/Chapter?p_subdoc_id=20747884&p_document_id=20747880

L. AV – refit

The installation cost of all necessary scanners, camera's and AOS on-board is estimated for all vessels at EUR 150,000. The ship is installed with four magnetic docking stations with two on each side or a cost of the complete ADS of 1,800,000. Every twenty years, the AV hardware needs to be replaced, bringing the total estimated cost at EUR 2,900,000. The replacement of living area by cargo space is included in the price, adding a cargo volume increase of 10%.

Accommodation on board the CV is estimated at 100m², usually for the family, and is located at the back of the ship. The main engine room is estimated at 90m² and is located under the main living quarters. Height is considered on average to be 2m, which mostly lies below deck. The width of the living quarters and wheel house in this example is 8m or 80% of the vessel's width. The length of the living quarters on the CV is 12.5m. The engine room is also assumed to be 12.5m long but the width is only 7.2 m (ballast water tanks and fuel tank are roughly included). The area of the wheelhouse which is usually located next to the cofferdam and two ballast tanks, comprises a width of 8m and a length of 3m. Removal of the wheelhouse could lead to less wind resistance and fuel consumption because it is higher than the deck in order to maintain an overview. For the main engine room in this example, the volume is 180m³. For the living quarters, it is 200m³ and for the wheelhouse 48m³. The total volume of the estimated components is 428m³. The areas are assumed rectangular. The living quarters for the boatmen in front of the ship are estimated to have a volume of 100m³ and the engine room (bow rudder) beneath the living quarters has a volume of 90m³ (including ballast tanks).

In the AV, the living quarters are removed, the main engine room is 45m², the wheel house is removed and only an emergency panel remains in front of the vessel. This would offer the possibility of adding transported volumes. This would lead to a possible increase of transported volume or an additional estimated 10% of loading capacity.

In a refitted vessel, the costs of the accommodation are not recovered. A new wheelhouse and luxurious accommodation can easily cost EUR 250,000 (incl. bathrooms, bedrooms, office equipment, kitchen, etc.). These are costs that a newly-designed AV can avoid.

As the CBA focuses on a newly built vessel, the costs related to an AV-refit are not included.

M. Value of time

As described by Blauwens, De Baere and Van de Voorde (2016), the value of time is determined not so much by the distance to be covered as by the total number of hours to be worked. Important cost elements are salaries of crew on-board and of personnel working at a terminal or in the office of a freight charterer. These costs include fuel for an electrical generator and hidden costs (transaction and opportunity costs). Other cost elements are insurance, commissions, tolls, port dues and depreciation costs. To include these elements in the calculation of the reduction of related costs while also regarding the elements as costs, there is a risk for double counting. In this case, these related costs are reduced by additional trips that can be made by an AV because of more trip efficiency due to less waiting time at locks. Each hour that can be saved of waiting time for loading or unloading, and queuing at a lock, reduces the costs for the business case. This cost reduction is then expressed by a higher revenue. The reasoning goes as follows: The value of time benefit is generated by the possibility to improve service productivity.

Full exploitation can be achieved without the necessity to respect resting time for a crew. The time needed to bunker drinking water, fuel for heating and electricity, gas for cooking and others also disappears from the operational costs. Automated navigation could possibly lead to more optimal sailing speed and thus decrease the necessary trip time.

The ADS is assumed to detach in 10 seconds and needs maximum 30 seconds for mooring. A conventional ship needs a boatman and a helmsman to perform the operation which could easily take up to 10-20 minutes for every operation for an IWT vessel depending on the vessel size, current, weather conditions, being loaded or not, infrastructure quality or accessibility (bollards could

sometimes be high above the vessel and several rope throwing attempts could be needed). Assuming that during the 10 hours trip, the vessel needs to perform minimum three mooring operations (e.g. passing a lock). The conventional vessel will take maximum one hour more than the AV with automated mooring devices. Annually, a conventional ship spends three till 6.25 days in this analysis on mooring procedures while an AV will need five hours. This is a total value of time benefit of six days. Within those six days it is assumed that the AV performs three more additional trips (on average). If maximum loaded, this would be an additional annual revenue of EUR 118,096 in the first year of operation.

N. Communication and administration costs

Without a crew on-board, there are no communication costs. The communication with the SCC and other important actors during the trip is included in the SCC service costs when automated communication is not possible. It is estimated in this analysis that 70% of the administration cost of the vessel is related to managing human resources (HR). However in a SME, it is hardly the case that the time needed for HR administration is valued within the cost structure since it is usually done by the VO during his or her 'free time'.

O. Technical compliance

The annual compliance costs related to renewed technical requirements and service instructions are approximately 10% of the total fixed costs without crew costs and financial costs or an annual amount of EUR 9,000 for the CV (RebelGroup et al., 2015). According to Belgian law, each vessel must be docked for inspection every five years, while in the Netherlands this is seven years. Every 2.5 years, the vessels will undergo a midterm classification survey by government and by a verification agency or an inspection body. These kinds of returning compliance costs are divided over the vessel's lifespan in this example.

It is assumed that the technical compliance cost will decrease for the AV despite the upgrades needed for the on-board systems (which need inspection), private developments in software, needed changes in existing standards, creation of new standards, more specialized inspectors and verification and more uncertainty. The compliance costs of the CV are not only borne by the AV but also by the SCC.

Nevertheless, in the refitted AV, the wheelhouse is removed (less inspection space and documents), no crew must be inspected or certified and all the vital information is gathered from the *Machine2human* interface of the AOS which collects all the data automatically. The specialized AV inspector knows all needed intelligence from the data-gathering of the AOS. The data of the official monitoring SCC of the waterway manager and the private SCC in service contract can be used to automatically cross-check the data of both the SCCs and the AV, and to rapidly give more precise information than a captain of a CV is able to give. This is a possible efficiency benefit for the VO, for the waterway manager, the inspectors and for the river police, which lowers private and social costs. If government is able to automate and follow the trend of digitization that started in the eighties, the benefit could really materialize in IWT. As the innovation becomes more accepted and market uptake is the case, while relevant data becomes more shared, the cost of the inspections and compliance costs would probably decrease during the life span of the vessel.

In the last years of the lifespan of the AV, compliance costs could possibly go up because of more equipment that needs to be replaced by obsolescence or stricter regulation and the increase of general higher renovation costs, but this is not taken into account. The evolution of the compliance cost invites further research, therefore, and because of a lack of data and high uncertainty, the compliance costs are estimated to decrease by 25% compared with the CV.

P. Fuel Cost

Efficient programming of the AOS could lead to less fuel consumption. Ecological sailing such as slow steaming, can be programmed and the AOS could be able to make many more associations with more relevant information to calculate the ideal speed and slowest resistance paths in the waterway in order to optimize fuel usage. Regardless if this claim is true, fuel reduction could be gained by removing the

domestic areas and wheelhouses, and of course the fuel consumption to generate electricity in these areas. According to Backer and van Ommeren E. (2011)⁹⁰, following determinants can be identified that have a significant influence on fuel usage (ranked according to importance):

1. Gauge of the waterway (depth)
2. Size of the ship
3. Speed of the vessel through the water
4. Current of the waterway
5. Transported freight
6. Shape and smoothness of the hull
7. Engine performance, transmission and propeller
8. Domestic use⁹¹

The VO will adjust the speed weighing the costs of deciding to sail with higher speed against the expected time gains and net revenue per hour of upcoming trips whereby the optimal sailing speed depends on the actual situation of the vessel and the expectations in the inland navigation and gasoil market. An example can explain this further. A VO on a conventional ship will change behaviour if he or she might expect attractive return trips at destination, a current change or an upcoming low water depth period, which would make the additional costs of sailing faster or slower more attractive.

The fuel costs are calculated for each consumed quantity and each year during the lifespan of the vessel. To calculate these costs, a forecast is needed. Forecasting oil prices is very challenging. Next to estimated supply and demand, other drivers are identified such as geopolitics, exchange rates, behaviour of the financial markets (futures) and the macroeconomic situation of the global economy (GDP growth, population growth). During the lifespan of the vessel, several unpredictable innovation actions could change the entire oil-addicted global economy. The evolution of shale oil, deep water drilling, blending with biofuels, and other alternative fuels such as LNG, other technologies such as batteries, hydrogen, ...etc. will probably influence the price of oil.

The International Energy Agency (IEA) predicts for several scenarios the price evolution for crude oil⁹². One of the scenarios is based on changes in economic activity and population with a tripled global GDP between 2017 and 2060. Another scenario is based on sustainable policies that support alternative energy technology. According to the reference technology scenario (RTS), global demand will continuously increase unless demand trends are broken by shifts towards alternative fuels and more efficiency because of technological breakthroughs.

The RTS of the IEA predicts for 2060 a price of USD 148 for each barrel of crude oil (based on current prices of 2015). This is more elaborated in the case research for alternative fuels where fuel cost is the main driver behind the innovation, which is considered here in this case as less important. I applied a more simplified approach for fuel cost estimation than for the LNG-D case but included the bunker-adjusted factor.

Based on a relatively short timeline of gasoil prices for the inland navigation (CBRB, Contargo, 2018⁹³), it was possible to generate trends until 2060 for the purpose of the CBA. Without any dramatic changes, the price of crude oil is predicted to increase. Two forecast scenarios are estimated by using the fill handle in Excel based on collected data from 2002 until 2018 and are expressed in Figure 27. The data is calculated for every year based on monthly averages and shows the same resulting trend if the monthly averages were calculated as yearly averages. The first scenario includes a rather stable and medium increase where the second one shows a very high price increase scenario. The prices

⁹⁰ Backer van Ommeren, E. (2011), *Globale schets gasolieverbruik binnenvaartschepen*, 29p.
https://www.evofenedex.nl/sites/default/files/inline-images/BB/CA1660DEBB8A4AC1257A6700510761/Globale_schets_gasolieverbruik_binnenvaartschepen_06.pdf

⁹¹ considered to be around 10% of total fuel use by Backer et al. (2011)

⁹² <https://www.iea.org/etp/etpmodel/assumptions/>

⁹³ <https://www.contargo.net/nl/goodtoknow/baf/history/> from 2002 until 2018

include the bunker adjustment factor (BAF) which is based on the fuel price, the trip distance and the weight of the payload (originally intended for containers, but also valid for bulk).

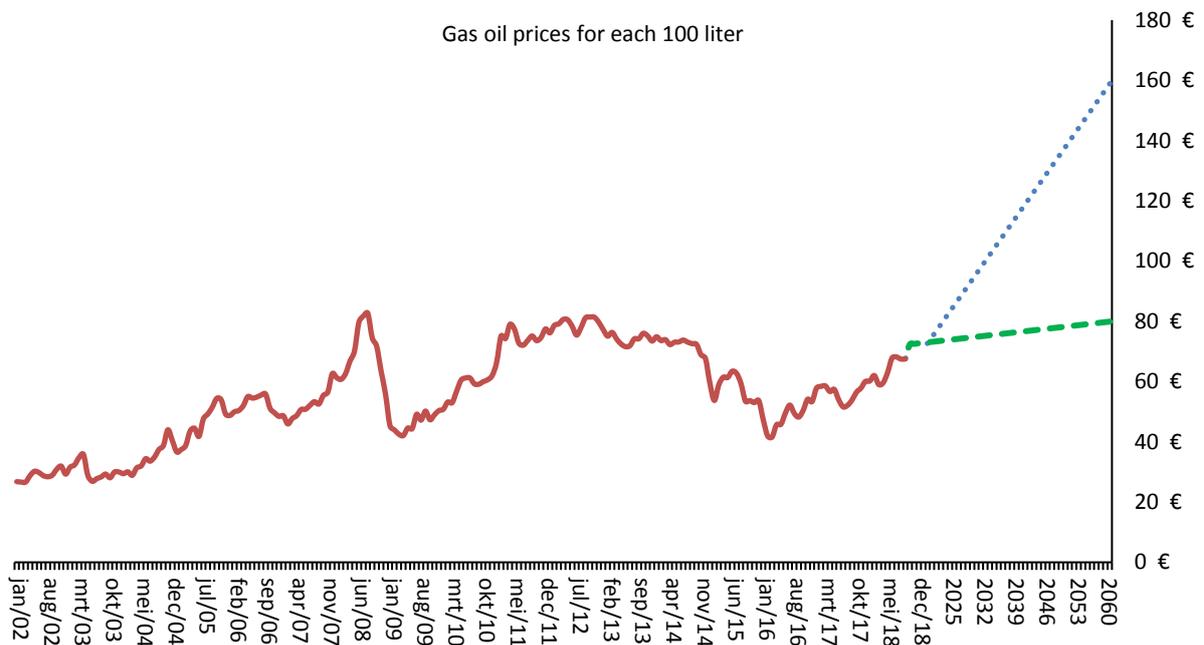


Figure 27: Estimated fuel price (gasoil)

Source: own calculations based on CBRB, Contargo (2018) and compared with RTS of IEA (2018). Blue dotted line is a scenario with most increase, while the green dotted line presents a more moderate price increase

To continue the analysis, a conventional and unmanned vessel are both described using gasoil fuel in a modelled scenario. The conventional vessel has an average fuel use of 150 litres / hour (including loaded and unloaded, up- and downstream with on average 60% of maximal power use).⁹⁴ To keep some degree of simplicity and comprehension, the extra engine that is used for electricity on board (power generator) is covered by 13% of the fuel use for the main engine but which is an uncertain estimation (Backer – van Ommeren, 2011: 13; Hulskotte, J. et al, 2003⁹⁵).

For the initial year, the average fuel cost is EUR 0.73 per litre of gasoil for the high price scenario, so on average, the fuel cost is estimated after one hour of operation at EUR 131. Furthermore, within the fully-continuous mode B, this analysis assumes the CV to have continuously three full trips between a fixed origin and destination (estimated 10hrs per trip, round trips with maximum loading) each week or an average of EUR 197,180 direct annual fuel cost in the initial year based on the assumption of 50 weeks of operation and 2 weeks of repair, maintenance and inspection. As assumed during the calculation of the private time benefit because of the optimal performance of the ADS and the lighter design without crew, an additional three trips are added in case of the AV with less fuel consumption.

Fuel is also used to supply the living quarters with electricity and heating for the entire crew. The AV could be lighter than the CV because of the removal of a large part of the accommodation, engine room and wheelhouse. The weight depends then on the type of cargo and its density in order to have a lighter vessel. Removing crew support systems for ventilation, laundry, lighting, kitchen, leisure time and others, could lead to an estimated reduction for the consumed energy together with additional ecological sailing programming and lighter design.

⁹⁴ Some studies suggest that the ideal propulsion for automated and autonomous vessels is electrical. To keep the CBA clear, only one innovation (automation) is taken into account for. No data was found for an fully electric IWT vessel.

⁹⁵ Hulskotte, J., Bolt, E., Broekhuizen, D. (2003), EMS-protocol Emissies door Binnenvaart: Verbrandingsmotoren, as mentioned in Backer van Ommeren, E. (2011)

The fuel reduction for an IWT AV is assumed to be lower and less significant than for the maritime example as described by (Kretschmann et al., 2015; MUNIN, 2015). All these factors combined, including the 13% of Backer – van Ommeren (2011), a rough estimation of 20% is used for potential fuel reduction on an AV compared with a conventional vessel.

This would mean that in the initial year, the reduction of fuel costs would be annually more than EUR 30,000 including three trips because of the efficiency benefits (e.g. ADS). The annual fuel cost for the initial year will be then EUR 134,082 for the AV.

Following the linear calculation with Excel, it is possible to calculate for the CV and for the AV a high price scenario and reference scenario where prices are kept stable. The assumption in the analysis relates to a high price scenario with an average annual price of EUR 73 for each 100-litre gasoil in 2018 with the bunker adjusted factor of Contargo and with an estimation of EUR 117/100 litre for the year 2040. The second scenario starts with an average annual price of EUR 72.7 for each 100 litre and estimates a value of EUR 77 for 2040.

Figure 28 shows the annual total fuel cost for both scenarios for the automated and conventional vessel. The annual sailing hours for the AV are estimated at 1,530 hours and the average fuel consumption per hour is 120 litres. For the reference case, 1,500 sailing hours are estimated with an average fuel consumption of 150 litre of gasoil per hour.

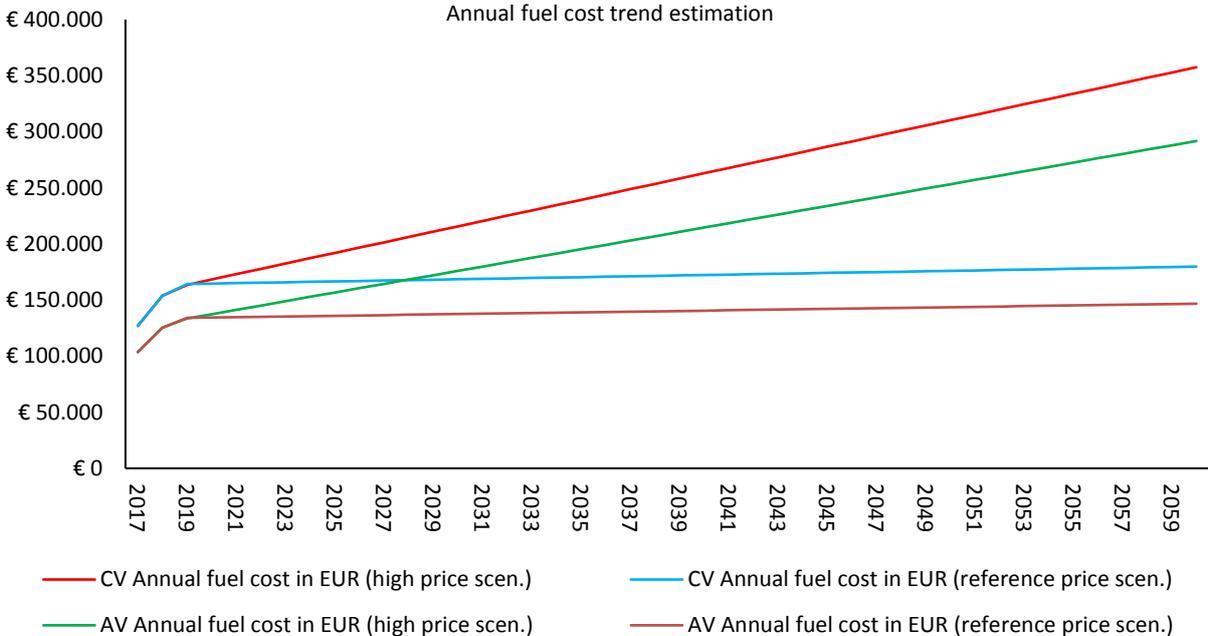


Figure 28: Annual fuel cost trend estimation for the AV and CV
Source: own calculations based on average annual prices of Contargo

Now that the costs and benefits are calculated, the structure of the cash flow analysis and the net present value are explained in the next part.

5.4.5. The net present value

The net present value (NPV) of investing in the AV will be determined according to different scenarios. The earnings and costs are identified and explained. The investment analysis of the AV user as described in the example, can be found in the annex. The cash flow statement is based on the revenue as assumed and the different identified cost components and explained in Chapter 4. The statement explains the method to calculate the cash flow of the AV given the described assumptions. The earnings depend on the usage of the AV and the profit margin depends on the market behaviour of other actors such as competitors within IWT and in other modes of transport. The bargaining power of the VO is

also important to maximize the profit margin. Following two simplified examples will explain the latter. A phenomenon which is typical for IWT is the unpredictable variable of water depth. In general, when water is low, more capacity is needed to meet demand, which will lead to higher profit margins for those who are still able to sail (problem for larger ships) and for more bargaining power on the side of charterers and/or VOs. Secondly, when a charterer urgently needs a specialized ship to transport a certain volume of cement, and only two cement ships with compatible size are one day away, competition will be between those two ships.

The AV could also be active under such conditions and will experience a volatile price setting depending on the market or will sail under a fixed long-term contract. To simplify the analysis, it is assumed that the earnings are at a fixed freight rate. The AV and the CV have a long-term contract with the same charterer in this example. As mentioned, an average freight rate of EUR 2.15 per tonnes for the first year is assumed in the reference scenario with a demand growth that allows constant prices.

The fuel cost is variable and forecast for the lifespan of the operation and takes 66% of the total operational costs in the first year. It is perfectly possible that the conventional fuel usage will be replaced by batteries, but this is an additional innovation which lies outside the scope of this case analysis.

The following part explains the reference case of the CBA and develops a model of a conventional vessel without the innovation. This is later compared with the developed AV model with the innovation.

5.4.6.Reference case: the Conventional Vessel

The reference case describes a conventional vessel (CV) of 110m with relevant costs and benefits. The CV gives a possibility to make a comparison with the business case of the AV and shows some important differences in costs and benefits. The CV provides insight in a situation where the innovation is not implemented. The cash flow analysis for the reference case and the project case are preceded by an overview of made assumptions.

A. Inputs for the CV

- High fuel cost increase of diesel.
- Loan payback period of 15 years with an interest rate of 4.5% and 70% of the capital value is loaned.
- Discounting factor of 10% for private equity (the minimum expected return on investment if invested elsewhere such as on the stock market)⁹⁶
- Discounting factor of 5.35% or WACC is the minimum where the return on investment is attractive for both financial institutions or other funding sources and private equity. Beneath this threshold, the opportunity cost is considered to be too high.
- Full loaded (payload) for every trip and 150 trips each year for a fixed rate at EUR 2,15 per ton
- Only four crew members with salary to correspond with the full continue exploitation mode
- The ship complies to all actual regulation
- Lifespan of the vessel is 40 years
- Residual value is set on EUR 80,000 which is similar with the AV and refers to assumed scrapping value of the vessel. The residual value of the innovation is considered to be zero.

⁹⁶ Following the findings of van Hassel (2011a). This rate implies the opportunity costs as calculated by NEA, 2003.

B. Cash flow analysis of the CV

The annual cash flow and the cumulative cash flow evolution of the CV from private equity and enterprise perspective includes an assumed scrapping value at the end of the life-span as shown in Figure 29. The adding of the residual value of EUR 80,000 (as explained in sub-section 5.4.4) in the last year of operation explains the sudden increase of the free cash flow from equity perspective. This value can be adjusted in other scenarios. The cumulative cash flow goes positive in both perspectives after seven years of operation in this model for the CV.

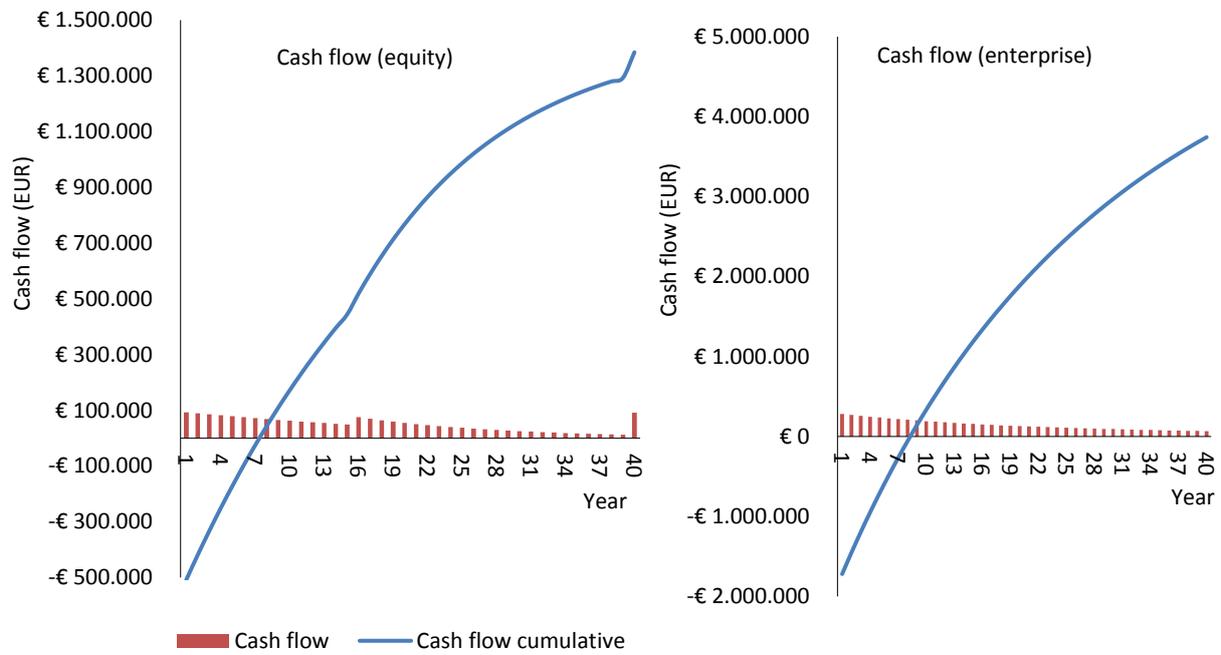


Figure 29: Evolution of cash flow of one CV (equity & enterprise) with 15-year loan
Source: method as applied in van Hassel (2011a)

5.4.7. Project case: the Automated vessel

The project case describes the investment of the automated vessel of 110m, according to the identified costs and assumptions.

A. Inputs for the AV

- High fuel increase, but efficiency gains;
- Loan payback period of 15 years with an interest rate of 4.5% and 70% of the capital value is loaned;
- Discounting factor of 10% for private equity (the minimum expected return on investment if invested elsewhere such as on the stock market)⁹⁷;
- Full loaded (payload) for every trip and 153 trips each year for a fixed rate at EUR 2,15 per ton;
- The SCC has an annual price and covers remote-control service, part of the administration, the non-engine related R&M, the software subscription and update of all automated devices and systems 'software';
- The vessel sails under the general assumption that all technology is on the market and guarantees reliability, safety and productivity.
- Regulation is put in place to allow unmanned vessels and no crew is hired for off-shore activities;
- Lifespan of the vessel is 40 years. The shorter lifespan of the automation technology is included in the capital value;
- Residual value AV = Residual value CV.

⁹⁷ Following the findings of van Hassel (2011a). This rate implies the opportunity costs as calculated by NEA, 2003.

B. Cash flow analysis of the AV

The annual cash flow and the cumulative cash flow evolution of the AV from private equity and enterprise perspective are shown in Figure 30, which includes an assumed scrapping value at the end of the life-span which is assumed to be EUR 80,000 for both vessels. Fuel cost is still expected to increase relatively strong during the lifespan of the vessel.

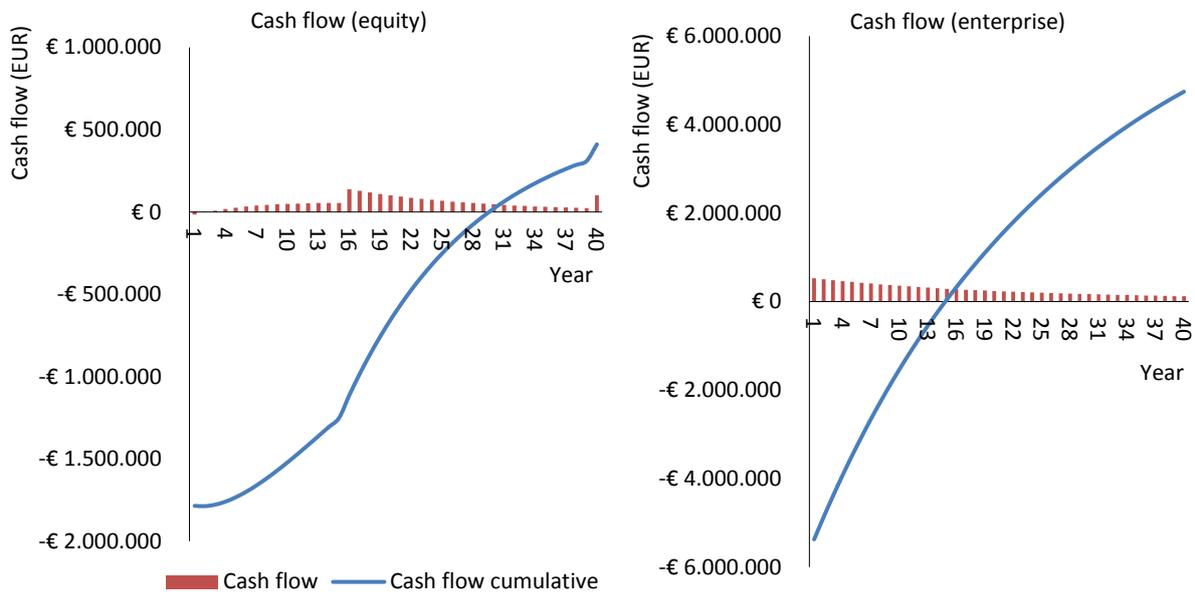


Figure 30: Evolution of cash flow of one AV (equity & enterprise) with 15-year loan
Source: method as applied in van Hassel (2011a)

From an equity perspective, there is a sudden increase in cash flow in the last year. The residual value in the last year of operation explains the sudden increase of the free cash flow from equity perspective. The sudden increase of the cash flow from equity perspective in the 16th year, is explained by the end of the payback period of the loan.

The cumulative cash flow becomes positive after 29 years from an equity perspective and after 14 years from an equity and debt perspective. The latter has a relatively high NPV of EUR 4,744,269 compared with the NPV of the null scenario of EUR 3,741,767.

To understand the following sub-section, it is important to remember that the reference case is often referred to as scenario 0 and the project case as scenario 1. In some scenario's the reference case is modified to compare with the similar modified project case.

5.4.8.Scenario-driven analysis of the AV

This analysis shows how the uncertainty of the developed model can be reduced by changing the inputs in different scenarios within the approach of the reference and project case.

Scenario 2 shows the situation for the AV project case (which is here called scenario 1), when the loan payback time is 25 years instead of 15 years. The results are higher NPVs than in the first two scenarios (except for the equity based NPV of scenario 0).

Scenario 3 shows the relative influence of a lower expected increase of the fuel cost during the life span of the investment with higher NPVs than scenario 1 and 2. In case of the NPV from enterprise perspective, the AV scenarios 1, 2, 4 and 5 score higher than the null scenario with the CV. However the IRR stays higher in most scenarios without the innovation, which indicates a difference in opportunity costs for potential investors between the AV and the CV (null scenario).

Scenario 4 shows the situation where the earnings are much lower than expected with annually 103 fully loaded trips instead of 153. In this scenario, the AV has annually more than 30% less operations than in the other scenarios. Because of the lower earnings, the charterers provision decreases as does the fuel cost, P&F and engine fuel-based M&R., which leads to a negative NPV from equity perspective of EUR – 2,143,143. From enterprise perspective the NPV is EUR 139,807 with an IRR of 5.5%.

Scenario 5 shows what happens if scenario 1 was applied on the investment of five AVs. In this scenario, it is assumed that the SCC can provide the same service for five ships as for one, with only a 50% increase of SCC cost (increased M&R and software subscriptions). The latter scenario shows the highest NPVs and the second highest IRR values in the described scenarios which proves the presence of economies of scale.

To compare scenario 5, the cash flow of five CVs is also analysed with scenario 6. Scenario 6 shows lower NPV values than scenario 5, but a higher IRR.

Scenario 7 changes the inputted value of the SCC. The service rate drops with 50%. The IRR (equity) is 13% and the IRR (enterprise) is 11% with an NPV of EUR 1,239,261 (equity).

Scenario 8 combines scenario 7 with scenario 5 but without the additional 50% increase of the SCC cost. The price of the annual service cost of the SCC for five similar AVs is then EUR 95,480 in the first year of operation. The IRRs become 14% (equity) and 12% (enterprise).

Scenario 9 shows the influence of the charterers' provision in the model. It is assumed that the role of the charterer is reduced because of automation and that the provision in case of the AV is set at 1% of the revenue. What if this would not be the case and a charters 'provision is demanded of higher percentages? The impact of the demanded rate of charterers is shown by the changing NPVs in Table 36 according to different rates and based on scenario 1.

Only in some scenarios the NPV_e (equity) becomes negative with a 7% rate which is used in the scenario with the CV (scenario 0 and 6). The influence of the provision is therefore considered relatively low in most cases (Table 36). Scenario 9 shows the results if a provision of 7% is added to scenario 1.

Scenario		2% provision	3% provision	4% provision	7% provision
1	NPV _e	316,690	222,465	128,240	-154,436
	NPV _{enter}	4,574,111	4,403,953	4,233,794	3,723,318
2	NPV _e	471,633	377,408	283,183	507
	NPV _{enter}	4,719,183	4,549,025	4,378,866	3,868,391
3	NPV _e	548,147	453,922	359,697	77,021
	NPV _{enter}	5,131,177	4,961,018	4,790,860	4,280,384
4	NPV _e	-2,207,956	-2,273,083	-€ 2,339,603	2,542,773
	NPV _{enter}	23,815	-92,506	-210,344	-567,954
5	NPV _e	3,312,808	957,177	-1,398,453	-8,465,346
	NPV _{enter}	26,568,808	22,314,844	18,060,880	5,298,988

Table 36: Impact of charterers' provision on NPV of AV in EUR

In the scenarios where a high fuel cost and high earnings are assumed, demand for IWT is considered to be inelastic in order to keep the freight rate on the assumed level. In reality, the freight rate could be much more volatile and the demand more elastic. Scenario 4 shows therefore the impact of the earnings after a relative high decrease of the number of trips. Scenario 5 examines what would happen if the fuel efficiency of an AV would be higher.

So far, the main cost driver in all scenarios is the fuel cost. An automated vessel could be more attractive if it could reduce the fuel consumption more significantly than a CV. Scenario 10 reduces the input of fuel consumption of scenario 1 with 20%, so with 40% more than a conventional vessel in scenario 0 which is more aligned with the findings of the MUNIN report for a maritime AV (Kretschmann et al., 2015).

Scenario 11 tests the main benefit of the AV which is the reduction of crew cost. In the basic reference model of the CV the assumption was made that the crew cost was 4 crew members with an average gross salary (including the employer tax) of EUR 68,200. What would be the impact of this input if there were six people working fulltime on the vessel. The minimum crew requirements for full continue operations on the Rhine are for this CV four persons, but it could be the case that more employees are hired. Some could be sick, need replacement or work in shifts.

Table 37 provides an overview of less and more crew members of the NPV and IRR. It is assumed that the additional crew members do not have an impact on fuel usage, what could be slightly the case. As mentioned by Backer – van Ommere (2011) an estimated 13% of the total fuel consumption, powers the gen-set for cooking, heating, lights, living appliances, etc. More crew members could increase these costs, but this is not taken into account any further.

Number of crew members on the vessel (FTE)	3	4	5	6	7
NPV _e	EUR 1,976,228	EUR 1,384,553	EUR 792,877	EUR 201,202	- EUR 390,473
NPV _{enter}	EUR 4,810,261	EUR 3,741,772	EUR 2,673,284	EUR 1,604,795	EUR 536,306
IRR _e	28,22%	21,69%	15,99%	11,35%	7,66%
IRR _{enter}	17,79%	15,27%	12,69%	9,99%	7,03%

Table 37: Difference of crew members of the reference case compared with the AV

The differences between the project case scenarios with comparable CV scenarios are shown by Table 38. The table gives a summary of the results of all described scenarios so far.

Scenario	0	1	2	3	4	5
Vessel	CV (4 FTEs)	AV	AV	AV	AV	5 AVs
Payback time (years)	15	15	25	15	15	15
Fuel cost increase	high	high	high	small increase	high	high
Earnings	high	high	high	High	Low (103 trips)	high
Charterer provision	7%	1%				
SCC cost in EUR (year 1)	0	190,960				286,440
Crew cost in EUR (year 1)	272,800	0				
NPV in EUR (equity)	1,384,550	410,915	565,859	642,768	-2,143,143	5,968,490
NPV in EUR (enterprise)	3,741,767	4,744,270	4,889,342	5,301,749	139,807	30,789,368
IRR (equity)	22%	11%	12%	11%	5%	13%
IRR (enterprise)	15%	10%	10%	10%	5%	11%
B/C ratio	1.47	1.92	1.85	2.09	1.45	2.28

Continues on the next page

Scenario	6	7	8	9	10	11 ⁹⁸
Vessel	5 CVs	AV	5 AVs	AV	AV	CV (6 FTEs)
Payback time (years)	15	15	15	15	15	15
Fuel cost increase	high	high	high	high	high but lower consumption	high
Earnings	high	high	high	high	high	high
Charterer provision	7%		1%	7%	1%	7%
SCC cost in EUR (year 1)	0		95,480	190,960	190,960	0
Crew cost in EUR (year 1)	1,364,000		0	0	0	409,200
NPV in EUR (equity)	6,922,750	1,239,261	7,625,181	-154,436	718,094	201,202
NPV in EUR (enterprise)	18,708,837	6,240,154	33,781,136	3,723,318	5,304,682	1,604,795
IRR (equity)	22%	13%	14%	10%	12%	11%
IRR (enterprise)	15%	11%	12%	9%	10%	10%
B/C ratio	1.45	2.31	2.48	1.72	2.05	1.22

Table 38: Scenario driven analysis of the CV and AV

To compare all scenarios of this analysis with a more comparable reference scenario of the CV, the difference in NPV shows the added value of the innovation. These differences are here expressed by ΔNPV_{CV-AV} for both equity and enterprise perspective, according the following formula:

$$\Delta NPV_{CV-AV} = NPV_{AV} - NPV_{CV}$$

This formula is applied on every scenario where the same input is changed for both the AV as for the CV. Scenario 0 for the CV is comparable for AV – scenario 1, 7 and 9. Scenario 6 where five CVs are taken into account, is compared with scenario 5 and 8. To compare scenario 2, the null scenario is also changed, according to the payback time of 25 years. Scenario 4 with lower number of trips is compared with a comparable CV case (100 trips). The formula results in the values that are given in Table 39.

Scenarios	ΔNPV_{equity} in EUR	$\Delta NPV_{enterprise}$ in EUR
1	-973,635	1,002,502
2	-871,214	1,098,397
3	-1,025,826	876,889
4	-1,497,340	55,300
5	-954,260	12,080,530
7	-145,289	2,498,387
8	702,431	15,072,299
9	-1,538,986	-18,449
10	-666,459	1,562,909

Table 39: AV scenarios compared with the aligned reference case
Scenario 6 and 11 are not mentioned in the table, because these scenarios are used as reference scenario

Table 39 shows that scenario 11 scores better than the original reference case. Increasing the crew from 4 to 6 FTE, gives more NPV for both perspectives. In this scenario, both the CV and the AV do not meet the requirements from an equity perspective concerning the NPV. Scenario 8 where the SCC provides a relatively cheaper annual service rate and where economies of scale are made for five AVs, the NPV becomes significantly higher in both perspectives and the IRRs meet the assumed conditions (>10% equity discounting factor an >5,35% enterprise). However for EUR 29.5 million for 5 AVs as initial total investment, the VO could have 14 CVs.

⁹⁸ Scenario 11 is an adjustment on the reference case by adding 6 crew members instead of 4.

5.4.9. Conclusion industrial-economic analysis of the AV

The CBA of the AV model or project case measures the feasibility of the innovation for a private investor before it takes in account the external costs. It showed if the innovation is attractive for investors or not. The internal rate of return measured the profitability of the investments and gives an understanding of the growth the investment is going to generate or is expected to generate. The analysis also showed the NPV which is the current worth of the stream of cash flows at the end of the investment life span at a given discount rate. Both the IRR and the NPV were calculated from an equity and enterprise perspective.

For the AV the innovation is most beneficial in scenario 8 when the investment concerns 5 AVs at a low SCC cost, a chartering provision of 1%, high earnings and a high expected fuel cost increase. The B/C ratio is 2.5 and both the IRRs are above the cost of equity and the WACC while both NPVs are positive. Compared with the reference scenario, the investment is in this scenario an improvement.

When the crew is kept at four FTEs, the conventional vessel reaches a higher return on investment within the constructed model. The CV performs better in comparable scenarios when the critical level of crew cost is not reached which is 6 FTEs. If less than 6 crew members are hired, the CV still performs better. When the number of the FTEs is equal or more than 6, the performance of the AV becomes more attractive and supports a better business case.

However the number of uncertainties concerning automation during its initiation phase, but also the relatively low benefit in replacing the crew of a conventional vessel by an SCC service, give less incentives (yet) and higher risks to invest in an AV than in a CV.

The uncertainties are not only related to the fact that several technological concepts are still in the initiation phase and need maturation before they can be implemented, but also with the difficulty to calculate the service price of an SCC before there is a market of SCC providers. Even when regulation is not a problem and technology (as assumed) is in place, the return on investment is probably still lower than in the case of the CV as described in the reference case. Nevertheless, it could still be a solid investment choice, both from an equity as from an enterprise perspective, to choose for an AV or parts of the AV in order to (gradually) decrease the cost and/or enlighten the tasks on-board.

Another argument that could persuade private and public actors, is the potential modal share loss. When automation would become successful in the inland navigation and/or in other transport modes, the CV could lose market share with resulting in a decrease in revenues.

First mover advantages could also be a strong argument to start with automation. A front seat in the policy cycle to offer an example for standards for the innovation or to be a reference case for all future AVs, could lead to a sustainable or growing market share and perhaps revenue.

The AV was assumed to have a diesel engine with stage II (CCNR classification). Several efficiency gains could be implemented in the model concerning the engine and propulsion. The VO could decide to add better fuel technology especially in regard of the upcoming new emission standards, which could decrease the fuel cost and therefore improve the business case with a relatively higher NPV such as in scenario 3. The cash flow analysis from the perspective of the VO results then in a more potential viable business case according to the assumptions within the model of the AV as elaborated in this research for IWT.

From an industrial-economics perspective, the potential private profit \times is positive, but only if there is a real incentive to replace the crew cost at a critical crew size or if economies of scale are taken into account. Figure 31 shows the identified innovation path so far.

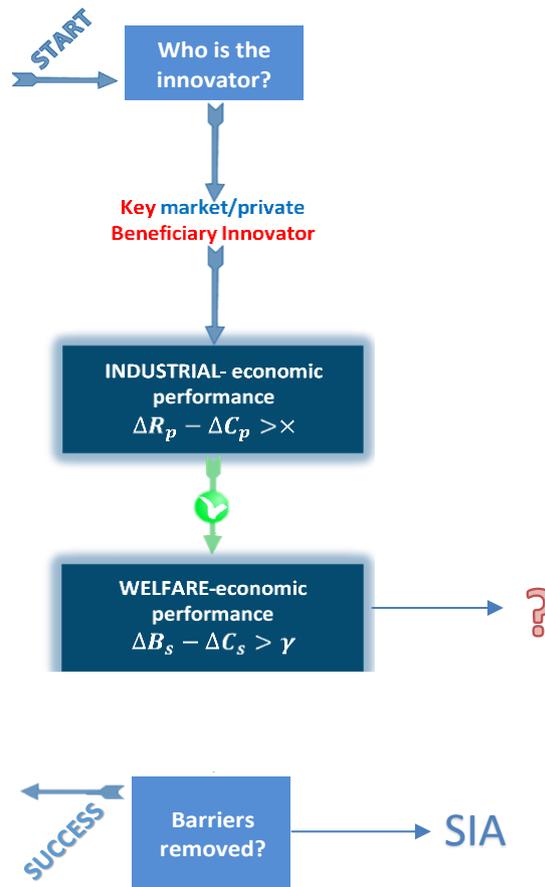


Figure 31: Innovation path of the AV from industrial economics perspective
Source: based on Aronietis (2013)

The question mark refers to the social benefits which are explained in the next part of the analysis and which answers partially the second research question concerning policy.

5.4.10. External costs of the AV

The external costs as discussed earlier, are now calculated for the innovation. Some costs such as the accidents and infrastructure costs will need to be adjusted for an automated vessel scenario because of the assumption that locks will need automated mooring devices to improve automated mooring.

A. Infrastructure costs

The investments in infrastructure are assumed to increase as unmanned vessels could need new automated berthing devices such as automated docking stations (ADS) and quay fenders. Assuming that the waterway infrastructure is not underinvested, the additional investments will include ADS in locks and waiting points (bridges), terminal equipment and a more advanced digital infrastructure that makes it possible for waterway managers to monitor and to communicate with the unmanned vessel whenever necessary and in a (cyber) safe way. For this part of the analysis, it is assumed that the investments in public assets such as locks will be funded by public actors such as the waterway manager.

In order to manage at least one AV at a time, on both sides of the lock, on average minimum four rail automated docking units are installed with two on each side⁹⁹. To equip all mentioned locks in Europe, more than a thousand units are needed or an estimated investment of EUR 814 million which is

⁹⁹ Only for vessels with sufficient hull space above waterline. For loaded IWT-vessels it can be the case that not enough hull area is available above water to dock. Adjusted design for ship or for docking station is assumed to be feasible but needs more research.

comparable with the total infrastructure budget for IWT in the Netherlands. If all berthing places would become equipped with an ADS, the investment on-board for the AV – ADS will not be needed. However in this case research, both are kept as possibilities. Because of the relatively high cost of the ADS on-board of the vessel, another choice could be to hire humans at locks to moor and unmoor. As more and more locks become unmanned, remote controlled or even automated, manning locks again is less likely. It is up to policy makers of private enterprises to decide what is the most attractive option. In this case analysis, it is decided to have a complete unmanned vessel without human intervention on-board and which can perform mooring and unmooring operations.

The infrastructure cost for the SCC can also belong to the waterway manager in order to control state-owned automated vessels or even inspect private automated vessels. In this analysis, the SCC is kept private. A state-owned SCC is therefore not required. The control centres in locks can perhaps relatively easily be upgraded to control the AVs, the ADS and even to communicate with the private SCCs.

The one-time investment in automated locks is estimated at EUR 814,448,048 and is based on a number of 272 identified locks in the EU-28 with each on average an installation of four ADSs or in total 1088 units. To calculate the external cost for the AV concerning infrastructure, not only the estimation of the extra investment is needed, but also the assumed increase of the performance with 153 trips annually instead of 150 for the CV in the base scenario which is a 2% increase. If the EU and its MS would pay for the additional infrastructure during the first year of operation, the total investment would increase with 25% (based on 2016 of OECD, 2018). This leads to the assumption that the given external cost per tkm for infrastructure will also increase with 25%.

Another scenario if policy would decide to invest, is that the investment would be done more gradually and not all at once which is also the case in Canada and the U.S. The infrastructure cost is then more spread over time and not only in the first year.

B. Climate change, emissions, up- and downstream

Ricardo-AEA (2014)¹⁰⁰ gives an overview and update of marginal air pollution costs for IWT derived from CE Delft (2011) and makes a distinction between different sizes of vessels and fuel usage. Values differ from EUR 0.4 per 1000 tkm for a pushed convoy between 9,600 and 18,000 tonnes of transported freight with a DFP+SCR fuel technology and a maximum of EUR 5.8 per 1000 tkm for a 650-1000 tonnes vessel with Low Sulphur Oil fuel technology. The marginal climate change cost varies between a minimum of EUR 1.2 per 1000 tkm and a maximum of EUR 3.1 per 1000 tkm.

For the calculation in this study, an average is calculated as presented in Table 40, which shows the average marginal external costs for IWT concerning climate change costs (CCC) and air pollutants from both the transport operations and the up- and downstream (U&D) emissions for IWT. The values are expressed in tkm and vkm (for U&D). This means that for every additional bulk vessel of 250 tonnes with an average load factor of 158 tons, EUR 3.1 is paid by society for each 1,000 ton-kilometre of the vessel as greenhouse emission cost. For the same vessel, the up-and downstream emissions or indirect external costs concerning CCC for each vkm, are estimated by an additional EUR 0.01.

	Average load factor, tons		Average cost
	bulk, tanker	heavy bulk	
Air pollutants € per 1000 tkm			2.3
CCC € per 1000 tkm	2,543	2,957	2.3
U&D €ct / vkm			0.8

Table 40: Average emissions and greenhouse gases of IWT
 Source: own calculation of averages based on Ricardo-AEA (2014)

¹⁰⁰ Calculating external costs for emissions are challenging as they represent costs based on measurements of emissions of different modes of transport. These emission are not static and improve over the years.

The U&D costs include the marginal external costs that are related to extraction, transport and transmission to fuel one vessel; the external costs from the building of one vessel, maintenance and disposal and the infrastructure that is needed to build, repair, bunker or maintain the vessel. To simplify the calculation, averages are used for all vessels.

With automation, a fuel reduction was estimated at 20% for an AV in comparison with a CV, which leads to an estimated 20% decrease of emissions, U&D, CCC and air pollutants. This can differ from case to case. For air pollutants CCC and U&D, averages are calculated for this analysis for the average load factor for every vessel type, which are then multiplied by a simplified forecast of the performance of IWT (expressed in tkm) and compared with a scenario without automation. U&D emissions are not taken into account because they relate to vkm and cannot be linked with performance.

The differences in emissions and fuel costs, is considered to be a benefit of an AV compared with a CV because of more efficient ecological sailing (if programmed) and the removal of domestic areas. This calculation leads to a roughly estimated reduction of EUR 175 million for emissions in the first year of investment for the EU-28 in a completely automated mode of IWT. In this calculation, no modal shift is expected. If a modal shift occurs, when IWT can be organized cheaper by cost reduction or subsidies or if road haulage would have an external cost internalization policy, the emission benefit could be higher, but this lies outside of the scope of this research.

A final assumption is that the emissions stay the same during the lifespan of the vessel, which with all developments as described in the case concerning alternative fuels in this research is hopefully most unlikely. Only an inflation factor of 1,8% is then taken into account.

Another important remark is that an automated vessel as described in the design of the Yara Birkeland, could be equipped with batteries instead of a combustion engine. The latter could make the ship design lighter (no fuel, no heavy engine and further machine room reduction) and recharging could be easier for an unmanned vessel than bunkering conventional fuel because of practical reasons of attachment (usually through manually attached tubes between bunkering station and vessel). This certainly would be easier if the infrastructure in locks and at terminals is equipped with automated on-shore docking stations that provide electrical power through hull induction such as the Norwegian example that is described in the SIA part of this case research (Jektevik-Hodnanes). If electrical power is used instead of diesel, this would lead to zero direct emissions. (U&D would remain and depends on the energy mix of the transformation sector).

C. Accidents

The main cause of accidents in IWT is related to human errors. An automated vessel is therefore claimed to increase safety. Although new types of accidents can occur whereby the human error is shifted to the programming side of the AV or to insufficient maintenance, obsolescence theory of electronic devices or wrong usage. When the AV is unmanned, the risk of human casualties is naturally reduced.

The insurance costs of accidents are not considered to be part of the external cost and should be subtracted. Following the UNITE case study, it is assumed that the premium amounts to 50% of the human injury of death costs for victims. Damages to ship and cargo are considered to be internal costs (ECORYS, 2005:116) but in case of large accidents with environmental damage, this is assumed not to be the case in this research and a 50% coverage by insurance premiums is also here taken into account. The value of life is also derived from Ricardo-AEA (2014) and refers to the EU-average, which was originally calculated for road accident fatalities but is assumed to be the same for IWT.

Severe and slight injured victims from IWT accidents as mentioned in Ricardo-AEA, are counted in one group and the average value is calculated between both, to make them correspond to the used accident data. For a fatality, the EU-average value is EUR 1,870,000; a severely injured has a value of EUR 243,100 and a slightly injured has a value of EUR 18,700 according to constant prices of 2010. The

used average of slight and severely injured becomes then EUR 130,900. The insurance premiums are assumed to cover 50%, which leads to EUR 935,000 for a fatality and EUR 65,450 for injured crew.

The disaster of the TMS Waldhof¹⁰¹ in 2011 caused an estimated damage between EUR 50 and 55 million (including two fatalities and two injured). To keep the value of life outside the total costs, the costs of the damage are set at EUR 50 million spread for 50% over twenty years (insurance) as an average external accident cost. Referring to the disaster of the TMS Waldhof does not mean that this disaster could have been avoided if it were an AV. Different causes were identified that led to the accident, but the main cause was the fact that the vessel was overloaded. Although an AV would have had completely automated processes that scan cargo and measure all needed information (weight, nature of cargo...), it does not mean that the same reasons to overload a conventional vessel, could not overrule automated safety procedures and programming by maleficent or accidental human manipulation. Nevertheless, the chances that the AV would have seen the passing vessel on time and would have scanned the current and the water depth, are higher than with humans and could have increased the chance to prevent capsizing. It is possible that the AV would have responded in another fashion and more rapidly, assuming that the programming would have foreseen a unique scenario as the circumstances of the accident. Furthermore, here lies an assumption that the overloading of the vessel would not have happened with completely automated and reliable systems that were not manipulated for increasing productivity. In case of an unmanned AV, the two fatalities and two injured crew members on-board of the TMS Waldhof would have been avoided.

Reducing the number of crew members on a vessel, while guaranteeing minimally the mandatory safety requirements, would eventually lead to a lower risk for lethal accidents and thus a safety benefit. The case of automation reflects a potential of more safety by removing the possibility of human error in navigation of the vessel. As said, the human error could be transferred to the input of programming the software or building the reliable components of the AOS, and to the SCC where intervention can come too late. This innovation will not avoid accidents but could create a new kind of accidents. There is also no guarantee that an AOS could be safeguarded for illegal and dangerous procedures such as overloading (cargo) or even hacking. However the main benefit is, that a collision between unmanned vessels will not have any human casualties. According to most reports in both inland navigation and maritime, human error is a dominant cause of accidents. Automation has the potential to increase safety, but as Hetherington et al. points out, automation also needs sufficient attention of the crew (2006) or in case of unmanned navigation of the SCC.

To summarize the safety benefit as developed in this research, in a fully automated scenario, with the assumption that an accident such as the TMS Waldhof could have been avoided, the reduced annual cost for major accidents in the first year is estimated at EUR 1,250,000 without the loss of life or injuries. To estimate the total value of potential loss of life, knowing that 30% of the EU-28 fleet is occupied by Dutch registered personnel on-board, the number of the Dutch victims are tripled for the entire EU-waterway and put in a scenario of fully automated IWT without humans on board. For the first year of a completely automated IWT, the benefit of accident cost and value of life saving, is annually estimated at an average of EUR 24.6 million for the EU-28.

Using the EU-28 average values for fatalities and injuries, would mean that between 2004 and 2017, the Netherlands has lost EUR 111,4 million on fatalities and injuries (estimated for 2017 and including the insurance subtraction) or on average EUR 7,8 million annually. Caution is needed in order to interpret the data for the Dutch waterways. Not all accidents are professional freight transport (e.g. in 2013 more accidents happened with recreational vessels than with freight IWT). Furthermore, to avoid all human casualties on the waterways, the recreational vessels should also be unmanned which is of course quite absurd. The input values can be improved by further research and with the implementation of a real accident casuistry system as in other transport modes.

¹⁰¹ https://www.elwis.de/DE/Service/TMS-Waldhof/Unfalluntersuchungsbericht-hohe-Aufloesung.pdf?__blob=publicationFile&v=3

For maintenance, the average expenditure is estimated to be lower when automation infrastructure is added. The latter assumption is based on less collisions between automated vessels and the infrastructure. Reliable scanners for measuring the air gauge under bridges, 3D Lidar scanner for locks and the removal of human fatigue could lead to less renewal and repair costs which benefits the waterway manager and the society.

In Germany, the number of collisions between infrastructure and vessels between 1994 and 2011 was estimated at 28% of all accidents (German Ministry). Data of all waterway managers was not available. Data with distinction between recreational users and freight transport was also not found. Nevertheless, the number of this type of accidents with damage to infrastructure, increases the maintenance cost. This cost is assumed to be higher than the replacement of repair of automated infrastructure such as ADS in locks. In the latter case, the challenge will be to guarantee the quality of the ADS during the assumed lifespan within harsh environments with all aggressive natural elements causing corrosion, dirt and so on. The assumption is that maintenance costs will go down by 10% despite the danger of extrapolating the German dimension to the EU-28 considering collision statistics.

Maintenance costs related to accidents, will not be included in the further analysis. The risk for double counting is too high because repair, replacement and other tasks are possibly internalized by the insurance premium of the AV and/or CV. The external infrastructure cost should tackle the non-insured damage. For the CV the calculated accident cost is used, and although the mentioned concerns of the remaining possibility for accidents, the accident costs for the AV are zero.

Another external cost that automation could have an impact on is congestion and which is discussed in the following part.

D. Congestion

In the case of the AV, no resting time is taken in consideration, and because of real-time communication between vessels, shore terminals, locks and bridges, the vessel's automated navigation can be programmed to react much faster with much more data than a human helmsman could. An automated IWT could therefore become more attractive for mode deciders in the supply chain.

Automated sailing implies automated communication with all actors in order to optimize terminal handling or decrease waiting times (Negenborn R., Hekkenberg R., 2017). The level of estimated earnings assumes that there is hardly any waiting time so that a weekly average of three trips can be maintained. The element of automated communication could lead to less accidents knowing that those are mainly caused by human errors. The continuing automation of all logistics processes could lead to a more resilient system of transport in case of ad hoc changes. All vessels are immediately notified in case of accidents or other events. The vessel and logistics processes will then be able to behave and adjust accordingly. Accidents usually cost time and not only for those who are part of the accident, but also for all the vessels that are obliged to wait until the wreckage is salvaged.

Now that the external costs are discussed, the following part examines the potential impact of automation on the IWT labour market.

5.4.11. The potential impact on IWT labour

The potential impact of automation on the labour market of IWT is examined here to establish if there are potential losers of the innovation and if compensation should be given or not.

According to Negenborn (2017) especially the smaller ships can relatively benefit from automation, because personnel costs weigh heavier in the cost structure than on larger ships or companies. In absolute terms, the possible cost reduction is higher on a larger ship with crews of more than three boatmen. On a post-Panamax vessel, the personnel cost is rather marginal compared with the other

costs. A small “*Kempenaar*” has relatively high personnel costs which could weaken the competitive position with road haulage, especially for relatively short distances.¹⁰²

A number of 44,518 people belong to a crew in the European IWT (European Commission, 2018a)¹⁰³. Most of them are registered in the Netherlands (13,318) and Germany (10,115). These numbers represent the workforce that is active on board of all registered vessels in the European IWT. On average, linking with the IVR-database, this means that between 2 and 3 people work on board of a vessel.

In order to have an idea of the ageing of the people working in IWT, Eurostat provides data at NACE level for the entire water transport sector (Rev.1.1 two-digit level). The data includes people working on-shore (e.g. charterers), and in maritime and coastal transportation. Of the 321,000 people that are accounted for in the EU-28 for water transport, 102,000 are older than 50 (Eurostat, 2016). This division is also noticeable for crews in IWT according to Panteia (2015)¹⁰⁴. Almost 32% is estimated to be older than 50 years in the sector. This is especially the case for the self-employed/boat masters or VO's. According to the market observation of 2013 (CCNR, 2013), more than 55% of boat management in the Dutch water sector was older than fifty years.¹⁰⁵

The shortage of labour supply is regionally divided in Europe and was decreased by the financial crisis, by technological innovations and enhanced mobility of crew members from Eastern European countries and third countries. With the ageing of the average crew, the replacement of retired people will be challenging. Furthermore, a possible benefit lies in the fact that with the ageing of the captain, innovative support systems such as an AOS can help in making the job easier.

The idea of the SCC can be attractive for young people and can convince them to choose for a career as an on-shore or remote operator. The SCC could resemble a high-tech gaming setting, but in this part of the analysis this is not further deepened.

The labour market situation of introducing automated navigation is shown in Figure 32. The vertical axis expresses the price of labour (wage) and the horizontal one the quantity of labour. In this research, it is assumed that the demand and supply curve are both convex.

There is a shortage of labour supply shown by S_0 before automated navigation and a further expected shrinking of the conventional labour supply (ageing of crew, less interested young people). As inland navigation is recovering from the effects of the global financial crisis and returns to the relatively stringent or restrained labour market for inland navigation on the Rhine with a shortage of labour supply, the supply curve will shift to the left (to S_1).

As automated navigation is introduced, the demand for labour shifts towards to D_1 . More automation, means that less labour is needed and that demand for labour decreases. The part of the crew that becomes affected by automation depends on which automation stage is reached (e.g. Stage 5) and with which systems (e.g. ADS affects boatmen; AWS affects the boatmaster).

¹⁰² The latter explains partially why small waterways are losing market share. Another explanation is bad maintenance and obsolete infrastructure such as monumental locks and the lack of interest of investors and VO's to choose a small vessel instead of a large one.

¹⁰³ European Commission (2018a), Statistical Pocketbook 2018, Mobility and Transport, Brussels, 164p. Economic activity according to NACE Rev. 2 classification. <https://ec.europa.eu/transport/sites/transport/files/pb2018-section21.xls>

¹⁰⁴ Panteia, PwC Italy (2015), Annex 13 Internal waterways, Background information for the study 'Analysis of the trends and prospects of jobs and working conditions in transport', JRC, <https://www.panteia.com/uploads/2016/12/Annex-13-IWT-to-EU-transport-labour-market-updates-2015-1.pdf>

¹⁰⁵ <https://www.inland-navigation.org/observatory/crews-skills/labour-market/>

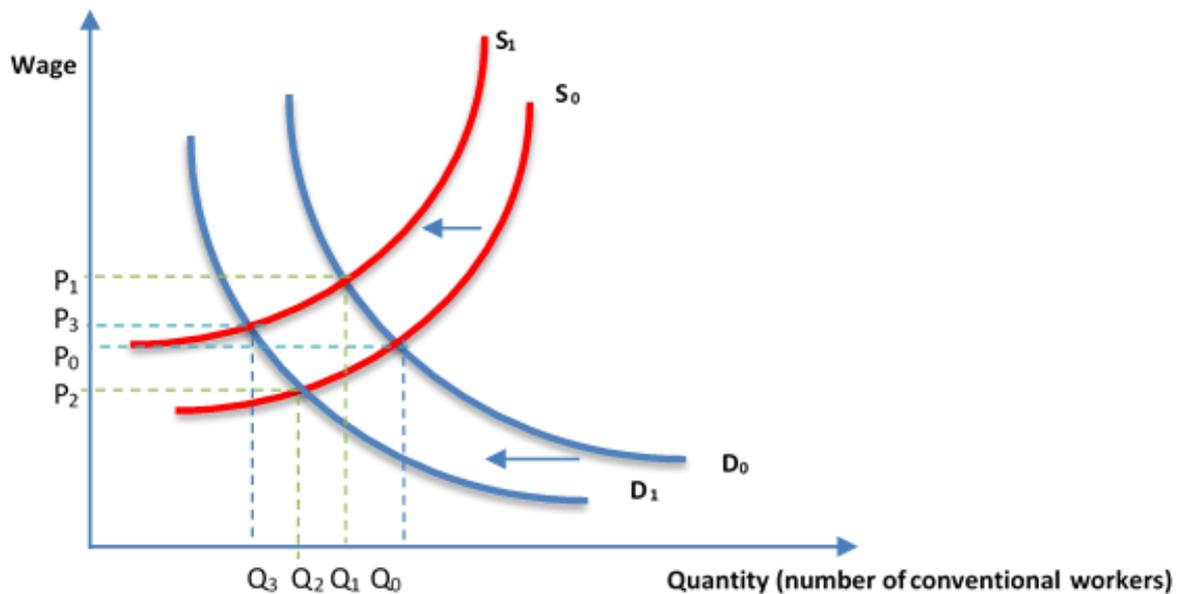


Figure 32: Impact on conventional labour market of automated navigation
 Source: based on OpenStax Economics (2016), Principles of Economics.

If only the demand would change (decrease) from D_0 to D_1 , the wages would decrease from P_0 to P_2 . In the scenario based on the assumptions concerning labour market restraints, the wages could increase from P_0 to P_3 in assumption that no other elasticities¹⁰⁶ are involved.

As the conventional crew is gradually automated, a new kind of worker profile emerges. The digital boat master in the SCC and the on-board caretakers (monitoring and intervention tasks) in the early years, are both profiles that are expected to be more expensive than a conventional boatman.

Figure 33 shows the impact of the increased demand for IT-skilled workers. In this case, it is expected that workers will be hired that are able to intervene in the AOS on board during a trip. This could be a specialized boat master or an AOS developer that has learnt how to sail. These new competences need possibly regulatory standards in defining their abilities, tasks, resting periods, knowledge and the ways of examination. In the first years of the development before the technology is proven safe (during the development phase of the innovation) and until all essential crew tasks could be automated, a minimum crew will be required to perform among others loading and mooring procedures and to intervene in the AOS if necessary. Before a truly unmanned vessel can become successful, several costs and benefits should be considered.

The fear of losing jobs in IWT because of automation seems ungrounded for the moment. New jobs will emerge (SCC, caretakers, external captains) and the labour supply shortage could be solved. The expected changes of demand and supply of conventional labour in IWT (if market uptake occurs), will establish a new equilibrium with low impact on the IWT labour market.

¹⁰⁶ Elasticity refers to the relationship between economic variables and how an economic variable responds to a change in another. In this case other economic variables could influence the supply and demand of labour. It could become more attractive to work in other segments with higher salaries such as cabin river cruises.

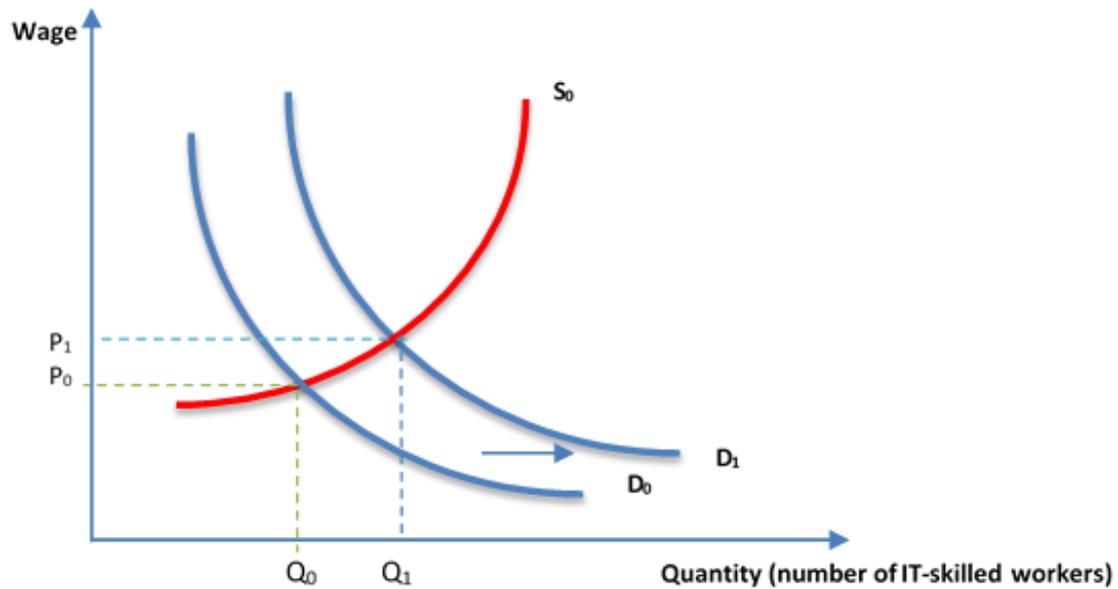


Figure 33: Automation and the new working force
 Source: based on OpenStax Economics (2016), Principles of Economics.

There are in this case no other potential losers of the innovation identified. The external costs can now be added to the CBA as developed. This is explained in the next parts.

5.4.12. Net present value after internalization of external costs

After the analysis of the identified private costs and benefits of the innovation, it becomes possible to build further on different scenarios including external costs. The external costs can be internalised in the cash flow analysis of the AV. Imagine if the vessel owner would have to pay for the external costs. What would this mean for the cash-flow. The difference between the NPV in the reference case and the project case can then be compared. The CV in the developed model has per trip a payload of 3,000 tonnes for 100 km. Thus, every trip the vessel performs 300,000 tkm. The identified external costs are internalized in the model next to the private costs. The total annual external costs in the first year of operation are EUR 572,997 in the scenario with one CV. Without a freight rate increase, internalization of the external costs would lead to an unprofitable operation with a negative NPV of EUR 4,457,443 for equity and of EUR 6,753,835 for enterprise perspective.

In case of the CV scenario, the total costs after internalization are increased with 75%. If internalization of external costs in all modes, would lead to a 50% higher freight rate or higher revenue for the CV because of modal shift an increase of demand, this would increase the NPVs of the CV. However as said, this lies outside the scope of the case analysis and invites further research.

The focus of this part of the analysis is to estimate the difference between the external costs of the AV and the CV. The outcome could deliver support for the decision of policy makers to remove barriers or the facilitate the innovation. It could also indicate that there is no benefit or that the threshold is not high enough for society as explained earlier. The internalization of the external costs in the AV-scenario is according the main settings of the CV in the reference case.

For the AV scenarios the assumption was made that the fuel consumption would decrease with 20% as do the related emissions and climate change cost. The infrastructure costs are increased with 25% as explained. The accident costs are zero despite the concerns as mentioned before. The additional EUR 2000 euro on the P&F for the AV to cover partially the investment by ports and the waterway managers, is now removed to avoid double counting. For the first scenarios it is assumed that the earnings remain the same as in the private cost analysis which would lead to negative values. These

negative values should be interpreted as such and explain nothing about the private business case. The difference between the CV and the AV should be taken into account.

Table 41 shows that the results of the NPV after internalization, given all assumptions, are not positive for the AV when comparing scenario 0 with scenario 1. Only the NPV from an enterprise perspective scores better or less bad than in the null scenario with the CV.

Scenario	0	1	12.5% infra	0% infra
Vessel	CV	AV	AV	AV
Accidents	7,497	0	0	0
Infrastructure	138,000	193,545	174,191	157,623
Emissions	427,500	383,724	383,724	383,724
NPV in EUR (equity)	-4,457,443	-5,054,881	-4,829,496	- 4,604,795
NPV in EUR (enterprise)	-6,753,835	-4,944,483	-4,537,467	- 4,133,965

Table 41: Internalization of external costs in the business case scenarios 0 and 1 (expressed in EUR)

The change in external costs related to accidents is relatively low which explains the less significant benefit for society. In a scenario where waterway managers and ports would decide to invest half of the assumed EUR 814 million in the automation infrastructure, this would lead to only half of the locks being equipped by an ADS but also to half of the increase of infrastructure costs for the AV.

When repeating this analysis, it should be kept in mind that the external costs are calculated according to the number of ton-kilometre or performance of the vessel. To improve the analysis of the difference between the AV and the CV, the same annual tkm can be compared but with adjusted prices as assumed. The following table shows the adjusted external costs per tkm for the AV.

External costs in EUR/tkm for the AV	Congestion	Emission (-20%)	Accident	Noise	Infrastructure (+25%)	Total
	0	0.0076	0	0	0.0038	0.0114

Table 42: External costs for the AV in EUR/tkm

The following sub-section investigates the results if certain parameters and assumptions would change.

5.4.13.Scenario-driven analysis with external costs of the AV

If the AV would have the same performance in tkm annually as the CV, this would lead of course to improved results for external costs in comparison with the CV and can give more insight in the benefit from a welfare-economics perspective. The external costs in such a scenario within the built model, do not include then the private benefit of more cargo space next to the time benefit of more possible annual trips. Fuel use, fuel-based M&R, P&F are then adjusted accordingly.

The private investment, other fixed and operational costs stay the same, but there is no increased revenue. The main private benefit caused by the improved performance makes the NPV in such a scenario less comparable with the NPVs of earlier analyses. In this situation this could cause confusion.

The absolute numbers of the external cost difference in the first year of operation should provide sufficient information as shown in Table 43. The external costs become for the VO relatively cheaper than with a CV (if external costs are internalized) if the performance (number of annual tkm) is made more comparable and all related costs are adjusted accordingly. The main cost driver is the infrastructure cost, but the accident costs remain insignificant. The emission cost is in all situations more beneficial because of the assumed lower fuel consumption.

Vessel	Scenario	Accidents	Infrastructure	Emissions	Total external costs	$\Delta CV - AV$
AV	CV performance, 0% infra	0	138,000	342,000	480,000	16%
AV	CV performance, 12,5% infra	0	155,250	342,000	497,250	13%
AV	CV performance	0	172,500	342,000	514,500	10%
AV	0%infra	0	157,623	383,724	541,347	5%
AV	12,5% infra	0	174,191	383,724	557,915	3%
CV	0	7,497	138,000	427,500	572,997	0%
AV	1	0	193,545	383,724	577,269	-1%

Table 43: Results of external cost analysis in EUR

5.4.14. Conclusion welfare-economic analysis of the AV

The analyses show benefits by lowering the external costs for each tkm by decreased fuel consumption and related decreased emissions. The infrastructure costs are not expected to become relative cheaper than for the CV. The accident costs are relatively insignificant even with the adjusted accident cost as developed within this research.

The threshold for the policy makers is perhaps not sufficient with only a 16% improvement of external costs in best case scenario.

If the external costs as described by several authors and further developed for the AV in this research, remain the same values, every loss of volume of IWT to other less sustainable modes, would cost more for society. This could support the decision in investing in automation infrastructure which could lower the cost of the AV for the VO by reducing the ADS or ad hoc on-shore lock human personnel for mooring operations. Within the built-up model there is a decrease in related external costs quantified and therefore, there is no incentive to resist the innovation from a welfare perspective.

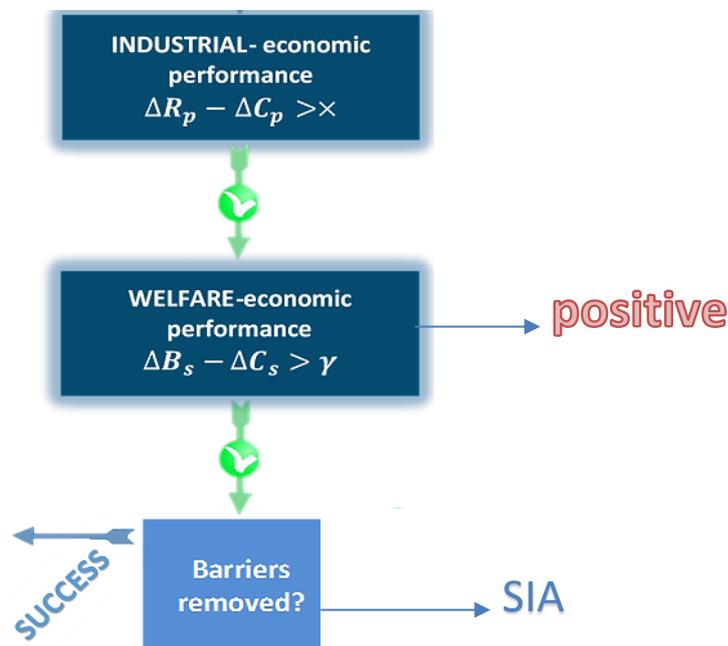


Figure 34: Innovation path of the AV from welfare-economics perspective
Source: based on Aronietis (2013)

5.4.15.CBA conclusion of the AV

The results of the cash flow analysis and the internalization of the external costs can now be linked with the RQ as shown by the following table:

Sub-questions Innovation	Answer
When is the innovation successful or a failure? What are the conditions that lead to failure or to success?	From both perspectives the automated vessel shows benefits but depends on several assumptions and conditions that are outside the developed model.
How can IWT innovation be analysed or measured?	The developed CBA shows the view from the vessel owner and reflects consequences of an innovation for both private costs and external costs. The financial parameters are however limited to the model. Every vessel has its own business case and special features. The full social cost of the innovation could not be calculated.
Who are the relevant actors in IWT innovation?	For the CBA, the actors are the vessel owner or investors and the innovator with the shore control centre. Furthermore, society can be added with external costs.
Sub-question policy	Answer
What is IWT innovation policy, how is it organized and which role plays IWT innovation policy?	The CBA of the automated vessel does not show negative results for welfare-economic performance. The impact on the IWT labour market is expected to be insignificant. Policy does not have to resist the innovation. Although close monitoring of the labour market can be advised.

Table 44: CBA conclusion of the AV

The following part is developed to answer the remaining part of the RQ concerning IWT innovation policy for the AV in addition to answers from the literature review and the SIA of this case. It is also the first test of this tool on an innovation case in pan-European IWT.

5.5.PEINPA of the AV

The policy situation (as-is) concerning automation, offers a window of opportunity because of the expressed interest of several governments, EU – funding possibilities, industry and no noticeable social resistance towards these developments (yet) as shown by the SIA.

Because automation is still in the initiation phase, and that the political debate behind the policy development just has started for inland navigation, quantification of transaction costs related to policy can only be largely assumed. This reason makes it challenging to determine in this case if the choice of the institutional level or variations within the multilevel policy model has an impact on the compliance costs of an innovative firm.

The policy setting of the AV will probably develop with a closely link to the RIS¹⁰⁷ policy (as explained in the literature review) which has several pan-European features (broader scope than only European Union). During the nineties, several countries and regions started to develop digital key technologies to support vessel traffic services (VTS) such as the inland automatic identification system (AIS), inland ECDIS with ENC (electronic navigational charts), electronic reporting international (ERI) and digital notices to skippers (NtS). The RIS framework consisted of public and private actors (e.g. Periskal, Tresco) which developed pilots, several systems and standards to digitize IWT and different projects around Europe.

¹⁰⁷ The harmonised river information services to support traffic and transport management in inland navigation, include interfaces to other transport modes (definition of RIS by UNECE, 2012), Guidelines and Recommendations for River Information Services, ECE/TRANS/SC.3/165/Rev.1, 46p.

The RIS policy framework is a complex network of organisations on different levels such as:

- International: World Association for Waterborne Transport Infrastructure (PIANC) with the RIS Guidelines; influence from international developments in maritime on the level of IMO (International Maritime Organization) and IALA (International Association of Lighthouse Authorities)
- Pan-European: UNECE with White Papers; resolutions, RIS guidelines
- Supranational / intergovernmental: European Commission with public funding in implementation of RIS and in R&D; development of directive and standards; expert groups;
- River Commission: expert groups, police regulation, standards and RIS index.

Currently, the EC is working on the evaluation of the RIS Directive 2005/44¹⁰⁸ and innovations such as the initiation of AVs are being discussed within expert groups on different levels. Since NAIADES II, a new expert group emerged which is called the expert group on the Digital Inland Waterway Area (DINA) and which offers a platform to exchange opinions on digitalisation of inland navigation. The DINA expert group is also involved in the evaluation of the RIS Directive 2005/44/EC. It is open to Member States and stakeholders to assist within this policy cycle.

Currently, one of the main challenges in the RIS policy environment is related to cross-border data exchange. Several European databases¹⁰⁹ and systems are installed but exchanging data between the levels and Member States are still an issue. Without going into technical detail of these issues, the main concern here is the policy setting. Despite a certain degree of harmonisation on EU and CCNR level, different RIS initiatives are taken on the national and even regional level which not necessarily focus on cross-border interoperability. The further development of RIS or another digital infrastructure is considered to be vital for the development of the inland AV.

The main question here is, how can policy be developed for the AV and by who at this stage of the development of the innovation. In case of automation, the development of CESNI standards is relevant in describing the minimum safety level that automated operation systems of different automation levels should maintain. Furthermore, the scope of the relatively young institution of CESNI must be taken into account for further evaluation.

A proper AV policy analysis or PEINPA is at this stage not possible yet and rather limited. The following parts analyses possible issues or policy failure factors through a new institutional economics lens influenced by the theory of transaction costs as discussed in the literature review. The identification of possible transaction costs in the next part is not the starting point of the analysis. For replication purposes in future research, a close and updated overview of the institutional setting provides the basis for the application of this analysis.

5.5.1. Costs of policy

As described in the methodology section, following costs are assumed: compliance costs, information costs and enforcement costs. As the public pan-European and even global debate just started, it is impossible to estimate or quantify the costs, but they can be linked to the related phase in the policy cycle.

A. Compliance cost

As previously mentioned, there is no such thing yet as an on-the-shelf automated unmanned vessel, nor are there any ready to use legal IWT AV-standards. Furthermore, an AV relies on different innovation elements such as the integrated AOS with subcomponents ADS, AWS and other systems which are currently all innovation elements without any IWT standards or defined policy (yet).

¹⁰⁸ Directive 2005/44/EC of the European Parliament and of the Council of 7 September 2005 on harmonised river information services (RIS) on inland waterways in the Community

¹⁰⁹ Such as the European Hull Database and the European Reference Data Management System

Consequently, it is not possible to quantify the compliance cost that easily. Compliance costs that are paid by the innovator are yet to be expected. This situation gives the innovator an important advantage. In building legislation and standards, the experience of the first mover innovator is likely to be used as a base for policy development. A pro-active innovator can have the opportunity to be significantly involved in writing the policy and indirectly in co-defining what future competitors should comply to. For the moment the AV must comply to different kinds of regulations such as crew regulations (unmanned is not allowed), technical requirements (e.g. vessel design) and police regulation (safety level) as explained during the SIA, that are designed for manned vessels. This compliance is only necessary if no derogations are given by the relevant public actor. Without an accepted electronic bill of lading, the AV also still needs to have cargo documents on-board as regulation 1960/11 (European Economic Community) requires.

Compliance costs for the policy actor are yet to be found. There is no preceding regulation yet, which means that subsidiarity and proportionality are also not defined. None of the public actors must comply or be consistent with existing or preceding policy, which means that every policy level in IWT policy model can create policy, including standards, regulations or grant funding at this moment. MS can make their own policy, UNECE can write resolutions, the river commissions can amend or adjust their regulations and technical standards and the European Commission can establish its own definitions of automated vessels without legal or institutional conflict. There is therefore a significant risk that compliance costs will be higher if policy makers choose to have a fragmented approach and therefore shrink the market by narrowing down the level playing field. In this regard, the number of existing regulations that is subject for change to facilitate automation is already fragmented among several policy actors with a not-that-distant past of institutional tensions.

A higher level of policy such as the UNECE and the EC has the advantage of addressing a larger scope of policy and therefore supporting possibly a larger market with the same set of rules in addressing externalities. A higher level has the (dis)advantage that debates from a lower level could be reopened with possibly another outcome which will then cost more time and could weaken or strengthen the more local existing legislation. The higher the level, the more rigid and complex it can become to change a policy and thus the compliance requirements.

For example, at a higher level the window of opportunity to adapt regulation may be quite small as there are only a limited number of annual meetings. This reality could influence the business case and lobby-strategy of an innovator. The complexity of a higher-level policy arena requires a higher specialism from the innovator/lobbyist which increases the costs for the innovator. Furthermore, if one meeting is missed, it could take one year longer in worst-case scenario to have the necessary policy change or clearance to proceed with the implementation of the innovation on the market and to achieve market uptake.

During the innovation cycle, specialized firms in compliance could add this time element, because of experience in dealing with this policy model, in the total development cost of the innovation in order to avoid setbacks and to ease the regulatory burden and bureaucracy for the cost structure of the innovator. Verification or classification agencies tend to take on this role for their customers.

Lower levels have the advantage to be more dynamic in theory. They are much closer to the market and the innovator, they could be relatively faster in removing regulatory bottlenecks and develop first practices, but their scope is only national, regional or even local such as a port authority and limited by preceding regulation from above. In some cases, the regional or national level can take the lead in developing the automated vessel which is the case in the Flemish region with the RAVEN project which higher levels of policy do not. No innovations were identified where supranational or inter-governmental policy levels took the lead in developing innovation for IWT.

In case of automation, if innovators would only lobby at regional levels, the market could turn out to be smaller. Adjusting only the Flemish infrastructure with ADS at a lock will help business cases on a limited market such as small domestic waterways and short distances for unmanned vessels, but for

international inland navigation, this would not be a solution. Nevertheless, local and regional levels could be valid partners in convincing upper policy levels and could provide test areas to prove the potential benefits of the innovation.

Focusing at one level of policy would also be a wrong approach. The multilevel approach (addressing all relevant policy actors) could get the most significant advantages of the policy system. On the other side, it will of course take more time and preparation which needs additional capability on the side of the innovator.

In this phase of the innovation, compliance costs and regulatory burden for businesses can probably be lowered by:

- Consistency and coherence of legislation (from private and public perspective);
- Facilitating innovators to gain access to the appropriate and relevant policy arena's by providing them an accessible institutional roadmap towards relevant regulatory bodies;
- Actively avoiding conflicting regimes within policy framework;
- Having a short line of communication and structural coordination between all policy actors and build stable relationships with stakeholders;
- Broadly disseminating funding options in a transparent way and initiate proper resource management.

Finally, the liability issue (see SIA of AV) is also important for the compliance costs. For this part of the analysis, the uncertainty because of lack of accepted legal definitions concerning liability for the AV, also increases the compliance costs for the innovator.

B. Enforcement costs

If potential safety standards for automated vessels are not enforced, the incentive to comply will decrease. Why pay for compliance if penalties are not or hardly given. Although some will find a lack of enforcement interesting in the short run, this could eventually lead to more uncertainty on the market and even affect the safety level.

The AV relies on several firms or manufacturers of software and hardware systems that must meet a certain level of standards for safety and reliability. Next to verification agencies, these firms can play an important role in providing suggestions and advices on how to create standards if needed. In this case it is important to understand the potential political bias. It is rather an ideological question to leave this completely to the market and to rely for example on private verification agencies to develop their own standards or to create regulatory bodies within the policy network and with actors involved that have effective enforcement possibilities. However such questions are outside the scope of this analysis. Although when analyzing the PEINP, it is important to be aware of this potential problem.

After observing how the European Commission, CESNI, the CCNR and some Member States work in other fields of policy and within the RIS environment, it becomes clear that several potential synergies are not made. Costs related to enforcement or compliance which can be cross-border or inter-organisational, are mostly borne on each organisation. Perhaps less significant costs such as administration, translation, information gathering, show the same lack of potential synergy.

For automation, it is too soon to calculate the enforcement costs without regulation, but additional investments in data-sharing between organisations such as river police or waterway managers, seem already vital to prepare the upcoming digital challenges with AVs from a policy perspective. It needs to be clear how the public actor can communicate with the AV and the SCC behind the AV.

Practical issues could increase enforcement costs. If inspection shows that a certain AV does not comply with safety standards and enforcement is needed, the responsible needs to be taken accountable. If a legal definition is lacking for the nautical error and other liability issues, or if the SCC is in another continent and the shore controller needs to be interrogated or arrested, the enforcement costs will probably increase. On the other hand, the enforcement costs can also be reduced because

of the potentially automated reception of AV data. Or the enforcer (e.g. automated police vessels) can become automated too.

Without any case law related to the AV in the initiation period, the costs concerning juridical enforcement cannot be identified or quantified. In the policy cycle, enforcement and compliance costs can arise. Another factor which could increase policy costs further, concerns asymmetrical costs and relates to credibility as explained in the following part.

C. Credibility and asymmetrical information costs

This part investigates the possibility of asymmetrical information costs of the AV development and the policy credibility of the policy model towards business. The technology which is needed for an automated vessel in Europe is mainly developed by private companies. Most of the technology is being developed by firms from all over the world which expresses the global window of opportunity where the innovation is currently situated in. Even if the innovator is not a global private player but a public actor, the potential problem of asymmetrical information emerges and manifests itself between levels within an organization or at a micro-level between individuals. Full guarantee of avoiding asymmetrical information is not possible, but there are ways to decrease these costs in every phase of the policy cycle by adding mutual transparency.

The cost of asymmetrical information could increase if IWT shifts the focus to productivity rather than safety. Public and private actors can avoid or reduce these costs by addressing specialized and dedicated experts (internal or outsourced) on different levels in the policy model. In this case, a fragmented policy among several institutions could enrich the debate and provide opportunities to perform a check-and-balances between the actors. Despite the higher costs for innovators to lobby at different policy levels and arena's (time consuming, travel expenses, number of partners, types of delegations, maintaining a larger network, fragmented focus, diplomacy skills), the current policy system has advantages to possibly narrow down the asymmetrical information cost if knowledge is shared and frequently checked by different levels.

In an automated world, asymmetrical information costs become an important challenge for governments and could reflect in a higher cost for policy. The institutional network with independent research and knowledge institutes, is crucial to keep these costs in every phase of the policy cycle tangible. Investing in scientific data (collection, quality, evaluation and verification) and research to support measured policy can be a solution to decrease these costs. Asymmetrical information can be both a cost or a benefit. National or regional policy levels are closer to an automation experiment than higher levels, but they have less means in supporting the innovation (e.g. public funding, public procurement). The close-by advantage could deliver more detailed information but not necessarily.

The mentioned costs are still rather theoretical in this case. Assuming that the RIS policy environment would be used as policy cycle for the automated vessel, the transaction costs will emerge through the different stages of the policy cycle as further developed in the following part.

D. Other costs

Other public costs can relate to public innovation infrastructure, public procurement, administration, communication, dissemination or evaluation, next to typical overhead costs that can be found in every organisation. Caution is needed to interpret these findings because of the theoretical approach during the initiation phase of the innovation and of the specific innovation PEINP. It is not the intention in this case to provide an answer on how it should be (normatively), but how it could be (theoretically) for the PEINP of the automated inland vessel. Second, the political rational through the described phases stays rather hidden but can be decisive in choosing or even evaluating the information, advices, propositions or issues during every phase. More fundamentally, it is also the political narrative that decides if there is even a PEINP needed for the AV, which both currently do not exist (yet). The stages of decision making, implementation and outcome evaluation are therefore not reached (yet) according to the observed traces of the initiation of PEINP development for the AV.

The development of the automated vessel already considers a rather large and international innovation network as analysed by SIA in this case. When examining closer the involved public actors and their relationships within the pan-European institutional setting of IWT, the network is (indirectly) in fact even larger than first discovered through the SIA.

Linking the potential costs with the phases of the policy cycle in the PEINP, proved to be possible in theory, but less in practice. Quantifying them requires access to costs of each involved organisation and not only access is needed, it also must exist. Cost data is not always this detailed collected within a public actor or even a firm. On the level of an individual, for example a civil servant working in different fields of IWT policy, it is not possible or preferable to measure the specific working time spent on a specific innovation in IWT. In several cases, civil servants or organisations have more activities than only IWT and work in other modes of transport or integrated environmental water policy.

Some of the mentioned organisations such as CESNI share their costs between the EC and the CCNR for translation, administration, communication and other overhead costs, but also here the involved experts, translators and administrators have other tasks in- and outside CESNI which do not include only automation. Automation is rather a very small item on the agenda of most expert groups and organisations at the moment. Public funding of R&D in automation is the only tangible and free accessible part of the budget behind the starting PEINP of the AV development. Another finding is that the synergy benefit could be in theory much larger and a number of potential synergies within policy are lost or not examined. Incentives to do this are not given and institutions find it difficult to look for inter-organisational public cost management for even a shared translation cost.

Table 45 summarizes the costs for stages of the initiated and expected AV innovation policy such as input and agenda-setting as developed within the institutional framework (Chapter 3). The table continues on the next page.

Input: demands and support, defining an issue		Agenda/selection of issues
costs of PEINP (AV)		
Information	<p>Input from network comprising:</p> <ul style="list-style-type: none"> • RIS working groups; DINA; River Commissions; CESNI TI (since 2019); European Commission; Member States (and regions); Stakeholders (ports, sector organisations, waterway managers, innovators such as ICT developers, SCC designers, shipyards and manufacturers); Knowledge institutions; Verification agencies • Identifying problems and its legal, technical, social, environmental and economic implications; • Ex post evaluation of related policy, pilots, other existing AV or automated transport policies • Agenda formation and discussion • Potential relatively high costs of cross-border exchange of information between policy network actors; costs of information management; and quality check with validation of information; • No real coordinating mechanism identified above all working groups • High fragmentation between public actors • Risk for asymmetrical information because of high complexity of innovation • Costs concerning gathering information are administrative and not included here. Described costs relate to actions that are not covered by salaries, but paid by organisations 	<ul style="list-style-type: none"> • Debating the agenda of known issues concerning AV such as potential need for PEINP • Agreeing on the agenda and ranking the issues by importance • Establishing working plans and financial implications; Budget information on suggested solutions • Research support for deliberation of the proposed actions concerning the development of the AV • Lobbying by innovators (first movers-advantage) and further political debate on the agenda-setting
Administration	<ul style="list-style-type: none"> • Every identified actor such as a working group, generates overhead costs that relate to administration such as secretary work, organizing meetings (internal and external); reports and preparation of meetings • Gathering information such as statistics, research findings, input from surveys or public hearings, reports for preparation of meetings and other activities • Dissemination of findings amongst involved actors (caution for double counting with the costs involving information exchange as mentioned for information costs) • Not centralised, every group, meeting, organisations have their own administration costs. No synergy or shared costs • Described costs relate to actions that are not covered by salaries, but paid by organisations 	
Translation	<ul style="list-style-type: none"> • Significant cost at UNECE, EC, CESNI, River commissions; Not centralised, every organisation has its own translators • Official documents such as reports, minutes and preparation of meetings, • Interpreters during meetings (synchronous translation) • No synergies identified such as common translation services shared between public actors 	
Communication	<ul style="list-style-type: none"> • Publishing official documents • Dissemination outside organisation • Communication with stakeholders and costs related to stakeholder appraisal • Website/social media costs 	

	<ul style="list-style-type: none"> • Related to costs that are not covered by salaries • No synergies identified between organisations
Employment	Salaries of civil servants, representatives and officials from Member States or stakeholders, experts.
Housing	Meetings and conferences at different locations, hotels
Transport	<ul style="list-style-type: none"> • Traveling abroad: moving official documents and working staff; • external costs not included. • The higher the policy level, the higher these costs are for individuals and organisations with regional/national having the lowest price (relatively)
Enforcement	<ul style="list-style-type: none"> • EC, UNECE, River Commissions need information related to enforcement from Member States relevant for the enforcement • National/regional: enforcement costs for lower policy levels and on sector (river police costs, monitoring costs, inspection of vessels). • Potential risk for asymmetrical information costs between actors (public vs public, public vs private). • Juridical costs (private vs private, private vs public and public vs public) relates to violations or non-compliance to policy. In case of AV, no court cases (yet)
Compliance (internal)	<ul style="list-style-type: none"> • Consistency with equal legislation (on the level of the public actor), hierarchical legislation (with higher levels) • Expected to run through the policy cycle. Competences check with subsidiarity and proportionality. AV has no AV standards or regulation (yet)
Project	<ul style="list-style-type: none"> • Investment of the chosen policy/project (subsidies, infrastructure). In the case of the AV, only public funding for R&D is observed on different levels. • In some cases, AV pilots are led by public actors in collaboration with private specialized firms
Opportunity	Use of scarce government means for specific policy cycle and not alternative policy cycles. Opportunity costs can be in the information phase and agenda-setting important parameters to list the issues according their financial implications
Benefits of PEINP	
Quality	<ul style="list-style-type: none"> • It is too soon to observe this benefit and assessing quality in this phase is highly problematic • Evaluation capacity during these stages of the policy cycle is not always present. Only on the level of the EC this is observed. • The higher the level, more resources can become available and more knowledge institutes and experts from all over Europe can join. • On lower levels there can be a lower number of actors giving information or resources to develop IWT policy. Less quantity does not necessarily lead to less quality. Lower levels can also be much closer to the sector and to individual experts than higher levels. The agenda-setting process has less actors involved which could be positive for a more efficient decision making (decide which agenda, which issues should be addressed).
Synergy	Bringing experts regularly together can cause sustainable synergies in research and other inputs. Exchange of best practices between MS becomes possible. As observed, there are still more synergies possible.
Social redistribution	If the innovation would have an impact on the labour market, social policy could be needed to compensate the losers of the innovation (workers that are replaced by automation). If this would be the case, in theory, a higher level could have more resources to compensate the losers. Most of the welfare distribution competences are situated on the national level of Member States as the higher levels do not have the instruments to implement such a policy.

Table 45: PEINPA of the policy cycle costs of the AV

5.5.2. Fragmented and/or supranational approach

In this part, the differences between a fragmented and a supranational approach are described. The first approach shows the benefits and costs when every institutional actor develops a legal definition and standards for automation. Secondly, the costs and benefits are shown when the institutional setting becomes more integrated towards one regime (dominant or centralized).

Although there is structural cooperation between public actors for the further development of an AV policy within the RIS policy environment, the development of the AV currently follows a more fragmented scenario. In this setting it seems that national and regional authorities are more competing against each other than cooperating in trying to be the first country/region with an AV. Cooperation and coordination between countries happens mostly multilateral and ad hoc in this case at the initiation phase of the innovation, or because of European public funding for R&D that stimulates cross-border collaboration. It is questionable if this policy situation will continue when the AV is further in its development. If the focus remains on the national or regional level, less opportunities to tackle cross-border externalities will be taken into account for a sector that is significantly focused on Rhine transportation which crosses borders. The potential costs of this fragmented scenario as explained in the last part, could imply:

- Additional compliance costs for the innovator because of further reduction of already a small market through differentiated, mostly national regulation which would lead to a smaller level playing field.
- Less quality and smaller learning capacity on state level and less expertise within national policy (although quality does not equal quantity);
- External costs increase because of potential negative mode shift. Weaker position against (pan-) European/international regulated modes of transport and weaker link within global supply chain;
- Financial costs. Although fragmented, European or higher-level funding is still possible;
- Costs resulting from a higher risk of asymmetrical information between MS and large or specialized private actors.

The identified benefits are:

- AV policy could be faster implemented, less complex and more accessible; although only national;
- Lobbying and participating during agenda – setting can be relatively easier for a national innovator
- Development of first policy practices, can have first mover advantages. Levels learn from each other. This can be observed during the development of RIS where Flanders, the Netherlands, Germany, France and Austria offered first practices and standards for RIS key technologies before higher levels of policy adopted.

There are possible additional infrastructural costs because of the fragmented approach to create an automated infrastructure. Infrastructure policy on Member State level could cause additional externalities in choosing for equipment or technology that is non-compatible for the AVs as developed in other Member States, which increases the compliance cost of the private innovator and which makes enforcement differential amongst MS.

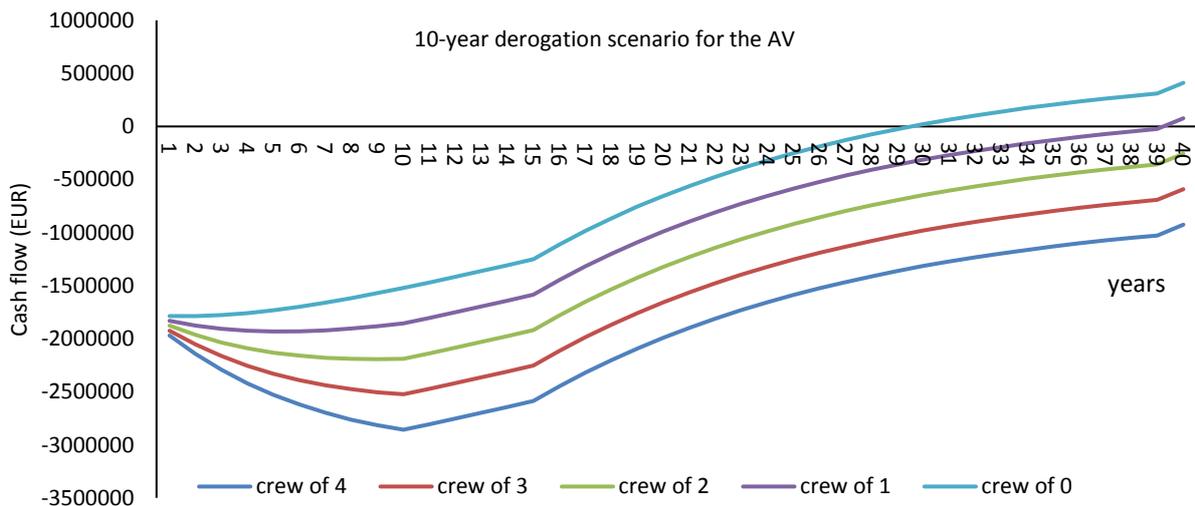
The fragmentation concern can be solved at this stage by applying a system of mutual recognition as explained in Chapter 3. Therefore, although differences between member states may remain, there is a larger level playing field within the European internal market as harmonisation or other ways of centralizing will take more time and perhaps political will. This system has been developed because of historical reason in European integration whereby harmonisation took more time and provoked more opposition of sovereign Member States. With the current institutional setting, a collaborative policy network seems feasible. This network involves all relevant policy actors and levels and would decrease the transaction costs not only for actors within the network, but also for private actors that could join.

5.5.3. The impact of policy on the business case

One of the identified policies so far from the PEINP is the application of the derogation tool next to R&D funding. In this case some public actors (e.g. The Netherlands and Flemish Region) decided to allow automated sailing as pilots on their waterways. Derogation of policy allows innovators to derogate from or to neglect parts of the existing regulation. In this part of the PEINPA, the developed CBA can be used to examine this derogation ruling and its complications of the business case of the AV.

If policy makers decide not to allow unmanned vessels and require the mandatory crew size for an AV as for an CV, scenario 1 would have a negative NPV_{equity} of EUR -1,955,786. If the regulator would make it mandatory to have a single caretaker on-board, the NPV_{equity} would be EUR -180,760 but the IRR (equity) would be 9.6%, which is below the assumed threshold of 10% cost of equity. In another scenario, the regulator decides to give a derogation for the first 10 years but with the mandatory crew to ensure safety until the benefits of the innovation are proven according to the derogation procedure. This would lead to an NPV_{equity} of EUR -925,384. Finally, a derogation for an AV during the first 10 years but with only one caretaker on board, would have a positive NPV_{equity} of EUR 76.841.

When zooming in to the derogation procedure, the following scenarios based on the private cost-benefit analysis, can be developed to quantify the impact of several derogation conditions. A first scenario could allow the AV (according to the AV scenario 1 or project case) during a ten-year derogation period to have one to four crew members on board (Figure 35).



Number of FTEs during 10-year derogation	IRR (ent)	IRR (equity)
4	8.01%	8.25%
3	8.45%	8.82%
2	8.92%	9.45%
1	9.42%	10.17%
0 (scenario 1 of the AV)	9.94%	10.99%

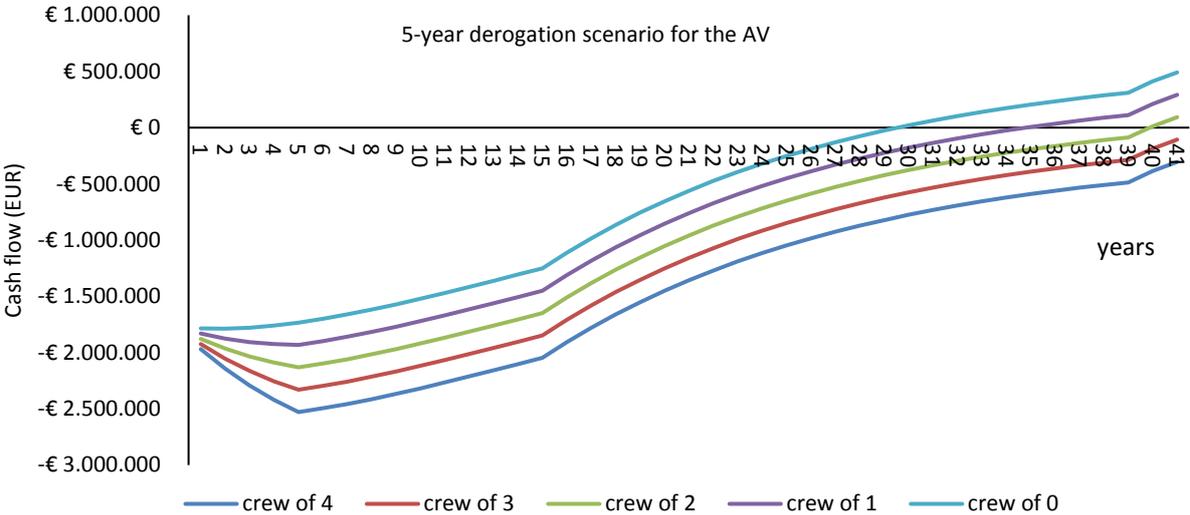
Figure 35: Impact of a 10-year derogation period on the AV business case
The values in red are below the preferred minimum of in this case 10% discount factor.

If the derogation conditions require only one crew member on board of the AV, which is assumed to be able to sail fully unmanned in this model, both IRR are above the assumed threshold (discount factors). In all other cases, the business case becomes negative.

A second scenario takes a five-year derogation in account with similar crew conditions as in the first scenario. This analysis shows the importance of the duration of the derogation period and explains

that a long derogation period has a negative impact on the business case. Strict conditions within the derogation procedure could also prevent further uptake of the innovation.

As shown in Figure 36, the mandatory crew of two still provides a positive business case within a period of five years. After these five years it is assumed that regulation is implemented after convincing evidence that at least all existing safety levels are met, which allows the AV to have a sustainable legal basis during the lifespan of the vessel. If policy makers instead decide to keep it mandatory to pay more than two crew members, the business case is negative.



Number of FTEs during 5-year derogation	IRR (ent)	IRR (equity)
4	8.76%	9.23%
3	9.04%	9.61%
2	9.33%	10.03%
1	9.63%	10.49%
0 (scenario 1 of the AV)	9.94%	10.99%

Figure 36: Impact of a 5-year derogation period on the AV business case

It becomes clear that the chosen policy of derogation has an impact on the business case of the private innovator as developed in the cash flow analysis in the previous sub-section.

5.5.4. PEINPA conclusion of the AV

The innovation is in the initiation period which also has a consequence for policy. There are traces of starting policy but not sufficient to completely test and quantify the PEINPA. Furthermore, no information concerning real costs estimates was found for the mentioned policy levels.

There is a growing awareness amongst policy makers on all levels to develop policy (including standards and regulation) which is monitored as participant-observer, but the supranational levels are mainly leaving the initiatives (such as pilots) to the national/regional/port levels and private actors. The only identified policy actions from public actors in the PEINP in relation to the AV, are funding of projects that focus on the development of devices, systems and concepts, provide derogation zones and in some cases taking a leading part in the innovation. Indirect to the AV, PEINP is strongly present in the implementation of the digital infrastructure such as RIS.

The PEINPA has limits to evaluate the funding mechanism for the AV. The funding actions cross many different projects with different objectives, and the divers targeted benefits are not revealed (yet). Linking a hypothetical derogation delay during the innovation implementation to the developed cash flow analysis of the AV model, provided some quantifiable effects, but are rather expected. Nevertheless, the relevance of this tool and its further theory development still stands as it investigates

the multilevel policy cycle through a lens of transaction costs and provides more detailed insight in the IWT policy.

Finally, the following table shows the linkage of the PEINPA on the case of the AV with the RQ.

Sub-question	Answer
<p>What is (IWT) innovation policy, how is it organized and which role plays IWT innovation policy?</p>	<p>The IWT policy for the AV is still premature. Several actors as defined in Chapter 3 are taking actions such as public funding; examining regulatory bottlenecks; in some cases even leading the innovation and derogating by providing testing zones. At the moment: Regional/national/ports actors are involved in initiation period of the innovation and of the policy (derogation, testing zones); River Commissions & EC started the debate concerning regulation; EC is funding related projects. No leading policy level is yet identified. The system of mutual recognition and collaborative policy network approach can be advised as national policies might emerge sooner than higher level policies.</p> <p>The multileveled policy comprises policy arenas where institutions compete in search of power. The lack of central policy invites several public actors to take actions, but with the risk of policy fragmentation and increasing costs for innovator and policy. Transaction costs concerning compliance, enforcement and coordination are theoretically significant at this early stage of policy development and could provide a bottleneck for the innovator.</p> <p>The implementation and further development of digital infrastructure such as RIS is important for the development of the AV</p>
<p>Which policy measures are applicable for IWT?</p>	<p>The explained public innovation policy mix of instruments, does not seem to suggest that the AV is any exception or requires a different approach.</p>

Table 46: PEINPA conclusion of the AV

Now that all analyses are performed, the case study can be concluded, and all sub conclusions can be integrated and linked for a higher level of understanding.

5.6. Case conclusion

By integrating the system innovation analysis, a CBA with attention for related costs and the first application of the developed PEINPA, more insight in this innovation can be gained.

The SIA identifies and analyses the failure factors for the automated and unmanned inland vessel such as the mooring problem, bunkering, (un)loading operations, and the need for further development of the digital and physical infrastructure. These factors can be solved by already existing technology or other options can be explored while taking into account any technological compatibility issues. There are concerns if there is sufficient consumers availability and capability (e.g. skills, financial). Some elements of cultural conservatism were also identified. The SIA helped to identify the regulatory bottleneck and the current lack of alignment between the soft and hard institutions. Several actors are identified within the global automation network that is emerging across all transport modes. The policy was found to be early in its own initiation period with traces of raising awareness which was supported by the findings of the PEINPA.

Another finding of the SIA is that currently most of the vessels in the Rhine countries are equipped with steering assistance such as autopilot and digital mapping, but no vessel is built yet that could offer a partial automated operation system where the human operator receives suggestions but remains the decision maker. This kind of advanced supporting system is still to be developed, although current technology allows such systems already. Systems that could replace the helmsman of an IWT transporting vessel are still conceptual, although some experiments are conducted that are backed by a shore control centre and could show promising results for other implementations.

The CBA took in account the external costs within a developed vessel model. It shows that the AV has benefits from an industrial- and welfare economics perspective at certain conditions. In case of automation, there is a decrease in external costs concerning the reduction of fuel use and consequently the emissions.

Accidents costs which are relatively insignificant in IWT, are decreased with an unmanned AV simply because of the removal of potential human casualties.

Even without infrastructure investments that could stimulate the implementation of fully unmanned vessels, the automated vessel should be able to moor and unmoor safely. The potential modal shift if all modes would become automatized except IWT, invites further research but could prove to be an additional incentive to stimulate the innovation from a welfare perspective. As the IWT fleet is not standardized with one type of vessel, but comprises several market segments (e.g. liquid, dry, containers, passengers), the results face limitations to be generalised.

The PEINPA showed theoretically that transaction costs concerning compliance, enforcement and coordination are significant at this early stage of policy development. The technical complexity of the innovation includes a potential risk for asymmetrical information. The lack of alignment and central steering between policy levels could lead to a fragmented approach which increases the transaction costs of the innovators and the involved policy makers (e.g. compliance, coherence). To perform a more quantitative analysis of the transaction costs more data is needed. Policy shows an impact on the business case of the private innovator. Regulation is needed to level the playing field for all actors and to give more legal certainty to the innovation. The timing of the derogation method and the posed conditions have a direct impact on the cash flow of the AV.

The developed tri-method in this research can be done for every component or subsystem of this kind of complex innovation or in a more generalist way that considers the AV as one product. Knowing that if one of the components fails, the entire autonomous or automated vessel can have a problem to continue operations and will need in worst case scenario a crew or specialized firms to fix the problem. Every component has its own company and innovation network behind it that usually goes further than only the inland navigation market. Every component presumably needs a special derogation procedure that needs time to prove the safety and reliability level towards policy makers.

Further research is necessary to explore broader possibilities and more scenarios. Every vessel, business structure, cargo (type and volume) and crew formation can offer different inputs for the vessel model that could lead to different results. Moreover, the differences between the business case of a large company or an SME could provide more information, especially if the shore installations and SCC are not outsourced.

5.7. Further research of the AV

This case study invites further research to replicate the methodology and gives following takeaways and considerations: The case study does not allow to conclude whether fully automated and unmanned vessels would radically push away conventional sailing. It could also become simply a new additional way to sail but with remaining limitations. In cases or trajectories where the crew cost is lower than the automation investment, manned vessels will have an economic rational to remain on the market. And even if there is a competition between unmanned vessels and conventional ones, the manned vessels need to look for more on-board efficiencies and/or to add value on their manned service.

It is possible that there are sustainable personal relationships between VO's and shippers/forwarders and that the latter would still prefer the presence of an on-board vessel owner. In passenger transport and dangerous goods, this could certainly be the case.

If one day, the inland navigation wakes up in a heavily digitized supply chain with further developed automated or even autonomous competing modes, the modal share of unchanged inland navigation

could be threatened. The potential impact of other modes (including cross-mode elasticities) is an interesting subject for future research.

Fully automated navigation systems and other automation devices that lighten the workload on-board, have on the short-run more chances to diffuse on the IWT market than a complete unmanned freight vessel at the moment. For the captain and the helmsman these systems could lead to shorter working hours. While the rest of the crew only must focus on tasks that are not yet automated in the short-run (mainly maintenance, repair, monitoring, mooring, loading). Being a family business, more time could be spent with the family on board, or even on other businesses. An automated vessel (level 2 or more) could become a floating office for other kinds of businesses while transporting goods.

In case of the SCC, it is relevant to research the labour circumstances and the impact on safety if the boat master will operate from an on-shore (remote) control centre. Will a 'gamer' be sufficiently (e.g. mentally) linked to the vessel? And could this lead to deskilling of the SCC helmsman as no real experiences on a vessel can be noted?

The automation technology that is currently used in the military, could bring fundamental changes to the transport sector. The potential impact from this kind of innovation on the supply chain or on transport modes invites further research.

Too many essential components are still in their initiation phase or early in the development phase. As they need to improve and integrate, their further development could give new information concerning costs and improve the inputs of the developed vessel model. Automated navigation (automation of the wheelhouse) will need a reliable integrated system of scanners and other devices next to the necessary software. Eventually, the highest automation level can be reached when an automated vessel becomes fully automated and when it is able to solve situations where even human boat masters must improvise based on their personal knowledge, experiences and capabilities. Furthermore, the development of artificial intelligence is in this regard important to reach level 5.

The research scope focuses on the Rhine fleet for the transport of freight. It was noticed that passenger transport experiences a significant growth. The capabilities to invest in innovations, are expected to be higher in this segment of the IWT market and invite further research. In case of automation, it could be interesting to examine if passengers would go on a river cruise without a captain or operational crew. As long as there is a cook, a barman and perhaps a ships doctor, people might still be willing to go on river cruises or would they prefer a complete crew? And will the AOS on-board be reliable, safe and still productive enough to deserve the trust to take care of hundreds of human lives?

It is not proven that the AV backed by an SCC will be safer indeed. Challenges such as situation unawareness, data misinterpretation, capacity overload, reliable connectivity, and as mentioned the lack of emotional attachment should be examined closer from a multidisciplinary perspective (socio-medical, computer-scientific, juridical, psychological) but this invites further research and is not included here.

The policy analysis needs more quantified data in order to calculate the benefits and transaction costs of different policy models. However in dealing with cross-border externalities in a relatively small sector such as IWT, it sounds reasonable to believe that a transparent coordinate institutional level playing field is essential to allow a successful innovation policy. The identified costs and benefits in the policy analysis, shows that a cost-benefit perspective on pan-European policy in IWT offers interesting insights to improve policy.

The next case goes further in the possibilities to address climate change and air pollution by shifting towards alternative fuels in IWT. The main analysed alternative fuel is liquefied natural gas. Literature concerning LNG is found at the beginning of the case study.

6. Analysis of the LNG-diesel dual fuel inland vessel

This case analysis examines the potential business case of liquefied natural gas (LNG) and answers the question what policy can do to support or to resist this innovation. The case analysis starts with a literature review in order to situate the innovation. Afterwards, the actual analysis is introduced and performed.

6.1. Case related literature

This literature review provides a starting point for the case analysis of the LNG inland vessel next to the in-depth interviews with engine manufacturers and vessel builders. The development of LNG as an alternative fuel for IWT has gained a lot of attention the past decade.

6.1.1. Definitions of alternative fuels and LNG

An important distinction is the difference between propulsion and fuels. Fuels can be diesel, gas-to-liquid (GTL), liquefied natural gas (LNG), compressed natural gas (CNG), methanol, biofuels, hydrogen and others (Figure 37). The propulsion refers to a system that consists of a source of mechanical power and a propulsion that converts power to movement. It is a system that generates thrust to move a ship across water and which usually consists of an engine and a propeller. The innovations concerning propulsion are not taken into account. Alternative fuel refers to fuels that provide a vessel's movement other than diesel or gasoil fuel which are considered conventional fuels. Most alternative fuels aim for a reduction in emissions and in total fuel usage. They can be relatively cheaper but usually come with a significant cost for the installation. They do not have a comparable infrastructure of distribution and production as conventional fuels.

Maes et al. (2015) give an overview of potential alternative fuels and after-treatment systems.¹¹⁰ Barriers and facilitating factors for innovation uptake of alternative fuels for IWT were also identified based on desk research and expert knowledge within the Prominent consortium. According to Maes et al. (2015) the following generic barrier categories or failure factors are identified for alternative fuels: Technical (immaturity of technology or lack of operational requirements); Legal (unadjusted legislation); Financial (access to capital or business case); Knowledge (lack of expertise or skills); Market (structure, conditions,...); and Cultural (conservatism, old habits). They concluded that LNG fuel¹¹¹, dual fuel¹¹², Stage V engines and hybrid propulsion with buffer battery were technologies that were confronted with the highest barriers. Technologies that faced the lowest barriers were GTL fuel, CCNR II engines and SCR technologies. There were also substantial differences acknowledged between different vessel types, referred to as *fleet family*. A number of 14 technologies were identified and analysed such as LNG, dual fuel¹¹³, GTL fuel, Right sizing, CCNR II engines, Stage V engines, Hybrid propulsion and diesel particulate filters (DPF).¹¹⁴

¹¹⁰ The Prominent study was funded under the Horizon 2020 programme of the European Commission between 2015 and 2018 and conducted by EICB, Ecorys, SGS, DST, FHOÖ, Panteia B.V., ADS van Stigt, TNO, BAW, Multronic B.V. Pro Danube, University of Craiova, Via Donau, Wärtsilä, Navrom SA, TÜV Nord and coordinated by the STC-Group.

¹¹¹ LNG is a liquified natural gas that takes 600 times less stockage space than gaseous natural gas. Components as dust, acid gases, helium, water and heavy hydrocarbons are removed through the liquification process. LNG is condensed into a liquid and cooled down to less than -162°C. The volume is smaller than compressed natural gas (CNG).

¹¹² 'dual-fuel engine' means an engine that is designed to simultaneously operate with a liquid fuel and a gaseous fuel, both fuels being metered separately, the consumed amount of one of the fuels relative to the other one being able to vary depending on the operation (NRMM, art.3 of Regulation (EU) 2016/1628)

¹¹³ Not only dual fuels with LNG and diesel are possible. The small passenger vessel Hydroville from CMB uses diesel and Hydrogen. The Dutch Texelstroom is a dual fuel CNG diesel electric engine with solar panels and is used as a passengers RORO ferry. Monofuels with hydrogen such as the small passenger boats of the former Amsterdam based Lover company, failed, as infrastructure did not follow.

¹¹⁴ The DPF and SCR are devices that aim to reduce emissions. The DPF reduces the particle emissions from the exhaust of a diesel engine, while the SCR aims at reducing NOx.

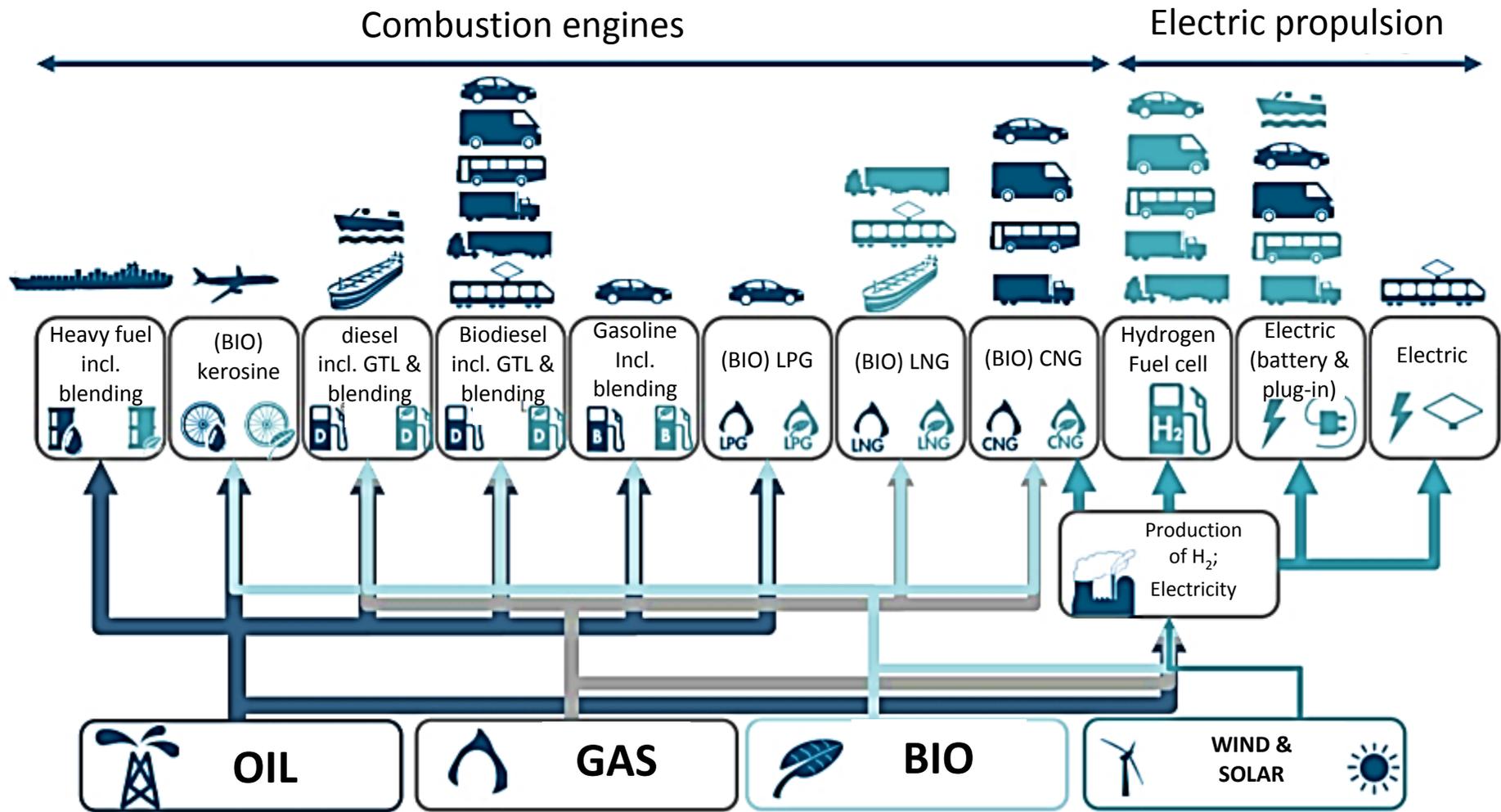


Figure 37: Overview of energy carriers and market segments
 Source: Translated in English from the Dutch Ministry of Infrastructure and Environment (de Wit, 2015)

According to Kruyt (2012), various options are available, such as a direct dual-fuel propulsion, dual fuel-electric propulsion, LNG-electric propulsion and Hybrid DF-Electric Propulsion. The best option for each vessel depends on annual sailing time, average power, the ship type and the sailing area (Kruyt, 2012).

Although still a fossil fuel, LNG is considered as an alternative fuel on diesel and heavy fuels. It is also referred as a transition fuel towards a cleaner IWT. LNG can be used as the only fuel on-board or in combination with diesel. The LNG engine can be completely for 100% running on LNG which is called mono-fuel. Most vessels in the market are however dual fuels whereas diesel is still used as ignition fuel. It needs to be said that the zero-emission fuel, the holy grail of alternative fuels, does not seem to exist (yet). Even if a vessel would be electrical, the electricity is generated according to the energy mix of a country's transformation sector which is still a long way from zero emissions. From well-to-propeller, there can be still emissions and greenhouse gases.

A technical report of the Joint research centre (JRC) of the European Commission (Moirangthem and Baxter, 2016) identified LNG and Methanol as most commonly considered alternative fuels for the maritime and IWT sector. Although, the cost associated with retrofitting the engine for Methanol has been reported to be less favourable compared to retrofitting to an LNG engine. Each of the two fuels have a biofuel counterpart Biomethane (Bio-LNG) and Biomethanol. The market uptake of the latter two depends on further technological maturation *and on the availability of cost-effective production technologies and environmentally sustainable biomass feedstocks* (2016:33).

Another possibility to reduce emissions is right-fitting or right-sizing, which means that several vessels have an engine that delivers too much power that is needed. An engine with a lower power, uses less fuel. Several authors (Panteia, 2013; Prominent, 2018) claim that an additional fuel reduction or emission decrease can be obtained by right fitting. On average, vessels tend to have indeed an overpowered engine. According to Panteia (2013), ships below 38m length have engines equal or below 220 kW. Ships with a higher length (38-55m) have engine up to 304 kW. Vessels above 110m have an engine with a performance that is higher than 981 kW (Table 47). The IVR database shows a high average value of kW for the main engine (4.2.B) than is regarded as necessary for the performance of the vessel.

CEMT Class	Beam (m)	Length (m)	Draught (m)	Load capacity (t)	Average installed propulsion (kW)
I	5.05	38.5	2.5	251-400	189
II	6.6	50-55	2.6	401-650	274
III	7.2	55-70	2.6	651-800	363
	8.2	67-73	2.7	801-1,050	447
	8.2	80-85	2.7	1,051-1,250	547
IV	9.5	80-85	2.9	1,251-1,750	737
V	11.4	110	3.5	2,051-3,300	1,178
VI	14.2	135	4.0	4,301-5,600	2,097
V/VI	11.4/22.8	170-190/95-145	3.5-4.0	3,951-7,050	1,331
VI	22.8	185-195	3.5-4.0	7,051-12,000	3,264

Table 47: Vessel types and average installed propulsion
Source: Panteia (2013)

The next part explains LNG more technical how it is structured, stored and transported. Afterwards, some problems related to LNG as a fuel for IWT are presented which are relevant to calculate the external costs and the benefits.

A. Technical definition of LNG as IWT fuel

LNG is stored on board, in a cryogenic tank, which is, according to Falck RISC (2015), between 40 and 160 m³. In IWT vessels, a tank of 40m³ is the current standard. The tank is up-deck in most cases or below deck as the MS Eiger-Nordwand (Danser, 2018) which puts a container on top of the extra – hulled tank.

LNG is a mixture of carbon hydroxide with a high percentage of methane gas (more than 91%). LNG must be stored under minus 162°C in special cryogenic tanks. For liquefying natural gas, an average of 50 MW of energy for each million tonnes of produced LNG is needed. A monofuel LNG will require two LNG tanks of m³. Indeed, the difference in volume between an LNG storage and a conventional diesel storage takes relatively four times the volume of diesel (including tank, tank room and fuel) to achieve the same energy content (Kruyt, 2012). Because of the cleaner spark ignition of the gaseous mixture than only diesel combustion, the engine needs less maintenance and is claimed to have a longer lifespan. The engine can also run entirely on diesel (Papagiannakis et al., 2010) but only the pilot (diesel) can start the engine.

There is also a difference in performance between a refitted or converted diesel Engine into a dual fuel. These dual-fuel engines offer the possibility to switch manually or automatically to the preferred fuel. In gas mode, it will usually be between 80-95% of LNG usage with 5-20% of diesel. In diesel mode, only diesel will be combusted. The ignition is started by the pilot (in this case diesel) and acts as a deliberate source of ignition for the combustion of the gaseous fuel-air mixture but contributes only a small fraction of the power output (Ashok et al., 2015). When running in gas mode, the engine works according to the Otto process where air intake is fed to the engine cylinders during the suction stroke. When running in diesel mode, the diesel fuel is fed to cylinders at the end of the compression stroke (Wärtsilä, 2018). The dual fuel has the advantage through combination of spark ignition (gas) and combustion ignition (diesel) to achieve a higher thermal efficiency because of faster burning, less toxic emissions and higher power density (Wattanavichien et al., 2011).

When natural gas is liquefied, the size of the gas shrinks (600 times smaller) which makes it easier to transport. At the end-destination, it can then be re-gassed for industrial or domestic use, or the LNG can be put on a truck that brings it to an LNG – fuelled vessel in need for bunkering. Natural gas can not only be liquefied (LNG) but also compressed (CNG). CNG is produced with approximately 200-250 bar and is stored under high pressure. To compress natural gas, an average of 6 MW of energy for each million tonnes per year of produced CNG is needed.

B. Known issues with LNG

The chemical structure changes over time and is highly dependent on the structure of the original gas and the liquefying process. The changing or “ageing” of the fuel is explained by the behaviour of light elements to vaporize sooner than other, heavier elements. Methane is the lightest element and the first one to leave. The storage of LNG emits organic carbons such as methane and ethane. It is also unavoidable that during the transport of LNG by a carrier, gas could be incidentally lost in the atmosphere (Oranjewoud, 2006). LNG also damps during the transport, which can be captured to be re-used or which is lost in the atmosphere. These damps are often referred to as boiled-off gas (BOG). During transport and production, energy losses are estimated at 5-8% of the total CNG and 10-15% of the total LNG until it reaches the consumer. (Valsgaard et al., 2004; as quoted by Holmegaard K. et al., 2010).

According to Rossert (1996), methane has a global warming power which is twenty times higher than carbon dioxide, but ten times less than nitrous oxide (N₂O) and 150 times lower than chlorofluorocarbons (CFSs). Methane slip may be prevented with a methane slip catalytic converter (Panteia 2013 in Wurster et al., 2014) but is not always included. Studies in the framework of the LNG Masterplan, stated that the greenhouse warming potential of methane is about 21 times higher compared to CO₂. This makes the methane slip in the natural gas supply chain, from well to the

liquefaction refinery and to tank-to-propulsion where several interfaces possibly emit methane, a significant challenge to overcome.

Some authors claim that the factor should be 25, while recent research shows that the factor should be 34 which virtually diminishes the greenhouse gas (GHG) reduction benefit of LNG (van Beek et al., 2017). Although, there is no consensus in literature about this factor, several values are tested during the CBA when taking into account the external costs.

LNG is a continuously boiling fluid which inflicts heavy burns in contact with human skin and reduces the quality of steel. LNG has an average energy density of 50% of diesel and therefore needs twice as much space for storage on-board for a comparable performance.

According to the World Energy Outlook Report of 2017, Special Focus on Natural Gas, of the International Energy Agency (IEA, 2018), the lower density of natural gas when compared to coal and oil, explains the relatively high cost share of transportation of the delivered cost. Gas transport infrastructure from well-to-wheel (in this case to IWT vessel) is very capital-intensive, and transporting gas includes volume losses as explained (boil-off on large LNG vessels, own-use in liquefaction plants and compressor stations, leakage in pipelines, methane slip). According to IEA, the transport over long distances is between seven and ten times more expensive than for coals and oil to deliver the same energy content.

C. Emission standards

The NRMM refers to the non-road mobile machinery regulation which covers emission standards of combustion engines installed in machines ranging from small handheld equipment, construction machinery and generator sets, to railcars, locomotives and inland waterway vessels. This regulation describes the emissions standards for engine-family¹¹⁵ and the type-approval procedures¹¹⁶ to allow them to be installed in non-road mobile machinery. The European Commission (2014b) presented an impact assessment concerning the review of the directive 97/68/EC on emissions from engines in non-road mobile machinery (NRMM) in view of establishing a new legislative instrument as a preparation for the recent NRMM regulation.

ARCADIS and RPA (Nwaogu, et al. 2010) conducted a study as part of the preparation for the revision of the NRMM where they compared the European emission standards with the ones used in the U.S. They made a distinction between emission limits for variable speed (VS) and for constant speed (CS) and evaluated the feasibility and associated socio-economic impacts of extending them while considering the option of alignment with the standards in the U.S. Nwaogu, et al. (2010) studied two harmonization options for the review of the NRMM. The first option was harmonizing with Stage IV limits for variable speed engines. The second one was harmonizing with existing U.S. Tier 4 limits. The latter option revealed practicalities in refitting American CS engines for the EU-market even if the same emission values would be used. While in the U.S., 60 Hz electricity supply is the output, in Europe it is 50 Hz, which entails necessary changes in refitting the American manufactured engine (e.g. new turbochargers, air intake system, fuel system).

Table 48 shows an overview of all identified possibilities to improve environmental performance of IWT in compliance with the upcoming regulation.

¹¹⁵ An engine-family is defined as a manufacturer's grouping of engines which have similar exhaust emission characteristics.

¹¹⁶ The type-approval procedure comprises the certification by the Member State of an internal combustion engine type or engine family with regard to the level of emission of gaseous and particulate pollutants.

Area	Innovation	Applicability	Decrease of energy consumption	Additional Costs (EUR 1000)	Payback time (years)	Infrastructure available
Technical	Father-and-son engine	New and retrofit	10%	150	7-8	y
	diesel-electric propulsion	Only new vessels	10%	200	10	y
	Electric propulsion	Only new vessels	10%	300	15	n
	Liquefied natural gas (LNG)	New and retrofit	No	New: 1,000 Retro: 1,400	16-20	Only trucks
	Particulate matter filter (PMF)	New and retrofit	No	500	n.a.	y
	Selective catalytic reduction (SCR)	New and retrofit	No	500	n.a.	y
	Flexible tunnel	New and retrofit	10%	60	1.5-3	y
	Optimized Hull form	New and retrofit	10%	150	3-4	y
	Weight reduction by composite materials	Only new vessels	5-15 %	Increase in hull costs by 30 %	10-15	y
Operational	Speed reduction / Smart steaming	All vessels	10-30 %	EUR 250 training course	0.1-0.2	y
	On-board information systems / Journey planning		10%	Low costs	< 1	y
	Optimal maintenance		5%	Low costs	< 1	y
Traffic & Transport management	Reduction of empty trips		high	No general quantification possible		y
	Improving interface in seaports		high			y
	AIS / RIS / Inland ECDIS		high			y

Table 48: Possible innovations to improve environmental performance of IWT

Source: Market Observation 2017, based on DNV GL (2015), Pauli (2016), Development Centre for Ship Technology and Transport Systems (DST), Hazeldine, Pridmore et al. (2009)

The main relevant finding of the assessment was that IWT was lagging and did not even reach stage III yet. Currently, emission stage 5 is adopted as the new standard starting from 2020 which differs from the standards in the U.S. Although still strongly aligned with US EPA tier 4 limits, the new NRMM limits include, for example, a particle number count and a methane slip calculation for both gas and dual fuel engines (Ponte, P., 2017).

6.1.2.LNG costs & benefits from literature

Since 2011, with the first dual fuel LNG-diesel MTS Argonon, several other vessels came on the market such as the MTS Ecotanker II and III (originally the Greenstream and Green Rhine) in 2013 which were the first 100% LNG or monofuels. The MTS Sirocco and the container vessel MS Eiger-Nordwand were both brought in operation in 2014. The MS Greenports 1 (2016), MTS RPG Stuttgart (2017) and the MTS RPG Bristol (2017) are also in operation. Other planned vessels are the MTS FlexFueller001 (bunkering vessel, 2018), MS Werkendam (2019) and another 13 remaining RPGs of the Plouvier group that are announced for 2018-2020.

A. Costs of the LNG vessel

In 2011, TNO published a report called “*Environmental and Economic aspects of using LNG as a fuel for shipping in The Netherlands*” which examined the emissions and greenhouse gas (GHC) of LNG for an inland vessel of 110m. The cost of an LNG engine and a fuel tank system is estimated to be two times

the costs of a conventional diesel design (TNO, 2011). An SCR catalyst for diesel engines only represents 25% of the additional LNG costs. The economic case for LNG depends on a lower LNG price compared to MDO, MGO and EN590 or what is also referred to as the LNG-diesel spread.

According to Kelderman et al. (2017), the capital costs are estimated and priced as mentioned in Table 49. These costs were calculated after a thorough analysis of the fleet and vessel profiles, together with trip up- and downstream.

Engine type	Minimum	Maximum
monofuel LNG above deck	EUR 1,882,825	EUR 3,152,925
dual fuel diesel LNG (new) above deck	EUR 1,441,662	EUR 2,200,170
dual fuel diesel LNG (refit) above deck	EUR 1,266,000	EUR 1,574,500

Table 49: Capital cost of an LNG engine

Source: minimum and maximum prices estimated for 11 ship categories, based on Kelderman et al. (2017)

Kelderman et al. (2017) made an ex-ante cost-benefit analysis for 11 vessel types with their own sailing profile. For a refitted tanker vessel of 110 meter with an LNG-tank above or under deck, the NPVs were negative if the payback period was shorter than 12 years with an assumed price difference between LNG and diesel between EUR 0.05 and EUR 0.35 based on one litre gasoil. The investment costs were calculated as additional costs of the application of LNG and compared with a common diesel engine and based on expert consultation without taking into account detailed costs such as maintenance costs, possible earnings and they only assumed increasing price difference scenarios. In all scenario's the study does not look at the entire cost structure of a vessel enterprise while it focuses on existing vessels that only need a refitted or new engine and not an entirely new vessel. They also considered the cash flow as the average annual fuel consumption multiplied by the price difference. Although very valuable as approach in addressing several detailed sailing profiles, the used CBA does not reflect the impact of an LNG investment on the business structure of an IWT vessel in much detail. Moreover, the condition of a new vessel was not included. Both the IRR as the NPV are not calculated from equity or enterprise perspective. They do not take in account a loan. Furthermore, capital values are given for the different considered vessels such as a 110m MTS which is estimated on EUR 5,027,240. The analysis of Karaarslan (2017) assumed a reduction up to 10% of GHG when switching from diesel to LNG. He assumed the lifespan of the investment to be 10 years with a residual value of 30%. One of the interesting findings was that the vessel needs at least a consumption of 500m³ of gasoil per year to earn back the investment which is quite a rough threshold.

Both studies did not show a reference case of a conventional vessel without the investment and did not provide the precise year when the costs were calculated. They calculated the price difference between EUR/kg for LNG and EUR/l for diesel. Another important issue, is that during these studies, it was not always clear if LNG dual fuel configurations would need after-treatment to comply with the upcoming NRMM with stage V. The analysis of the dual fuel engine was based on a diesel engine with emission standard CCNR 2 or the near equivalent euronorm Stage IIIA of the EU which is mutual recognized by both the CCNR as the EU. Now it is clear, that investments after 2019 will have to include after-treatment systems which do not have a return on investment. Finally, the calculation of the CO₂ equivalent factor of methane was calculated with factor 25 for each emitted gram which has consequences for the calculation of the external costs for GHG as developed in the CBA of this dissertation.

B. Benefits of the LNG vessel

LNG offers benefits in reducing PM, SO_x, NO_x and CO₂ compared to diesel engines. According to the TNO report (2011), the well-to-propeller (WTP) greenhouse gas is 10% lower than diesel fuel chains, although further benefits are possible by lowering the high methane emissions of the engines.

The most exposed and highlighted innovation in this field is the dual-fuel engine with LNG. According to Deen Shipping (2018), a dual-fuel engine (LNG-diesel) has the following benefits:

- Fuel supply: the estimated gas fields in the world allow a much longer supply than oil¹¹⁷.
- Reduction of air pollutants.
- Noise emission reduction: Due to the disappearance of the 'diesel throttle' and due to less severe explosions in the cylinders.
- Less lubrication oil: burning a blend of LNG-diesel, decreases the amount of carbons in the lubrication oil of the engine, which explains the lower cost of lubrication oil replacement than a conventional diesel-engine.

Another benefit is the lack of possible water pollution (gas evaporates) whereas accidental diesel spills contaminate water quality. There is also a potential reduction of port dues. Port authorities give reductions for cleaner vessels up to 30% (Rotterdam; 2014 in Karaarslan, 2015) but the effectiveness of these measures does not show any significant impact so far (Rijkswaterstaat 2013) and vessels with a CCNR 2 diesel engine (or stage III) get reductions.

The main private benefit of LNG is the reduced fuel price compared with diesel. The business case depends on the price difference or spread between the two prices and the expectation that especially diesel will increase in price. Fuel costs are more than 40% of the total annual IWT costs (PWC, 2013 in Karaarslan, 2015).

6.1.3. Conclusion of LNG literature review

The literature review defined the context for the case analysis of the LNG and explained what the known problems are with the innovation. Although, the literature review reveals that there are barriers for LNG related to infrastructure and regulation, it is perfectly possible that these conditions already changed. The literature also provides CBAs that offer insight for further analysis.

LNG is currently being sold on the IWT market as fuel. The fuel cost in the LNG case will probably present an extra challenge. Fuel costs have their own complexity (evolution on world market). In the case of LNG two kind of fuel costs (diesel and LNG) must be calculated while in the AV only one. Third, while the AVs in development are focusing on dry bulk or containers, the LNG is mostly aimed at tankers which is quite a different market. The following sub-questions can be partially answered for the LNG cases:

What is innovation in IWT and what are the main trends? LNG, although rather a (transitional) fossil fuel than a clean zero-emission fuel, is considered as an innovation in IWT as are all other identified alternative fuels. However only a relatively small number of LNG engines are sold, the number is growing as market uptake is slowly taking place. Complete diffusion is not reached yet. The methane slip and the effects on climate are a major issue for society and need to be analysed further. As regulation enforces less engine emissions and the fuel cost of diesel increases, several innovations can be identified, and more innovations will probably be developed to address these issues.

How can the innovation be analysed or measured? The case seems fit for a CBA as it is already been performed in literature during European projects. Although a refinement seems necessary. The possibility for applying the PEINPA is to be explored but the mentioned regulatory bottlenecks relate to PEINP. The current and potential diffusion of LNG in IWT can be measured with desk research through the IVR data-bank, LNG studies and news articles.

¹¹⁷ Concerning this claimed benefit, the evolution of supply depends on several factors that are price determining. Geopolitical stability, the size of production and the quality of the distribution are amongst these variables. According to the Shell LNG market outlook of 2018, there will be an expected shortage on the supply side of natural gas according to the forecasted global demand during the next decade which will probably boost prices. More significant changes in supply are expected with oil the upcoming decades.

When is IWT innovation successful or a failure? And what are the conditions that lead to failure or to success? Literature shows several possible barriers in relation with alternative fuels. All the examined literature analysed LNG for IWT in a setting with regulatory bottlenecks and were optimistic in the fuel price forecasts concerning the LNG and diesel price spread. Furthermore, the applied methane emission factor varies between the studies. The found CBAs were ex ante and did not give a detailed impact on the complete cost structure of a vessel.

Who are the relevant actors in the innovation? Several companies were identified that have LNG vessels. Other relevant actors are identified such as the European Commission with public funding, shipyards, research institutions and LNG distributors such as Shell. Port authorities provide discounts for LNG vessels.

What is (IWT) innovation policy and how is it organized and which role plays IWT innovation policy? Further research is required if the LNG diffusion is desirable for society despite public funding. Especially the methane slip still raises questions. The policy is not successful yet if the objective is to stimulate market uptake of LNG.

Which policy measures are applicable for IWT? In case of LNG, the NRMM is already an important driver for alternative fuels in general. Another driver is the (public) funding possibilities of LNG in IWT.

Now that the literature concerning LNG is reviewed, the following sub-section introduces the SIA, CBA and the PEINPA of LNG or more precise the dual fuel vessel that uses mainly LNG with diesel as ignition fuel and which is more diffused than the monofuels.

6.2.Setting of the analysis of LNG-D

Following the typology of Arduino et al. (2011), Roumboutsos (2013) and Sys et al. (2016), the innovation of the LNG vessel with a dual fuel engine, is a technological, managerial, organizational, cultural – business which is currently situated in the implementation stage. It is an incremental change to the business and is mostly aimed at the tanker segment of IWT. However it is currently not successful (yet) as diffusion is rather limited. There is an international network of private firms that were involved in this open innovation and its components (e.g. cryogenic tank). Furthermore, public actors supported the innovation (Table 50).

The total number of identified built and almost built LNG ships (dual and 100%) is identified at 23 vessels in 2018, whereas 20 vessels are intended to transport liquid bulk. Those tankers are mainly used in the ARA region and on the Rhine. Only two vessels are identified to use only LNG while the other use LNG in combination with diesel.

Type of innovation	I TECHNOLOGICAL	II TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - BUSINESS CHANGE	III TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	IV MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	V POLICY INITIATIVES (MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE)
Implementation level	Initiation		Development		Implementation
Degree of Innovation	Incremental	Modular	Systemic		Radical
Level of Success	Success		Failure		Not Available

Table 50: Innovation typology of the dual fuel LNG-diesel inland vessel
 Source: applied typology derived from Arduino et al. (2011), Roumboutsos (2013) and Sys et al. (2016)

The innovation has an impact on the organisation of the vessel concerning fuel bunkering. Only a few locations allow the bunkering of LNG by truck on-shore. During the research a bunkering facility was

being built in Germany and a bunkering inland vessel was planned. However no other infrastructure was identified. The bunkering also needed an additional safety checklist and crew required special training and certificates. It also requires a more complex set of pre- and post-bunkering procedures. LNG did not change the IWT market, but rather, although slightly, the business of bunkering fuels. This change is incremental and does not radically push diesel outside the business (yet).

Although the innovation is developed by private firms, the main drive behind implementing alternative fuels, is environmental policy such as the NRMM as explained in Chapter 4 and which is further analysed by the SIA and the PEINPA.

The SIA explains and investigates the barriers of the dual fuel LNG vessels from a consumer perspective which is applied in the following part.

6.3.SIA of LNG-D

The results are comprised of literature review, interviews with innovators and expert panels. The scope is the Rhine and ARA region (Amsterdam-Rotterdam-Antwerp) where all LNG vessels are active.

6.3.1.Current situation

The regulatory barriers are recently removed in the European IWT for the use of LNG as fuel. Despite this removal the enrolment of LNG-engines on the market of IWT is slower than originally anticipated. In the segment of newly built tankers of minimum 110m in the Rhine fleet since 2011, the number of newly built LNG vessels is slowly growing. Of the 206 identified tankers that were built since 2011, seven were LNG-vessels or 3.4% of the segment of minimum 110m. As the price spread becomes more significant (increasing diesel prices compared with LNG prices), more infrastructure is made available and as the deadline of the NRMM comes closer, more investments in alternative fuels are expected, but necessarily in LNG. Recent findings have indicated that there are environmental issues with LNG related to the emission of methane as explained by this SIA and taken into account during the cash flow analysis. Several funding programs from public actors such as the EC, ports and even Dutch provinces were identified during the previous stages of development. Large companies such as Shell also play a significant role in diffusing the innovation.

6.3.2.Initiation period

The first known operational vessel in IWT with LNG is the MTS Argonon which was finished in 2011. The chemical tanker has two engines (*Caterpillar dual fuel 3512* with 1,119 kW/1,521 bHp and 1,600 rpm) with dual fuel technology, which claims to use 80% LNG and 20% diesel. The vessel was the first of its kind with an LNG-diesel-Electric propulsion. The tanker has a length of 110m, width of 16.2m and a tonnage of 6,100. The cryogenic tank system is put on the middle of the deck.

Drivers of the innovation at this period, are primarily large LNG suppliers that want to enlarge the existing LNG market such as Shell. The usage of LNG as a vessel fuel is a niche market that is dominated mainly by Shell, that also has a significant share in the global supply chain of LNG. Secondary are the engine manufacturers that developed smaller engines based on the same principles as applied in maritime transport for IWT. Caterpillar was the first one to sell an LNG dual fuel engine that was tailor-fitted for IWT. Other manufacturers such as Wärtsilä would soon follow.

During the initiation phase, regulation was not set to use LNG as a fuel for IWT. Regulators in IWT had the advantage that LNG was already used as a fuel for seagoing vessels and that this could provide an inspiration to fill the gaps in the European legal framework. The Argonon was used as a first example to create CCNR and UNECE regulation for usage as a fuel, training, technical requirements and standards for crew competences which is clearly a first-mover advantage. The first followers such as the Sirocco, and the Eiger were the basis for refits and all had specific designs. The Greenstream and Green Rhine were the basis for regulators to implement standards for monofuels (100% LNG). In the

meantime, all these vessels had to be exempted for the existing regulation by an admitted temporary derogation. The Ecoliner from Damen Shipyard was the third mono-fuel vessel. This ship was finished under compliance of the new installed regulation. The derogation for the Argonon to start operations on the Rhine was admitted on 21th January 2012 by the CCNR or as quoted from the press release:

On the basis of a recommendation under Article 2.19 (3), of the Rhine Vessel Inspection Regulation ("RVIR"), the provisions of its Articles 8.01 (3) and 8.05 (1), (6), (9),(11) and (12) are to be waived in respect of the self-propelled tanker "Argonon" until 30 June 2017. The use of LNG is considered to be sufficiently safe if the conditions laid down by the CCNR in its recommendation are observed at all times. These conditions set a strict framework for the various specific aspects connected with using a fuel of this kind, such as the method of construction and the classification of the vessel, the regular inspection and maintenance of the LNG propulsion system, the procedure for fuelling, and the training of the crew. The vessel' owners are also required to send an annual assessment report to the CCNR Secretariat for circulation to the CCNR's MS.

This derogation made it possible for the MTS Argonon to start activities and to prove to the regulator the safety and performance of the dual-fuel engines. The regulation was changed in 2016 to allow dual-fuel engines on the Rhine. The flash-point of fuels for IWT vessels was before 2016 not allowed to be lower than 55°C which was only fitted for diesel (e.g. art. 8.01, RVIR¹¹⁸).

In both the European (including the national transpositions) and CCNR regulations, LNG was not allowed as a fuel without exemptions or derogations. LNG was not included as cargo in the list of substances of the ADN on the UNECE level (LNG Masterplan, 2015). Therefore, training or skills were not described to handle LNG in a safe manner.

In the initiation phase, except for the ports of Antwerp and Rotterdam, LNG bunker vessels, truck-to-Ship (TTS), ship-to-ship (STS) and Terminal-to-ship via pipeline (TPS) bunker operations also suffered from a lack of regulation and were not allowed. The Ports of Rotterdam and Antwerp have adapted changes in their by-laws to make bunkering possible for IWT. It was already described for seagoing vessels and now also for IWT. The rest of the Rhine Corridor does not show any location for bunkering in this phase. The two tanks of the two mono-fuel vessels are strongly depending on Rotterdam and Antwerp to perform TTS bunker operations. The bunker operations require a pre- and a post-process and are certainly not that easy as conventional diesel or gasoil.

Another strong element which could lead to success, is the presence of a strong network of sector organizations that support the innovation. Specialized organizations such as verification agencies actively support the innovation through study work, lobbying at regulators and attracting public funding. The EICB, CBRB and others play a role in the initiation of LNG in IWT. Several projects with public funding were conducted with a focus on LNG (Prominent, LNG Platform, Promovan, LNG Masterplan, etc.) which benefits the initiation and further development. The knowledge institution network provides necessary information to regulators and improves the insight in the technology for IWT. Soft regulation such as subsidies are available and are often half the extra cost (of a diesel engine) to invest in an LNG engine. Subsidies are at different levels available, but mainly in the Netherlands (national, provinces and port) and from EU-funding.

In the initiation phase, IWT has no large network of bunkering facilities for LNG as for gasoil or diesel. Bunkering operation routines are less familiar for most crews, which demands an increase in transaction costs during this phase (planning, safety, training, etc.).

Not many vessel owners have the capability to invest in LNG engines and the main trend is to renovate the existing engine as long as possible. Furthermore, the dry cargo, which is the largest segment of IWT, shows little interest in the technology. Expect for the MS Eiger, no dry cargo vessel was identified

¹¹⁸ The regulations for LNG fuelled inland waterway vessels are governed by the CCNR Rhine Vessel Inspection Regulations (RVIR) and Rhine Police Regulations (RPR). The EU directive laying down technical requirement for inland waterway vessels extends the RVIR to apply on all EU inland waterways (LNG Platform, 2015)

during this phase. The reduction of cargo space because of the relatively large LNG tank (on a dual fuel, 40m³, mono-fuel 80m³) and the lack of infrastructure, regulation and the perceived danger are factors that prevent market uptake. The perceived danger can be considered a cultural barrier, which can be removed by effective dissemination of safety procedures and training. The barriers concerning reduction of cargo space and the perceived danger are less present in the tanker segment. Configurations with above-deck tanks lead to less cargo space reduction. The perceived danger is less of an issue for crews that have a strong familiarity in dealing with dangerous goods.

Another barrier for market uptake in the initiation phase is the ageing process of LNG. Liquefied natural gas is more effective for ships that are in continuous operation with preferably long distances and sailing hours (as explained in the case related literature review). This also explains why larger vessels with frequent operations in the tanker segment of IWT are more attractive for the first wave of LNG. A more important barrier in this segment are the funding possibilities. The tanker segment in Europe had the last decade a cold (without subsidies) phasing-out of single hulled vessels. The relatively expensive renewal of the fleet also included the installation of engines that comply with the regulatory standard of CCNR II and EU stage IIIa (only a few ships were refitted into double-hull and are assumed that they kept older engines). For small- and medium-sized enterprises in the tanker segment, it could be more difficult to invest in new engine technology, especially after the double-hullization operation and when there is already a relatively young engine on board. Moreover, the initiation phase shows no SME finding its way to subsidies for LNG. These capability challenges explain partially the slow pace of LNG in this phase towards market uptake.

6.3.3.SIA Matrix initiation period

Table 51 shows the identified failure and success factors for an LNG dual fuel for the discussed initiation period. These factors are linked with each identified actor within the innovation network. Public and/or private actors need to enrol LNG masterplans for bunkering facilities on-shore. Funding for SMEs which comprises the largest part of the fleet still does not follow. The regulation of NRMM will oblige those who need to install a new engine that the exhaust complies with Stage V of the regulation. It can be expected in order to comply with the regulation that more Stage V engines will find their way to the market in 2019. The matrix is applied on LNG dual-fuels. The black shaded areas present the areas where system failures could be observed, and which are linked to the actors that are related to the cause of these system failures ¹¹⁹.

In the initiation period, there is a lack of sufficient infrastructure, hard rules, lock-in effects (strong network) and a capability barrier on the demand side. There are subsidies available but mainly for larger companies that have sufficient funding to calculate the risk and are sufficiently linked with the network. On the side of the manufacturers, there is infrastructure to build engines which are fitted for IWT. Sector organizations are aligned and take part in subsidized research and projects. There is a strong network effect between ship yards and the business case which can lower the ship yard choices and has lack of risk spread. There is a number of knowledge institutions active in research and design as are standardization bodies (in this case CCNR) that are giving derogations. There is funding available for research and pilots.

In all innovation phases there were no success or failure conditions identified that could link shippers and forwarders. It could be the case that this group does not shown any resistance towards the innovation or is not responsible to provide success conditions. Nevertheless, the area in these columns remain unshaded for now. The role of the shippers and forwarders invites further research.

¹¹⁹ Next to the InnoSutra project as referred to in the Literature review, Woolthuis et al. (2005) also refers to SIA.

Institutions	Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure					
Hard Institutions					
Soft Institutions					
Weak Networks					
Strong Networks					
Capabilities					

Table 51: Systems Innovation matrix of the initiation phase of an LNG fuelled IWT vessel

Source: based on Aronietis (2013). Legend: black shaded cells represent identified failure factors. Grey shaded figures show identified success factors

6.3.4. Development period

Every additional ship that followed the MTS Argonon also had to request for a derogation at the CCNR in Strasbourg and to address the ADN committee in Geneva because of the differences between the LNG vessels¹²⁰. Some of them were new designs (TMS Greenstream, Green Rhine), others were refits of an older vessel (e.g. MTS Sirocco, MS Eiger). Most of them are tankers but also a container barge (with possibility for barge convoy) was included. Other manufacturers such as Wärtsillä, are coming on the market and more vessels are ordered. Findings of studies are positive for the further development of LNG as a fuel.

However during the development period, extra bunkering facilities as agreed in the LNG Masterplan and by several ports, find difficulties to be implemented. The infrastructure shows a chicken-and-egg problem. Where relatively high investments are needed to install on-shore bunkering facilities for IWT, investors show reluctance because of the absence of critical mass at demand side. Investing in supply when demand is not there yet to develop a positive business case, causes a delay in the development of the LNG infrastructure. The European Commission's Clean Power for Transport initiative, which requires LNG bunkering along the inland waterways of the core TEN-T network by 2025, has not been successful yet. Several presentations during the LNG platform event in Strasbourg in 2015 by port officials (Antwerp, Strasbourg, and others) showed plans of bunkering facilities for LNG. The general feeling at that time with the relatively high diesel prices at the background which were expected to even increase, caused a strong optimism among several actors. Since then, only a few vessel owners decided to invest in this fuel type and still no on-shore bunker facilities have been built at the moment of this research. Only the number of approved sites to allow truck-to-vessel bunkering has slightly increased.

As explained by van Hassel et al. (2017), the tanker fleet does not adapt that easily to market conditions. The relatively low freight rates are partially explained by overcapacity on the supply side. The double-hull policy transition period since 2008 caused overcapacity because new double-hulls with larger capacity were introduced next to remaining single-hulls that were usually free of loan and relatively cheaper to rent, which caused a downwards pressure on the freight rate. Furthermore, the negotiation power of the individual ship owner, as elaborated in the case research of e-barge chartering, is generally weak to negotiate higher rates. When a bankruptcy occurs, the vessel is usually sold under the original value and remains active¹²¹. The market strongly depends on the demand for

¹²⁰ There is hardly any standardization to be found in the inland navigation, every ship design has proper features. Only broad but strict safety and technical requirements give a certain level of standardization. Vessels are more comparable with houses than with cars.

¹²¹ The Greenstream and Green Rhine were sold for less than EUR 3,000,000 against a building price of almost EUR 15 million and are still operational.

transport and must compete not only with other vessels but also other modes. The economic crisis of 2008 also had an impact on IWT with less demand and lower freight rates.

In liquid cargo (40% of the market) as well as in containers (45% of the market), time charters are often found of which half are long-terms contracts with an average duration of 2-3 years. In case of the LNG vessels, the contracts have a duration of 7 years and are mostly with Shell (CCNR, Market Observation, Annual report 2017). Nevertheless, the spot market remains very important for the tanker market. One of the leading companies in bunkering inland navigation vessels is PitPoint B.V. which is a subsidiary of TOTAL-FINA, one of the major competitors of Shell. In the latter case, PitPoint of Total-FINA buys LNG from Shell and bunkers vessels that are sailing for Shell. The fuel prices of conventional fuels were lower than predicted in the initiation phase and the spread (when looked at in kg and litre) between diesel and LNG was on certain moments rather negligible, which made the business case vulnerable and less attractive.

From a regulator perspective, at the end of the development period, the regulation was adapted sooner than anticipated by different studies. The regulators made it possible to accept a flashpoint of -162°C and to create standards for training and crew requirements to handle LNG as an IWT fuel in 2016. The UNECE accepted LNG as a dangerous cargo and adopted the ADN in 2018. Bunker vessels with LNG in IWT also received a legal framework to operate.

So far, the development period of the LNG inland vessel is descriptively analysed. These early findings are further investigated by applying the SIA Matrix on the development period of the innovation as explained by the next part

6.3.5.SIA Matrix development period

Table 52 shows the SIA matrix during the development phase. Infrastructure is still missing, but more TTS locations are allowed. The pilot vessels received a derogation and the adjustment of regulation is proceeding in this stage. The strong network lock-in effects are still in place and the focus lies mostly on the tanker market. The price spread between LNG and diesel has shown strong volatility against most predictions and made the business case vulnerable and poses an extra barrier in capabilities.

The implementation of onshore facilities in Antwerp and other places has slowed down because of difficulties in finding a private partner. The sector organizations, standardization bodies are still in favour to endorse LNG as fuel and the derogated pilot vessels are positively being appraised by regulators but as long as there is no consolidated regulation, the innovation stays uncertain and the regulatory barrier remains. There is still a strong network effect with Shell as being the most important charterer with fixed contracts. However at the most locations to unload or load, there is no bunkering infrastructure and here TTS is needed.

Institutions	Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure					
Hard Institutions					
Soft Institutions					
Weak Networks					
Strong Networks					
Capabilities					

Table 52: Systems Innovation matrix of the development phase of an LNG fuelled IWT vessel
 Source: based on Aronietis (2013). Legend: black shaded cells represent identified failure factors. Grey shaded figures show identified success factors

6.3.6. Implementation period

In this phase, the innovation has a regulatory framework and can be bought from the shelf without the need for a derogation. LNG as a fuel for IWT has received a legal basis but the emission standards have changed with the update of the Non-Road-Mobile Machinery regulation. As European policy becomes stricter on emissions in all modes, the upcoming NRMM regulation of the European Commission goes further than what current engines on the market can provide according to several branch organizations. This is an extra drive for the implementation of alternative fuels, but again barriers seem to slow down market uptake.

Although the LNG fleet has doubled (with the order of the Plouvier Group for 15 dual fuel vessels), the envisaged market uptake after the regulatory bottleneck would be removed, is not yet taking place. The infrastructure of bunkering is still truck-to-ship (TTS) but more locations are being allowed (Ports of Mannheim, Cologne, Moerdijk, Strasbourg and Basel). The realization is backed by the project Breakthrough LNG Deployment in Inland Waterway Transport which is co-financed by the European Union's Connecting Europe Facility. Bunker vessels are being built but with the focus in bunkering maritime vessels. Dedicated and smaller bunker vessels for IWT which exist for conventional fuels, are not yet seen.

More knowledge is gained by further research and improved measurement concerning the methane slip and the impact on climate change, which urges engine manufacturers to solve this problem. As the European Commission tends to evolve to a zero-CO₂ policy, LNG will be losing its appeal as long the methane exhaust is not tackled. Recent findings (van Beek et al., 2017) of the Intergovernmental Panel on Climate Change (IPCC) consider the impact of CH₄ not 25 times worse than CO₂ but 34 times worse, diminishing the claimed greenhouse gas reduction during the initiation and development period of the LNG as fuel for IWT.

The price spread has increased but the geopolitical situation shows several uncertainties. The strategy of OPEC and Russia is an important determinant next to the development of technologies that allow relatively cheaper oil and gas fractioning, exploration in remote and formerly unreachable depths and pre-salt layers, the political stability of the Middle East, the global demand of emerging economic giants in the Orient and the breakthrough of competing fuels, are also uncontrollable variables that will shape the oil and gas price and thus the spread between them. The price of conventional fuels could also drop because of lower demand, which could lead to higher prices of LNG or other alternative fuels that experience higher demand and vice versa. There are so many scenarios possible which makes any forecast challenging. A fuel-based business case is therefore vulnerable because of the high uncertainty. This insight has made several potential investors less enthusiastic.

Subsidies are still available and dual-fuel engines with 90% LNG and 10% diesel are coming on the market. The technology is being disseminated as are the practices and experiences by the rest of the fleet. It is still clear that the LNG is mainly focused on the larger vessels in the tanker segment of IWT which is a niche in a niche market. The small size of the market can jeopardize further market uptake. The size of the tanks cannot easily be reduced, but the electrical drive allows the placement of the tank and the engine anywhere on the vessel.

The freight rates of the tanker segment are slightly increasing because of higher demand but especially because of longer low water level duration in 2017 and 2018, which could offer a window of opportunity, also for the small vessel owners, to invest in more fuel or engine innovation. The phasing out of the single-hull vessels is coming to an end and hardly any single-hulls are left in the segment above 110m long vessels.

6.3.7.SIA Matrix implementation period

The innovation is now ready for implementation and market uptake and is at the beginning of the implementation period. Failure factors are still present (Table 53). Regulation is adjusted to allow further implementation of LNG.

Institutions \ Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 53: Systems Innovation matrix of the implementation phase of an LNG fuelled IWT vessel

Source: based on Aronietis (2013). Legend: black shaded cells represent identified failure factors. Grey shaded figures show identified success factors

In this period, new research shows the underestimation of the methane slip and the effect on climate change. The European Commission is starting to express more interest in zero carbon emissions because of the Paris declaration and moves forward with a more stringent stage V. This could influence public funding (subsidies), however this is not the case for now. As the market becomes larger, more customers are expected to find their way to LNG as a fuel, but for many VOs the cost of an LNG – D engine and installation stays relatively too expensive.

The subsidies did not find their way (yet) to the majority of the market, but sector organizations (KBV and the greening consultant) and other actors such as EICB (e.g. total cost of ownership model) can promote LNG and other greening options and are filling the gap as intermediary support for smaller individual VOs. Furthermore, the LNG engine and installation, as more engine builders arrive on the market, could become relatively cheaper.

6.3.8.Discussion and initial conclusion

As in the AV case, the typology and the SIA provide important first insights. The following findings can be identified:

- Most relevant actors are LNG providers such as Shell and Total-Fina; (semi) large companies such as Daemen, Jaegers, Danser and Plouvier; ports such as Rotterdam and Antwerp; Provinces such as Zuid-Holland (subsidies); research institutions (e.g. EICB) and verification agencies; public actors such as the CCNR, CESNI, EC (including funding) and UNECE (standards and regulation); Engine manufacturers (such as Wärtsilä)
- The price spread between LNG and diesel is a key element for a company's business case;
- The still limited diffusion of the innovation is mainly in the tanker segment of IWT which is a relatively small part in IWT
- The issue of the methane slip and the discussion of the methane emission factor
- The importance of a fixed contract
- Infrastructural issue (chicken-and-the-egg)

The later finding refers to a chicken-and-egg problem which is identified in all the periods of the innovation. Whereby infrastructure investors are reluctant to build onshore facilities with relatively high sunk costs (liquefaction plant, pipelines, large tanks, etc.), only the truck-to-ship bunkering is finding its way in several ports (during this research).

Giving subsidies and developing infrastructure masterplans for alternative fuels such as LNG are two specific ways to give vessel owners the incentive to invest in these kinds of technology as long as diesel prices and its performance (still highest energetic density in a non-cryogenic vessel storage during non-operation) explain partially the relatively longer return of investment schemata of alternative fuels. However as new research reveals a smaller reduction of emitted GHGs by LNG vessels, it could be the case that social benefits are too low to justify any subsidies from a welfare-economics perspective. This is further analysed and explained during the CBA with the calculation of external costs.

For now, smaller medium-sized enterprises with usually one vessel hardly find their way to greening technology such as LNG. The market remains small and limited to larger firms in the tanker segment. Other segments seem not to follow despite the claimed successes of the Eiger and others.

Although the dependence of the price spread between LNG and diesel has proven the vulnerability of the business case, LNG still has a large potential, as many expect an increase of the conventional fuel prices (Prominent, 2015). In the case of the dual fuel engines, although strongly disagreed by the dual fuel vessel owners, the switch can easily be made between diesel and LNG. When the price of LNG is too high or when LNG bunkering is not feasible or on time because of infrastructure problems, the vessel is perfectly able to solely run on diesel to continue operations.

Another potential problem is the possible underestimation of operational costs. At this moment, most bunkering happens by trucks adding to more transaction and external costs and making the energy supply relatively more expensive. The truck-to-ship bunkering can be further investigated during the CBA.

To summarize, the positive business case depends on the price spread next to the fixed contract reliability of both parties, frequent operations, the implementation of infrastructure, subsidies, technological reliability, access to specialized shipyards and adapted regulation. The further market uptake depends on the necessary capability of the vessel owners and dissemination of experiences and findings to remove any cultural biases or safety concerns.

The relevance to the RQ of these findings will be shown after the more detailed analysis of the innovation conditions such as infrastructure, institutions and interactions in the following part.

6.3.9. Innovation conditions of the LNG-D

The barriers were briefly identified and situated in the initiation, development or implementation phase. A more detailed approach is now conducted, and the barriers are classified according to infrastructure conditions, institutional conditions such as regulation and interaction conditions such as strong network effects. The SIA matrix links these barriers with the actors within the innovation network.

A. Infrastructural conditions

The LNG Masterplan for Rhine-Main-Danube of the European Union's TEN-T program (EC, 2015b) tried to quantify the possible required LNG fuel infrastructure along the Rhine river corridor to meet future fuel demand. Several private players already are in operation in supplying seagoing vessels with LNG such as GDF, SHELL and LNG Europe.

There is an operational production and distribution network of LNG as a fuel on a global scale such as liquefaction plants, regasification facilities and terminals. Storage facilities capacity varies approximately from 160,000 m³ to 200,000 m³ (EC, 2015b:17). As more masterplans and LNG hubs are being developed in the main ports of the Rhine corridor for both maritime and inland navigation, the infrastructure problem or lack of sufficient facilities will gradually be dealt with, but as shown in a slower pace than intended or envisaged.

Even dual-fuel bunkering is a problem where no regulatory framework is at hand to allow simultaneous bunker operations (diesel and LNG on the same time). Although bunkering by TTS only takes one hour

for one tank of 40m³ (LNG Platform, 2015), bunkering with one of the numerous bunker vessels such as shown in Figure 38 can be performed during sailing without inflicting waiting or idle time. Next to more transaction costs, the bunkering cost is relatively high of LNG TTS bunkering within the currently existing bunkering framework.



Figure 38: Bunkering ship-to-ship of gasoil in operation during sailing
 Source: www.aukevisser.nl

It seems to be rather unadvisable to allow LNG bunkering as shown in Figure 38 during sailing. The risk of gas escape could be considerably higher than on-shore TTS because of the lower stability of the coupled vessels. The process of LNG bunkering is also much more complex than with conventional fuels, as shown in Figure 39.

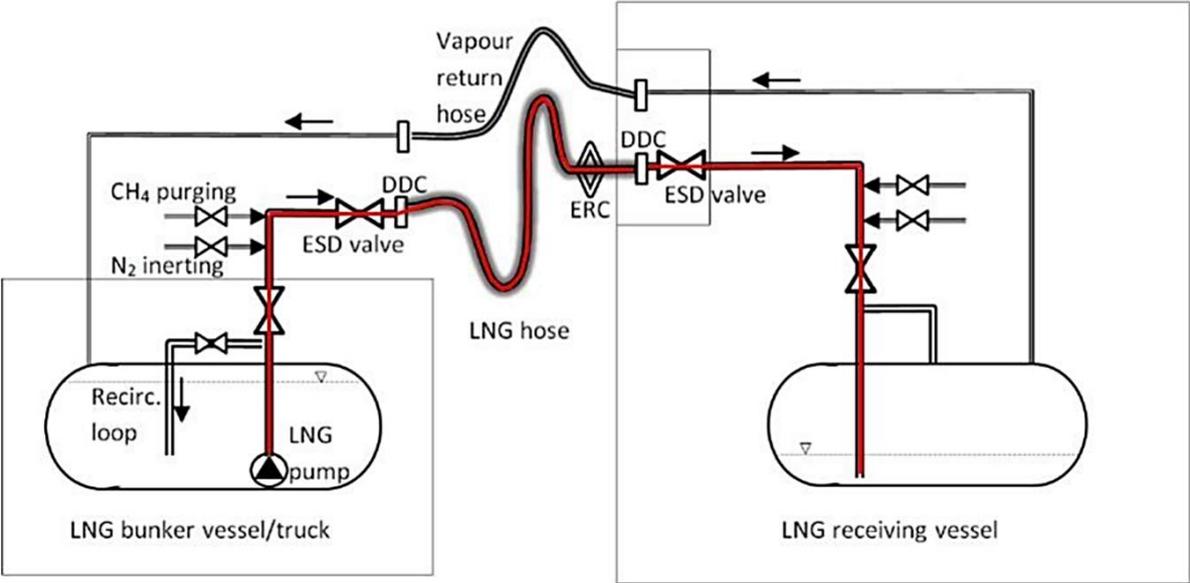


Figure 39: Bunkering process of LNG from tank to tank
 Source: LNG Masterplan 2015, DMA, “North European LNG Infrastructure Project – A feasibility study for an LNG filling station infrastructure and test of recommendations”, (March 2012) ¹²²

¹²² http://lngmasterplan.eu/images/D_231_LNG_Bunkering-Regulatory_Framework_and_LNG_Bunker_Procedures_v2.0_FINAL_2015-2-5.pdf

As with bunker operations with gasoil, there are also Emergency shutdown valves (ESD) in the bunkering system of LNG. The main difference here, is that if natural gas escapes, the slip is colourless and odourless and monitored with the height of the tank pressure. The bunkering uses dry-disconnect (DDC) or drip-free couplings, which connect the loading arms or hoses to the ship's bunker connection.

The Emergency Release Coupling (ERC) or dry break-away coupling is activated in case of excessive motions. CH₄ (methane) purging, N₂ (nitrogen) inerting and cooling operations are part of the generic bunkering process (DNV, 2014). Before bunkering can start, inerting is needed in the connected transfer system whereby moisture and oxygen is removed. Inerting is necessary to avoid ice in both the tanks and the bunker lines and pump pipes. Bunker lines and pump connections must be precooled to avoid LNG boiling and again be made inert. The connected system can now be purged to remove remaining nitrogen. After bunkering, the lines must be drained to remove remaining LNG (DNV, 2014). The LNG bunkering operation needs a vapour return equipment to control the pressure in both tanks where natural gas is sent back to the supplying storage tank.

The process described above is simplified in order to introduce the main operational steps. In reality, many more operations will be conducted before and after bunkering, including mooring of the vessel(s), pre-bunker system and ESD tests and filling out the required checklists. The latter is similar to the conventional bunkering (LNG Masterplan, 2015) next to bunker procedures, emergency stop facilities and personal protection equipment.

The procedures for conventional bunkering are mostly quite straight forward and often not mandatory. A special approval with a contingency planning in case of calamity, is hardly needed for conventional bunkering from TTS or often neglected. The compatibility between the truck and the LNG vessel should always be checked, while more standardization is common in conventional fuel distribution. Another difference in bunkering procedures is human contact with the substance. Conventional fuels do not inflict burns as cryogenic substances do (LNG Platform, 2015). Other disadvantages are the extra bunker rates of LNG (distance related from LNG hub to ship) and the possible restriction on SIMOPS (Simultaneous operations) for dual fuels which could cause longer and stationary bunker times.

According to Mariani (2016)¹²³, the total CAPEX of a refuelling station for LNG and CNG combined on-shore cost in the range of EUR 850,000 and 1,150,000 without the cost of land acquisition. One of the reasons to explain the relative height of the CAPEX, is that many components are sold on a case-by-case basis. Further developments could provide a decrease of average prices.

Figure 40 shows the difference between the installed distribution network of diesel and other conventional fuels. The liquefaction processes as well as the lack of distribution and bunkering options, add additional steps and complexity compared with the conventional fuel network, which is a barrier for the diffusion of LNG. Hub prices through on-shore stationary facilities could become cheaper than paying for the extra cost of truck bunkering which depends how far the vessel is located from an LNG terminal (Zeebrugge, Rotterdam or Ruse).

As most plans of on-shore facilities (LNG Masterplan, 2015; Prominent, 2015) include also bunkering of trucks driving on LNG, there is a positive spill-over effects between inland navigation and other modes. This also must be taken into account by potential investors when discussing the critical mass of consumers needed to make the facility profitable.

Another challenge lies in the different policies between countries. In the Netherlands, a truck is allowed to carry 21 tonnes of LNG. In Germany, this is only 18 tons. Furthermore, it is forbidden to drive into tunnels. Drivers of the trucks are allowed to assist in the bunkering operation and in the paper work (PitPoint B.V., 2018).

¹²³http://lngbc.eu/system/files/deliverable_attachments/LNG_BC_D%203%208%20Cost%20analysis%20of%20LNG%20refuelling%20stations.pdf

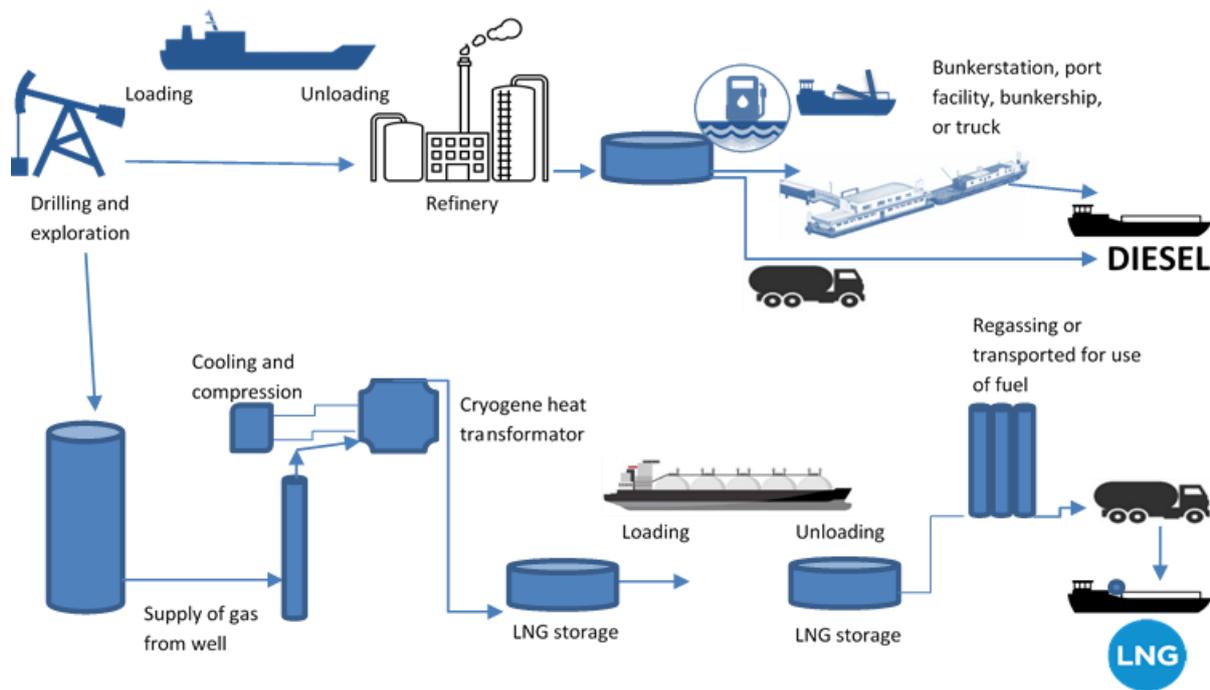


Figure 40: The LNG supply chain compared with diesel for IWT bunkering
Source: based on Oranjewoud (2006)

B. Institutional Conditions

The main drivers behind the development of cleaner alternative fuels and propulsion, are stricter regulation and the price increase of conventional fuels as explained. The former concerns hard rules such as technical regulation and emissions standards, while the latter concerns financial incentives such as subsidies which are considered soft rules.

B.1. Hard rules

The EU has implemented standards for emission since 1998 with the first stage I and II engines (Directive 97/68/EC, Exhaust emissions¹²⁴). The scope of the EU regulation was first not intended for IWT. Before the EU regulation, the emission standards were regulated by the CCNR. Along the regulatory process, both institutions have developed a closer cooperation. The date of the new NRMM stage V engine will be 1 January 2019 for all vessels with a power between 19 and 299 kW. One year later, the engines will follow for vessels with a power above 299 kW. The engines must be type-approved in both cases one year in advance. No engine replacement provision is included in the regulation for IWT. Only new engines must comply after the placing of the emission standards on the market or the policy implementation date (VDMA, 2017).

The development of LNG as a fuel originates from the boiling-off gasses that can be used in combustion engines. The LNG fuel for IWT, as we know it today, was developed at the end of the nineties, but the idea of using LNG for IWT took approximately ten years according to some expert interviews from idea towards development, implementation and regulation.

¹²⁴ Comprised drilling rigs, compressors, construction wheel, loaders, bulldozers, non-road trucks, highway excavators, forklift trucks, road maintenance, equipment, snow plows, ground support, equipment in airports, aerial lifts, mobile cranes, agricultural forestry tractors

Emission policy can be classified in three groups (CCNR, 2017, Market Observation) such as:

1. Technical: improvements related to the vessel design or equipment, propulsion system or use of alternative fuels.
2. Operational: related to speed reduction by better planning, ecological slow steaming, use of RIS and other systems, maintenance.
3. Transport management: logistics organization of supply chain, optimal logistics planning can lead to emission reduction.

Legal barriers to enrol LNG are pointed out by the Prominent study (2015-2018). They could be vessel type-specific, fuel-specific or operational (e.g. flashpoint regulation below 55°C of CCNR regulation) and are different at national level, EU level or even locally (Bastein, Koers et al., 2014; DNV GL, 2015; Panteia, 2013; Prominent, 2015). However as the regulatory bottleneck is removed and derogations are not needed anymore, the emission policy still remains relevant. Until the adoption of EU Directive 2004/26/EC, which amended the NRM Directive and set emission limits for IWT from January 2007 onwards, there were no EU-wide compulsory emission limits for inland waterway vessel engines. During the second edition of the NAIADES program of the EC, a working paper was added concerning emissions in the fleet¹²⁵ which broadened the policy objectives with an improved sustainability performance of the fleet and the preparation of infrastructure for LNG fuel use together with technical standards.

European guidelines to limit pollutant emissions from IWT were introduced but without real baseline analysis of emissions in different stages of operation (Pillot et al., 2016: 4-5). The first emission limits for IWT on the Rhine were introduced in 2002 by the CCNR. The CCNR – 1 limit for NO_x is identical to the first MARPOL limit introduced in 2000. There are differences in regulation between CCNR (Stage II) and EC (Stage III A) for emission limitations for IWT engine exhaust because of the fact that the CCNR used maximum power (PN) and rated engine speed (n), whereas the EC regulation considered unit cylinder displacement (D) of the engine and maximum power (P) in addition for some cases (Pillot et al., 2016). Despite these differences, both regulations run parallel and there is a legal system of mutual recognition between CCNR phase II and EU stage IIIA.

Table 54 shows the different approaches between the CCNR II and the EU stage IIIA. Where the CCNR standards make a classification based on power expressed by kilowatt of the engine, the EU standards are based on the displacement per cylinder in the engine. A more detailed analysis of this table of emissions lies outside the scope of this research.

¹²⁵ EC (2012b), Commission staff working document, Towards Naiades II, Promoting, greening and integrating inland waterway transport in the single EU transport area. EC (2013), Greening the fleet: reducing pollutant emissions in inland waterway transport. Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Towards quality inland waterway transport /* SWD/2013/0324 final

Regulations	POWER (kW)	Displacement (D) dm ³ per cylinder	CO (g/kWh)	HC (g/kWh)	NOx (g/kWh)	PM ₁₀ (g/kWh)
CCNR Stage I (2002)	37 ≤ PN < 75	Not applicable	6.5	1.3	9.2	0.85
	75 ≤ PN < 130		5.0	1.3	9.2	0.7
	PN ≥ 130		5.0	1.3	n ≥ 2800 rpm: 9.2 500 ≤ n < 2800 rpm: 45.n ^{-0.2}	0.54
CCNR Stage II (2007)	19 ≤ PN < 37		5.0	1.5	8.0	0.8
	37 ≤ PN < 75		5.0	1.3	7.0	0.4
	75 ≤ PN < 130		5.0	1.0	6.0	0.3
	130 ≤ PN < 560	3.5	1.0	6.0	0.2	
	PN ≥ 560	3.5	1.0	n ≥ 3150 rpm: 6.0 343 ≤ n < 3150: 45.n ^{-0.2} - 3 n < 343 rpm: 11.0	0.2	
EC Stage IIIA (2007), Small & normal engines IIIA (2009) larger engines V1:4-2:5	Not applicable	V1:1 = D ≤ 0.9, P > 37 kW	5.0	NOx+HC		0.4
		V1:2 = 0.9 < D ≤ 1.2		7,5	0.3	
		V1:3 = 1.2 < D ≤ 2.5		7,2	0.2	
		(Larger) V1:4 = 2.5 < D ≤ 5		7,2	0.2	
		V2:1 = 5 < D ≤ 15		7.2	0.27	
		V2:2 = 15 < D ≤ 20, P ≤ 3300 kW		8.7	0.5	
		V2 = 3 15 < D ≤ 20, P > 3300 kW		9.8	0.5	
V2:4 = 20 < D ≤ 25	9.8	0.5				
V2:5 = 25 < D ≤ 30	11.0	0.5				

Table 54: Pollutant emission limits for IWT

Source: based on Pillot et al, 2016; HC= Hydrocarbons; NOx=Nitrogen oxides; CO = carbon oxide, CO₂ = carbon dioxide; PM= particulate matter; P & PN = net power output; D = displacement

Starting from January 1st, 2017, the new NRMM regulation (EC, 2016b) came into force, skipping the enforcement of stage IV engines and applying a new standard for stage V engines. The new NRMM regulation could be considered an important driver in the market push for alternative fuels. One of the key elements that obliges IWT to comply, is the relationship between engine performance and exhaust emissions, as mentioned in the regulation.

The recent NRMM regulation sets out emission standards for IWT engines are shown in Table 55.

Emission stage	Engine sub-category	Power range kW	Ignition type	CO g/kWh	HC g/kWh	NOx g/kWh	PM mass g/kWh	PN #/kWh
Stage V	IWP-v-1	19 ≤ P < 75	all	5	(HC + NO _x ≤ 4,70)		0,3	—
	IWP-c-1							
	IWP-v-2	75 ≤ P < 130	all	5	(HC + NO _x ≤ 5,40)		0,14	—
	IWP-c-2							
	IWP-v-3	130 ≤ P < 300	all	3,5	1	2,1	0,1	—
	IWP-c-3							
	IWP-v-4	P ≥ 300	all	3,5	0,19	1,8	0,015	1 × 10 ¹²
IWP-c-4								

Table 55: Emission limits for main and auxiliary engines in IWT in the new NRMM regulation

Source: EC, 2017, NRMM annex I, table II-5 and 6

As mentioned in the staff working document of the EC (SWD/2013/0324 final), engines over 19 kW installed before 2003 are not subject to any emission standards. Engines installed between 2003 and 2007 on vessels operating on the Rhine have to comply with CCNR I standards, whereas those installed since 2007 are covered by the CCNR II standards, in accordance with the relevant CCNR Regulations. Furthermore, the staff document mentions that the emission of SO_x from IWT is regulated by a different legal framework, Directive 2009/30/EC governing the quality of gasoil used in inland navigation, which limits the sulphur content of fuel used in IWT to 10 mg sulphur per kg fuel as of January 2011, the same value as for road haulage, resulting in a substantial reduction of SO₂ emissions from IWT. Finally, the document refers to LNG as a potential fuel to reach Stage V of the NRMM and as a possible solution to reduce emissions further by implementing after-treatment systems such as SCR and DPF filters. The complete overview of the emissions for IWT as mentioned in the recent NRMM are to be found in the case related annex (IWT Emission limits, Regulation; EC, 2016b).

Figure 41 shows the current situation of emission standards for PM and NO_x in IWT compared with other modes. The distance of engine performance for PM and NO_x between modes is significant. Although stage IIIa of the European Commission is mutually recognized by the CCNR with their CCNR II standard, there are differences. For IWT vessels, the CCNR II emission limit for NO_x lies between 6 and 11 g/kWh depending on the nominal engine revolutions per minute while the emission limit for the EU Stage IIIa only gives combined values of hydrocarbons and NO_x between 7,2 and 7,8 g/kWh depending on the water displacement. The upcoming stage V of the EU (stage IV was skipped for IWT) will introduce only one emission standard for the European IWT and makes the distinction between NO_x and hydrocarbons. For visual reasons, the median value in case of intervals is chosen and for the distinction in stage IIIa the same approach is used as in Pauli (2016) in estimating the value for NO_x and hydrocarbons in EU stage IIIa. The values for EU stage V are for ships with a net power above 300 kW. Stage V gas engines have specific provisions concerning the hydrocarbon emission limit (HC). The limit is set on the following formula:

$$HC = 0.19 + (1.5 \times A \times GER)$$

Whereas GER is the average gas energy ratio over the appropriate test cycle. Where both a steady-state and transient test cycle¹²⁶ apply, the GER shall be determined from the hot-start transient test cycle. Where more than one steady-state test cycle applies, the average GER shall be determined for each cycle individually (VDMA, 2017). The factor A is set on 6 for IWT in the NRMM (European Commission, 2016b). Every category of vehicles or vessels has an A-factor, and this is an estimated weight to determine HC emissions. This factor A means that the methane slip of an engine running on methane may be up to 6 g/kWh (Pauli, 2016). The maximum HC equals HC=0.19 + A which means that the GER is maximum 68.8%. For categories with a combined HC and NO_x limit (as in the NRMM for stage IIIa), the combined limit value for HC and NO_x is reduced by 0.19 g/kWh and only applies for NO_x which gives a reference for emissions complying with stage IIIa for HC (in stage V, only vessel categories with a power under 130 kW still have combined NO_x and HC values). For this research the focus lies on vessels with a power above 300 kW (cat. IWP/IWA-v/c-4 in stage V).

¹²⁶ The European Transient and Stationary (or Steady state) Cycle are used to test the emissions in several circumstances. Steady-state test cycle means a test cycle in which engine speed and torque are held at a finite set of nominally constant values. Steady-state tests are either discrete mode tests or ramped-modal tests; Transient test cycle means a test cycle with a sequence of normalised speed and torque values that vary on a second-by-second basis with time (as defined in European Commission, regulation 2016/1628)

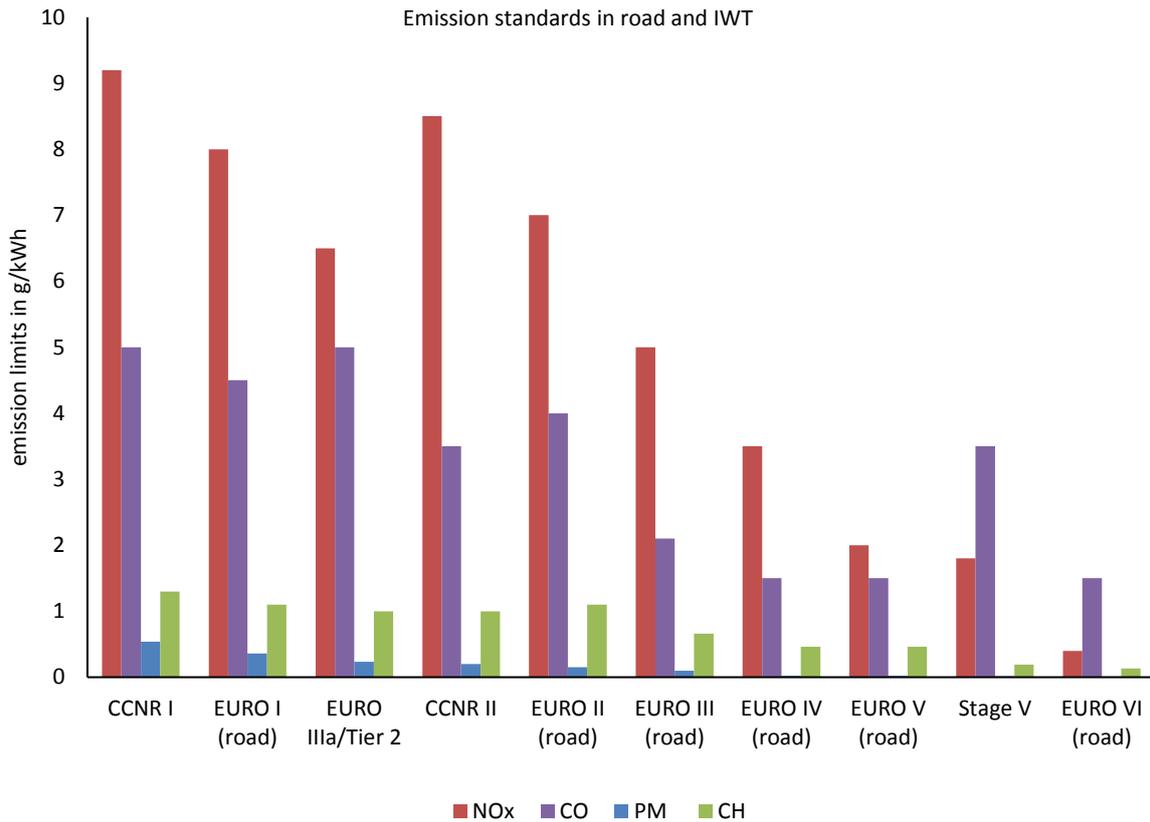


Figure 41: Comparison of selected emission limits from European regulations
 Source: own compilation of Pauli (2016), dieselNet (2016), CCNR (2018), EC (2016)

Regarding the emission standards, it is easy to claim that IWT is lagging behind other modes. However some particularities have to be explained to have a more accurate view on the IWT emissions. First of all, there is a high variety of vessel sizes in the European IWT freight fleet, which makes it difficult to estimate the total energy consumption and emission performance of IWT. Secondly, the natural aspects of the waterway make measurements more complex. For example, sailing on shallow waters (low water level), needs higher power requirements of a large vessel (above 110m) than of a small one. A third particularity relates to the carrying capacity which has a negative relationship with the power requirements, expressed by kW/tkm (CCNR, 2012; Planco, 2007; Renner & Bialonski, 2004, as mentioned in Pauli, 2016). The larger the carrying capacity of a vessel, the lower the needed power and thus the lower the energy consumption.

Finally, the age, ship design and condition of the vessel are also determinants of energy consumption. The fuel consumption of the fleet is therefore very difficult to measure and very few actual values are known, which makes it for policy makers difficult to design a datadriven policy. It could be expected that involved actors will have to address the methane slip and to focus more on carbon dioxide because of the Paris Declaration. This would demand the industry to invest in solutions such as after-treatment.

Engine manufacturers claim that LNG can reach stage V with after-treatment. In the meantime, given the reduction of emissions compared with conventional fuels, LNG can still be considered a relevant transition fuel that relatively easy could be implemented despite the low performance of carbon dioxide equivalents of emitted methane.

B.2. Soft rules

The past ten years, the European Commission provided funding for several programs related to LNG implementation in IWT. The LNG Masterplan for Rhine-Main-Danube (2013-2015) received half its total budget from EU contribution. The total budget was almost EUR 34 million, to invest in pilots, research and development¹²⁷.

Most vessels with LNG that are being built or already are operational, could receive public funding for at least the half of the additional cost of the investment when compared with conventional technology. Several research projects emerged with public funding from the EU, national governments, ports and even provinces (in the Netherlands). Of all identified LNG related projects for IWT, a total of EUR 66.7 million was contributed by EU funding between 2002 and 2018.

The total budget of the identified projects since 2002 was more than EUR 127 million. The outcome of the projects is diverse with deliverables such as cost-benefit analyses, engineering studies, compliance studies and broad support towards vessel owners in refitting or newly built LNG fuelled vessels, real life experiments and pilots, approval procedures and measurements, intermediary support between regulator and innovators, building innovation networks and furthermore. Within the framework of the LNG Masterplan, several vessel owners received subsidies.

Several public funding possibilities were identified at national (Dutch case) and European level. The Dutch government provides following funding possibilities and has a special tax regime for LNG which is lower taxed than diesel:

- Lower tax on labour involved in research and development of innovation¹²⁸.
- Tax deduction of expenditures in research equipment.
- Innovation box: companies can allocate profit from the innovation in a lower tax tariff.
- Special TKI-Gas (*Topsector Kennis en Innovatie*): funding mechanism for energy innovations
- BMKB (*Borgstellingskrediet*): the Dutch government can protect loans up to EUR 1,5 million when requested by the financial provider of the loan. Although applicable for LNG, this credit protection has a broader scope.
- Innovation credit (IK): up to EUR 5 million with an interest rate that depends on the risk level of each case.

Moreover, the Argonon, the Eiger-Nordwandt and the Sirocco, received subsidies through the *Provinciaal Actieprogramma Luchtkwaliteit* (Province of South-Holland), the European Fund for regional development (EU) and the LNG Masterplan (EU)¹²⁹.

Table 56 shows more detailed the studies which received EU funding.

¹²⁷ https://ec.europa.eu/inea/sites/inea/files/fichenew_2012-eu-18067-s_final_0.pdf

¹²⁸ Wet Bevordering Speur en Ontwikkingswerk - WBSO

¹²⁹ <https://www.eicb.nl/wp-content/uploads/2016/08/Consultatieronde-Subsidies.pdf>

Project name	Description	Coordinator	Duration	Total budget (EUR)	EU contribution (EUR)
LNG Tanker	Demonstrating the effective and safe use of LNG as fuel for ship engines for short-sea shipping and inland waterway transport.	Bijlsma Projects B.V.	2002-2005	4,922,900	874,245
MOVE IT! (Modernisation of Vessels for Inland waterway freight Transport)	Aimed to accelerate implementation of new developments into IWT for economic and environmental performance (including LNG)	Stichting Maritiem Research Instituut Nederland	2011-2014	3,962,477	2,790,344
Promovan	Alternative fuels and propulsion for the Rhône basin	VNF/CFT	2012-2014	1,344,171	898,436
NEWS (Development of a Next generation European Inland Waterway Ship and logistics system)	Redundant Gas-electric energy system for propulsion; developing a next generation European inland vessel and logistics system to make inland waterway transport more economic, more ecological, safer and time efficient: The NEWS Mark II vessel.	Technische Universitaet Wien	2013-2015	2,241,287	1,760,097
LNG Masterplan	Prepare and launch full-scale deployment of LNG as environmentally friendly and efficient fuel	Pro Danube Management GmbH	2013-2015	80,520,000	40,260,000
Sustainable multimodal transport chain	Efficient propulsion technology for inland shipping facilitating use of state of the art efficient and clean diesel, and diesel LNG multi fuel engines	Oscillating Foil Development B.V.	2013-2015	5,805,080	2,902,540
Prominent, Promoting Innovation in the Inland Waterways Transport Sector	research in alternative fuels, after treatment, and other possibilities to reduce energy use and emissions in IWT	Stichting STC-GROUP	2015-2018	6,572,616	6,249,998
Breakthrough LNG Deployment in Inland Waterway Transport	Reduction of investment barriers in LNG in IWT	Stichting Projecten Binnenvaart	2016-2019	21,870,230	10,935,115

Table 56: Project overview of LNG in IWT and EU-contribution (non-exhaustive)
Source: own compilation, based on INEA 2018, project websites

C. Interaction conditions

The innovation network is an important success factor for the innovation. In case of LNG, several actors are involved. The network consists of knowledge institutes, policy makers of different levels, investors, shipyards, engine manufacturers, verification agencies, ship designers, sectoral organizations, vessel owners, charterers and classification societies.

During the first contacts between the innovator and the policy actors, the innovators were asked to give demonstrations in order to convince policy actors to adapt to the regulation. These first contacts can be situated in 2008 with the building plans of the MTS Argonon. All the innovators of the first LNG vessels are strongly linked with the innovation network, regulators and funding institutions.

Until regulation was adapted, all LNG driven vessels needed to have a derogation in order to use LNG as fuel. One standard derogation could not be given because of the variation of the vessels. The Greenstream was a mono-fuel, the Eiger wanted to cover up the LNG tank with a container hull and put containers on the tank; the Sirocco installed two 44m³ tanks under deck, while the Argonon installed a 40m³ tank above deck.

At the side of the customer (VO), several partners are lined up such as:

- Engine manufacturer: provides reliable engines, specialized installation and service, and gives information concerning training and manuals.
- Classification societies: these societies support the VO to comply with regulatory standards and to get approval for the installed innovation. A classification report is usually mandatory for the authorities.
- Shipyard: the shipyard needs to have specialized knowledge concerning the innovation and be flexible enough for maintenance and repair of the vessel in an acceptable time frame
- Shippers: the customers of the VO. A failure factor would be customers that oppose the innovation and would choose other vessels instead. An important question remains, if these customers are also willing to pay for a premium for the innovation on-board. According to the interviews and supported by the market structure (few customers and many vessels), this is hardly the case. In case of LNG, major customers offer fixed contracts which are a success factor in the business strategy of the customer.
- Freight charterers: the intermediary role of the freight charterer is already analysed in other cases within this research (sub-section 1.1.6). They can be involved as co-investor within the vessel.

In addition, several other actors are crucial for the success of the innovation, which are highlighted in the following part.

C.1. Strong network

Strong networks are identified between the shipyard, main customer and the vessel. The case of the mono-fuel showed two lock-in effects that made it very difficult to adapt to changes. First, the vendor lock-in between sole customer Shell and the mono-fuel vessels, made the business case vulnerable. Having only one customer, which has the choice of numerous suppliers (monopsony), makes the innovation strongly dependent and could lead to failure. The other lock-in effect is with the shipyard. In the initiation phase, the level of expertise for maintenance and repair supporting the maturing technology must be sufficient and easily available. When a shipyard or another player has the monopoly of the needed knowledge, the vessel is strongly dependent and locked-in the strong network. In the case of the mono-fuels, the shipyard was not only considered to have the exclusive knowledge, it was also strongly linked in the business structure as an investor. In the development phase, with more shipyards getting acquainted with the technology, the LNG vessels become less technology-dependent.

LNG is mainly imported from Russia, Algeria, Norway and Qatar. Forecasting gas demand goes with several uncertainties. Geopolitical stability concerning the main suppliers and the growth of demand

of importing countries, determine to a large extent the world price of natural gas. Major players in the market, such as Shell, have discovered IWT as a new market during the past decade to sell their LNG supply. The strategy of Shell is not only focused on the supply side, it also generates the market on the demand side with long term contracts for LNG-fuelled vessels which makes them dedicated customers.

The latter also entails a lock-in effect. Agreeing the long-term contract with Shell and to build the business case of the LNG-fuelled vessel under these conditions, makes it more difficult to switch to other and better fuels if any. In case of LNG, lobbying activities are undertaken by main gas suppliers such as Shell, who have sustainable relations with all levels of power all over the world. To create as many markets as possible, it is in the advantage of these actors to actively lobby to adapt regulation and to be allowed to sell LNG as fuel for both maritime as IWT.

At the side of the innovation customers, mainly relatively large companies (multiple vessels) invested in LNG vessels (especially dual fuel). Companies such as Deen Shipping, Danser, Plouvier, Chemgas, Damen, Victrol and Somtrans took the lead in the implementation of this technology in the European IWT. They were able to provide the lessons learned and expertise for building the regulatory framework.

The MTS Argonon was used as a first example for the derogation of the CCNR, for shipyards and classification agencies. This brings several advantages. The regulation is mainly built on the first example, which makes the cost for compliance more tangible. If policy makers would have chosen another dual fuel vessel as a starting point, the MTS Argonon could have been paying more compliance costs. Another advantage is market share in the new emerging market of LNG fuelled vessels. The MTS Argonon is easier known to other actors than the innovation followers. The exposure in transport sector dedicated media for the first vessel offers another advantage. This exposure is positive if the innovation remains a success story, but this was not the case for the failed mono-fuel inland tankers.

D. Capabilities

The innovator must be capable to consider the possible delays, barriers and innovation pace to make realistic estimates to develop the business case. In all stages, challenges could arise that have to be addressed. However funding is not the only capability the innovator should have as explained in the following parts.

D.1. Financial

The tanker segment invested heavily in the double-hull requirements during periods of relatively low freight rates, high water levels and lower demand after the financial economic crisis. Since 2017, this segment is recovering, and the overcapacity caused by remaining single hulls is coming at an end. VOs are now more financially capable and after learning from the pilots, also perhaps willing to pay for the innovation.

The financial side of the business cases of alternative fuels, could make it less attractive than traditional fuels such as diesel. The level of investment costs for LNG for example is approximately four times higher than a classic engine. The large amount of SMEs and one-vessel owner / operator limit the investment capacity at customer side. The bargaining power of these SMEs and market conditions (most routes have higher supply than demand or IWT service) do not always allow a premium to be paid off by customers or the service demand side.

Charterers are sometimes enablers of innovation by helping the chartered vessels of the mentioned SMEs in their administration (e.g. applying for subsidies), in providing low interest capital or by spreading the risk as co-investor. Large IWT companies or multiple vessel owners can offer an economic scale of advantage for the involved actors. Engines could become cheaper when bought for several ships at once.

The inherent network aspect of the latter described business cases involving multiple parties, depends on trust, symmetrical information, reputation and common believe of success. Sometimes even actors

from the demand side can be convinced in joining an investment in vessel innovation if their conditions are met or if the innovation would also benefit the customers. In the case of LNG, major companies such as SHELL can support development of this fuel, benefitting due to their position as major fuel seller.

Offered fixed operational contracts, together with European subsidies can be necessary incentives to overcome the lack of infrastructure or other barriers for innovators and their first movers or followers. The latter example is the case for vessel engines with 100% LNG or dual engines with 80-90% LNG and 20-10% diesel.

D.2. Cultural

The VO that is attracted to dual fuel engines with LNG and diesel, are mostly active in the tanker market in IWT. Most of them have the experience and knowledge how to work with dangerous goods and could feel much more at ease in working with LNG or other alternative fuels. Another barrier could lay in the practical operation from day to day. LNG and alternative fuels in general require more transaction costs in safety procedures, in bunkering planning (given the current infrastructure) and in case of LNG the cryogenic tank takes significant space on-board. In most current ship designs of dual fuel diesel and LNG, the idea that the cryogenic tank is not far from the living quarters, could make operators who live with their family on-board less appealed to pay for the new technology and prefer to sail as long they are able to with their old CCNR I or II engine.

According to Vogelaar (Schuttevaer, 2016), the mandatory adjustments of the engine emissions because of the NRMM stage V regulation, would lead to a cubanization of the fleet, which refers to an endless revision cycle of existing engines to avoid the cost of a new engine. Those who cannot afford a new engine, will more likely comply by replacing parts of the old engine as long they are able or allowed to.

Concerning the European Commission emission standards, the investment costs to fulfill stage V emission limits are estimated by Pauli (2016) at 3.5 times higher than EU stage III. When R&D costs are included would cause fivefold additional cost for large engines. This could force VOs to apply cost avoidance strategies such as advancing investments before the deadline (implementation of stage V for new engines); postponement of investments and increase frequency of engine repair; use smaller engines which have less stringent emissions regulations.

D.3. Market

According to IVR data (2017), most vessels with a dual fuel engine with LNG are tankers of 110m and longer, which gives a remaining potential market (diesel users) of more than 380 vessels or a capacity of 1,469,629 dwt that could be hypothetically refitted with a new engine or replaced by newly-built vessels. On average this part of the European tanker fleet is built in 2006 and has therefore in most cases an engine that is not yet depreciated and which complies with the given engine standards of this period.

At least 171 tankers have a Caterpillar engine with an average power of 1,531 kW. 72 tanker vessels sail with an engine of the Anglo Belgian Corporation (ABC) with an average power of 1,630 kW. Other identified engines are Mitsubishi (49 vessels, average power 1,508 kW); Cummins (19 vessels, average power 1,511 kW); and Wärtsilä (6 vessels, average power of 1,704 kW)¹³⁰. The Netherlands has the largest share with 231 vessels in this category, followed by Germany with 72 tankers, Belgium with 40 vessels, Switzerland with 21 vessels, Luxembourg with 15 vessels and France with 5 vessels. The power averages are calculated with the available data in the dataset.

Table 57 shows the diffusion of most commonly used engines with their average engine power.

¹³⁰ The dataset does not show engine manufacturers for 24 vessels and for 208 vessels the engine power is not given.

	The Netherlands	Germany	Belgium	Switzerland	Luxembourg	France
Total number of vessels	231	71	40	21	15	5
Caterpillar	121	22	9	8	6	2
ABC	40	11	13	6	2	N.A.
Others	70	38	18	7	7	3
Average engine power	1,507	996	1,828	1,194	1,989	898 ¹³¹

Table 57: Tankers <110m in the European fleet
Source: based on IVR (2018)

This segment of the fleet is mostly double-hulled¹³² which is also the main reason for the relatively young average age. According to the database, there are still 10 single-hull vessels¹³³ registered in this part of the fleet (>110m) which were on average built in 1979 and which normally shall disappear at the end of 2018. The remaining single-hulled fleet have a remaining capacity which is estimated at more than 26,000 dwt in the segment of vessels with a length above 110m.

According to van Hassel (2015), the tanker capacity is dominated by several actors in the primary market. Of all tanker vessels, 87.25% are linked to a freight charterer or a larger ship owner (with more vessels). The distinction between charterers and multiple vessel companies, is difficult to make, because larger multiple vessel companies are often also active in freight chartering. Several charterers are also often co-financer of vessels of single vessel companies. Figure 42 shows that the largest share of capacity in the European IWT is dominated by large companies such as Interstream, Jaegers, Unibarge, Bftrans, Imperial, Tankmatch, Somtrans and Stetrag, which already have almost 1.3 million tonnes in ownership or under contract, which represents 58% of the tanker fleet capacity (based on van Hassel, 2017).

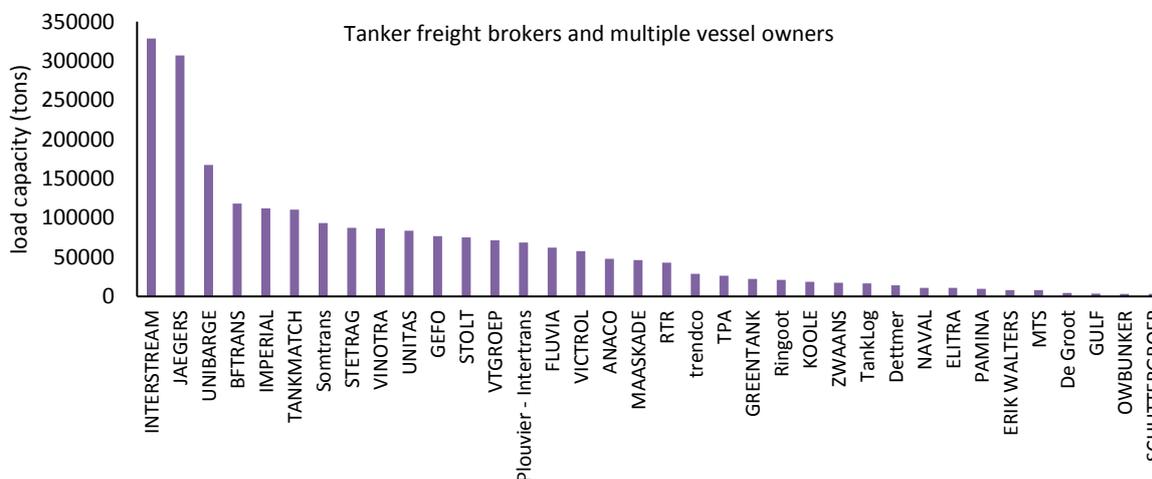


Figure 42: Overview multiple tanker owners and freight charterers according their capacity share
Source : based on van Hassel et al. (2017). Last update 2018. Data from fleet registers of identified companies

When preparing the CBA part of this research, the potential users will be further identified, but it becomes clear that the market of IWT is relatively small which makes the potential revenue for engine

¹³¹ based on one given value. Only one French vessel showed data on engine power.

¹³² In 2008 major customers such as BP and ESSO preferred double-hull vessels and policy soon followed, no single-hull tanker was built in Europe anymore. Most of them were demolished or sold to Nigeria.

¹³³ The number of single hulls in the IVR dataset were cross-referenced with debinnenvaart.nl. The first data-set relies on data delivered from national governments. In Belgium this is the Federal Government which uses the national vessel mortgage register, but relies on voluntary reports of vessel owners to be removed from the register. The debinnenvaart.nl offers information that is regularly online updated by its viewers. Single hulls that were demolished or sent to Nigeria were removed from the data as much as possible.

manufacturers also relatively small. This is the main reason why this niche market provides just a few incentives to rapidly develop new and improved systems. If regulation could decide to enforce this innovation, revenue could increase for the engine builders and more engine builders will have a higher willingness-to-pay for R&D in developing stage V engines or after-treatment systems. This would increase investment costs for the relatively high number of one-vessel companies. Knowing that ships usually stay on the market after bankruptcy and can sail under relatively cheaper freight rates, the capacity will not change and thus enforcement of innovation has a downside for the business structure in IWT and for development of other innovation.

6.3.10.SIA conclusion of LNG-D

The RQ and its-sub-questions can be partially answered after applying the SIA. It helps to identify the remaining gaps that can be investigated in the analysis in the next sub-section.

Sub-questions Innovation	Answer
When is the innovation successful or a failure?	The LNG vessel is not successful (yet) as diffusion is rather limited in the implementation period. Important failure factors need to be solved such as: More infrastructure for bunkering: Cultural: perception of dangerous and cubanization of the engine: Consumers availability and capability; Lock-in effect related to the fixed contract with majors; Consumers availability and capability; Methane slip and climate change concerns; Price spread advantage between diesel and LNG is uncertain
How can innovation be analysed or measured?	The SIA proves to be a powerful tool to explore, identify, categorize and qualitatively analyse the LNG case, but as with the AV, it does not prove quantitatively if the innovation is a good business case for investors as well for society. The current LNG users can be identified, and the innovation can be situated according to its stage of development through interviews, extended desk research and IWT newspapers.
Who are the relevant actors in IWT innovation?	Actors are identified as a global network of innovating firms, knowledge institutions, public actors, verification agencies, standardization bodies, charterers and industry with own vessels and shippers/forwarders, large vessel owners, manufacturers (including ship yards), consultants, regulators, ports and waterway managers. The LNG vessels during the periods of development needed a derogation on existing regulation that did not accepted LNG as fuel. This regulatory bottleneck has been removed.
Sub-question policy	Answer
What is (IWT) innovation policy, how is it organized and which role plays IWT innovation policy? Which policy measures are applicable for IWT?	<ul style="list-style-type: none"> • EC provided funding and interacted through CESNI PT with the CCNR to tackle the regulatory bottlenecks. The UNECE has adjusted the ADN in a similar favourable way. • The environmental policy with the NRMM and the mandatory stage 5, together with increasing and expected environmental policy from major ports. • TTS is made regulatory possible at ports and although public actors claim to actively look for private partners to build on-shore LNG bunkering infrastructure, no infrastructure has become available (yet). At the moment of research there is a bunkering station planned in Germany. • Although, the innovation is failed as explained (or not yet successful), the innovation policy that stipulated to stimulate LNG by removing bottlenecks in an acceptable period of time and to provide funding succeeded in supporting the innovation development, but not the diffusion as such. • As said the SIA is here rather exploratory but offers a first valid attempt to reveal how policy has removed the regulatory bottleneck which sets the scene for the PEINPA. • River commissions allowed derogations for the LNG vessel on the Rhine and adjusted regulations and standards. • European commission adjusted the community's IWT regulation. CESNI PT has introduced common standards for both CCNR and EC. And as said the UNECE adjusted the ADN. • Ports also play an important role for allowing TTS and as partner for the development of port LNG infrastructure • Applied measures: Funding R&D; derogations; subsidies and fiscal incentives; adjusting standards and regulations

Table 58: SIA conclusion of the LNG dual fuel inland vessel, answers for the RQ

The next sub-section applies a similar approach as in the AV case and analyses the LNG dual fuel inland vessel as a potential business case for IWT. It also allows to identify the significance of external costs and the benefits that could advocate the further development of the innovation or not. Special attention is given to the price spread and the methane emission factor.

6.4.CBA of LNG-D

During this analysis estimations are made based on the average annual power (expressed in kWh) and a number of assumptions concerning emission factors, as explained further in this research.

It should be clear by now that there is a variety of alternatives for replacing conventional fuels such as diesel with each their own costs and benefits. As during the cash flow analysis of the automated vessel, the analysis is conducted from a vessel owners’ perspective (VO) and focuses on one vessel. In practice, LNG-dual fuel, is being implemented in IWT, mainly in the market of dangerous goods transportation (DGT).¹³⁴ The analysis focuses on the potential business case of a self-propelled tanker motor barge of an independent VO of 110m. This case also offers an opportunity to test the developed methodology on a tanker, next to the developed vessel model of the AV in the previous case which carried dry bulk.

Costs and benefits are mainly given by recent research as mentioned in the literature review and own developed methods and estimations as explained further. The focus is on costs related to fuel usage, emissions and GHG. The business case of the LNG usage as fuel, depends mainly on the spread between the price of diesel and LNG. Although, the infrastructure problem (lack of onshore bunkering facilities), gives an additional cost to the bunker price, the private business case prospects are positive as the diesel price is expected to increase the upcoming decades. This expectation invites the necessary caution as prices were almost equal between diesel and LNG in 2016 without taking into account the energetic value of both fuels. Price evolution of fuels are volatile and depend on several factors such as worldwide economic development, geo-strategical policy and political stability which requires constant monitoring and business analysis, but which lies outside the scope of this study.

6.4.1.Cost and benefits for different actors

Table 59 shows the structure of the main costs and benefits grouped by the different actors involved in the innovation. As explained, only the vessel owner perspective is taken into account together with model related external costs.

Actor / SCBA component	BENEFIT	COST
Companies (the innovator)		
LNG engine and tank development		X
LNG installations	X	
LNG bunkering infrastructure		X
Customers (vessel owners)		
Expected fuel price difference	X	
Bunkering infrastructure		X
Maintenance, training and repair		X
Installation of LNG system		X
Society		
Subsidies		X
Emission reduction	X	
Fuel consumption	X	
Building of LNG infrastructure		X

Table 59: Actors and their direct costs and benefits of LNG-fuelled navigation
Source: based on Aronietis R. (2013)

134 as mentioned, there is a containership that is refitted with an LNG-dual fuel engine (Eiger-Nordwand from the Danser Group) since 2014 and the recently-built MS Werkendam which is a crane vessel.

According to the applied methodology, the cost components are grouped to fit the sides of the cost benefit equations:

- Industrial-economic side, and the
- Welfare economic side

The thresholds¹³⁵ to achieve a successful innovation are derived from following equations:

$$\left\{ \begin{array}{l} \Delta R_p - \Delta C_p + S_p > \times \\ \Delta B_s - \Delta C_s + S_s > \gamma \end{array} \right.$$

ΔR_p equals the change of revenue caused by the innovation and ΔC_p represents the changed costs for the innovator. ΔB_s symbolizes the changes in benefits for the society and ΔC_s relates to the change in costs for society inflicted by the innovation. A more fuel-efficient inland navigation is a private and a social benefit. The lack of infrastructure is considered a private cost. The infrastructure relates to bunker facilities. If bunkering infrastructure is implemented, this could be allocated as private or social costs, or both in case of public-private cooperation.

In order to conduct a CBA, a vessel model of a motorized tanker with a dual-fuel engine is developed with and without the implementation of the innovation. The choice of vessel and innovation is based on the most common implementations so far in the market as identified.

6.4.2. Data challenges

Because of the strong variation of vessel types in the European IWT fleet, it is difficult to identify categories that give a generalized view on the market. Ships differ in power use, emissions, fuel consumption, design and in many other aspects because of the lack of standardization and the individual preferences of a ship owner. Cost data is usually undisclosed because of the business sensitivity and confidentiality towards other competitors. For the time being, several estimations concerning fuel power output and fuel consumption are made for the analysis.

Regarding the different fuel usages and performance of diesel and LNG, it was challenging to look for a method that could compare them in equivalent units. Original data sources provide cost data where LNG is expressed by EUR/kg and diesel by EUR/l. Literature provides several ways to do this as shown further in this analysis. In this research, the equivalent is calculated based on the median heating value of both products and expressed in EUR/kWh. The LNG price is added with the logistics costs from well-to-ship. Because LNG trucks are not allowed to enter a tunnel, these costs could be significant in a scenario without onshore bunkering facilities.

To compare the greenhouse gas impact of methane, the CO₂ equivalent unit is used. The conversion factor for the latter shows no unanimity in literature. The conversion factor lies between 21 and 34 of the CO₂ equivalent unit which means that methane is at least 21 times worse than CO₂ for the climate. The values for the emission of methane are expressed in external costs and during the sensitivity analysis at the end of the CBA, different conversion factors will be examined on their effect.

The emission values as set for Stage IIIa in the 2004 NRMM directive (directive 2004/26/EC) experienced some challenges according to the technical review of the directive (European Commission, 2008). Indeed, the engines of IWT vessels were in the 2008 review assumed to have a lifespan between 20 and 30 years, but engines were even older. There was also a lack of engine data to estimate the limits of emissions for the Stage IIIa.

Costs for society refer to the building of on-shore bunkering facilities. An LNG distributor will prefer to build the facility nearby potential consumers. As the diffusion of LNG in a niche market such as IWT is

¹³⁵ Thresholds are defined as the preferred value for an innovator/end-user (\times) or for society (γ) that gives the main incentive to continue the innovation. The height of the benefit or the profit should be higher than zero.

slowly taking off, it will probably take several years to experience market uptake while facing several uncertainties (e.g. price spread and evolution of fuel prices). There is also a potential of social resistance against bunkering facilities which could include loss of natural habitat. The investment cost of a bunkering station is quite significant, and the LNG distributor will assumable prefer to build a station that also serves other customers than only IWT. The ideal bunkering location for IWT would be nearby frequent origins and destinations of inland vessels. This can be near populated areas. The external cost of LNG infrastructure requires more research and was not feasible to calculate during this research. The complexity of LNG bunkering needs to be explored much more to determine the social costs and no relevant cost data could be given or was found. The latter remark needs to be taken into account, invites future research and is especially important when creating a complete SCBA.

As there were no costs and benefits identified for the engine manufacturer or innovator, the next part goes directly to the costs and benefits for the consumer or end-user which is in this case the vessel owner that decides to invest in LNG. The building of the vessel model is explained as detailed as possible.

6.4.3.Costs and benefits for the innovative vessel owner

The costs and benefits of a dual-fuelled LNG – diesel vessel are in the further proceeding of the analysis estimated based on the available data, literature and interviews. These are described in following paragraphs.

The costs and benefits are inspired by Verbeek et al. (2011), Van Hooydonck and RebelGroup (2015), Karaarslan (2015 and 2017) and Prominent (2015-2018) for the conventional tanker vessel which presents the reference case. The costs of the combination of LNG and diesel (LNG-D) are based on literature review, interviews, own developed insights and several assumptions and uncertainties.

The following paragraphs explain the cost structure of the developed model which considers a tanker vessel of 110m in a reference case (conventional tanker vessel, CTV) with a CCNR II engine and a comparable tanker vessel with a dual fuel engine combining 80% LNG and 20% diesel. To take in account the beginning of the first dual-fuel vessel, prices are adjusted to 2012. This approach makes the analysis partially ex post and gives the possibility to look at the impact of real fuel price changes which were usually forecasted in previous studies. Especially, the unexpected narrow price spread in 2016 which none of previous studies have taken into account.

Another difference with previous studies, is that the reasoning of Verbeek et al. (2011) is followed who showed that there is a difference in energy input and mechanical output between LNG and diesel. Another new aspect in this research, is that the comparison between LNG as expressed in kg with diesel expressed in litre has been abandoned although in business this is common practice. An equivalent mass unit is calculated according to the energetic value of the different fuels and monetarized as explained.

The costs and revenue of both the reference as the project case are the basis for a scenario driven analysis where a number of changes will be added such as the payback period of the loan, the impact of subsidies and changes in fuel costs. At the end, an insight is given of changes in possible revenues in this model, but this is not considered to be influenced by the innovation.

A. Capital value of vessel and engine

The initial investment of the CTV is estimated at EUR 5,900,000 (current prices of 2015) with a main direct drive engine (conventional diesel propulsion with the engine mechanically coupled to the fixed pitch propeller) that complies to the CCNR II standard and with a standard after-treatment system. The price of the CTV engine is estimated at EUR 300,000 as one-time investment cost and is included in the total investment.

The engine price estimate corresponds with the average between EUR 170 and EUR 270 for each kW (Prominent, 2018, prices for 2015)¹³⁶ for the main diesel engine (including the gearbox), assuming an engine power between 1,322 and 1,550 kW.

The dual-fuel vessel (LNG-D) has a dual fuel electric engine installation with a capital value of EUR 1,441,662 (price of 2015) and with a tank above deck (under deck tank is estimated at an additional EUR 160,000). The latter amount is added to the investment cost of the CTV to estimate the price of the LNG-D which results in an estimate of EUR 6,966,533 (prices of 2012). To adjust all prices to 2012 and for the cost evolution after 2018 a fixed inflation rate of 1.8% is used.

B. Lifespan

The lifespan of the vessels and the engine is estimated at 25 years which is rather low in comparison with the rest of the existing fleet in the European IWT. The focus of the research lies on the main engine and not on the gen-set or bow thrusters. They are included in the capital value, but the lifespan of the gen-set and other systems is not taken into account in the further analysis.

C. Residual value

The residual value after the end of the lifespan of the CTV is estimated at EUR 147,500 as scrap value according to prices of the initial year of investment. This is also the case for the LNG-D. Because of the relative long lifespan of the vessel and the engine, it is challenging to make proper estimations of the residual value. The residual value depends on whether the vessel can be sold on the second-hand market to continue operations or is sent for scrapping. In case of the second-hand market, the value of the vessel depends on the future demand for freight capacity, expectations in the market where the vessel is active (chemicals, crude oil, derivate, gas, ... for trips to ARA, Rhine, Danube, etc.) and the height of estimated renovation costs to meet classification requirements. Other determinants are the financial position of the VO and his or her negotiation skills, ability or capacity to answer the demand of the second-hand market.

In the case of scrapping, the estimated value of the engine parts, the material of the hull, the value of all components and the willingness-to-pay of the scrap yard are very difficult to predict, even in the short run. In this model, the residual value does not show any impact from adding the innovation and is set on EUR 150,000 or 2.5% of the initial investment of the CTV. It is assumed to be the same percentage for the LNG-D. The residual value of the ship is also put at 2.5% or EUR 174,163. Thus, to simplify the vessel model, the vessel will be scrapped at the end of the lifespan for 2.5% of the original value for both vessels.

D. Maintenance and repair

For the LNG vessel, Prominent did not include maintenance and repair cost (M&R) in the LNG cost benefit. According to Sames et al. (2011) operation costs such as crew, spare parts and maintenance are assumed to be 10% higher than the reference vessels on an LNG maritime container vessel. This is not the case for IWT according to Kuipers (2016) who claims that maintenance costs are reduced on an LNG-D as does Nikolaisen (2014) who claims that these costs are 9 percent lower (based on an LNG ferry). The main argument is that LNG is engine friendlier than gasoil. Other sources (Nationaal LNG Platform, 2017; Verbeek et al., 2011) claim that the maintenance costs are equal with a conventional tanker.

According to Hartviksen (2014), maintenance costs can be divided between preventive and corrective maintenance. The first category focuses on hull, superstructure and propeller, machinery, electrical equipment, safety and rescue and navigational instruments and equipment. Engine maintenance and

¹³⁶ http://www.Prominent-iwt.eu/wp-content/uploads/2018/07/18_03_13_Prominent_D2.8_D2.9_Standardized_model_and-cost_benefit_assessment_for_right-size_engines_and_hybrid_configurations.pdf

repair depends on the number of cylinders, consequently the number of piston rings, valves, liners and bearings which need timely inspection. The interval between inspections is determined by the number of engine running hours (Molland, 2008; Hartviksen, 2014; Nikolaisen, 2014)¹³⁷.

In comparing the maintenance cost between the CTV and the LNG-D, detailed assumptions are important. In Nikolaisen, it appears that an older conventional ferry is compared with a newly-built LNG ferry and claims that new ship invites less maintenance costs. In comparing a newly built CTV with a newly built LNG-D, this argument could lose value. It could easily be stated that the fact that the LNG-D has more equipment on-board than a diesel engine, that the inspection area increases and therefore also the maintenance costs. Nevertheless, the argument that an LNG-D emits less pollutants that could weaken the engine, which is considered valid for this research, it is assumed that the maintenance costs do not change in this research between an LNG-D and a CTV. If there is an impact, it is not significant in the analysis. Furthermore, the total M&R in the cost structure of an inland vessel are not only engine-related. Painting of the vessel against corrosion or cleaning of the tanks is also M&R but cannot be related to the type of fuel use.

RebelGroup (2015) estimates the M&R cost at EUR 50,000. It is therefore assumed that unforeseen M&R costs that would lead to a higher annual M&R cost of EUR 50,000 are transferred to the next accounting year. For this model, the M&R is considered fixed for both vessels and only increases with the assumed inflation rate (cost is adjusted to 2012 to fit the model).

E. Port and fairway dues

Several ports stimulate cleaner ships with a port dues discount when the VO has a Green Award Certificate. Vessels can receive a Green Award certificate (GAC) by an independent third party (Green Award Foundation) who invested to improve environmental performance, safety and quality. The port due discount benefits vessels with:

- a CCNR class 2 engine that have a GAC (-15%);
- propulsion engines that are 60% cleaner than CCNR 2;
- a GAC after 2014 (-30%).

At the same time, vessels that do not meet the CCNR2 requirements have a 10% penalty on port dues¹³⁸. The procedure of the Green Award inflicts renewal costs for the VO every three years. Next to submission costs of the application, an audit of the enterprise must be repeated every three years to establish conformity between management procedures and practice¹³⁹ together with a vessel survey and annual checks. The tariff for an oil tanker of 2,000 DWT for the three years certification is annually EUR 3,525 concerning the office audit; EUR 2,930 concerning the vessel and together with additional costs related to survey expenses (accommodation of survey team).

The GAC is only used for reduction of port dues in most Dutch ports and the Belgian port of Ghent for inland barges. According to the Green Award Foundation, the list of inland barges with a GAC mentions a number of 650 inland vessels (Green Award Foundation, 2018).

At the Port of Antwerp, there is currently no GAC system, but inland vessels can receive a strategic reduction of 15% if certain conditions are met.¹⁴⁰ A more accessible measure of the Port of Antwerp is

¹³⁷ https://brage.bibsys.no/xmlui/bitstream/handle/11250/2445595/11134_FULLTEXT.pdf?sequence=1

¹³⁸ <https://www.portofrotterdam.com/nl/scheepvaart/binnenvaart/meldingen-en-ontheffingen/binnenhavengeld>

¹³⁹ The procedure of the GAC is described on <https://www.greenaward.org/greenaward/347-procedure-.html>. The tariffs for application and surveys to obtain the GAC can be found at <https://www.greenaward.org/greenaward/file.php?id=1845&hash=54d74d64338990aa390f590f51492688>

¹⁴⁰ The vessel stays in the port at least three times a week and this during two months; has an engine of class CCNR 2 or better; berths maximum three terminals within each port stay; loads or unloads in the port; at least 75% of the double TEU capacity of the vessel has to be loaded (in case of a container ship); stays maximum 7 days at the port and trip of the inland barge may not result in shifting maritime volumes to another port. http://www.portofantwerp.com/sites/portofantwerp/files/2018_tariefverordening_op_de_binnenvaart.pdf

a reduced rate based on environmental performance. To receive a strategic reduction from the Port of Antwerp, inland vessels must show that they have:

- A Stage V engine or that they are built before 2008 with a CCNR II engine to receive a 7% reduction;
- A diesel-electric propulsion with a CCNR II engine to receive a 15% reduction;
- An LNG engine (mono – or dual fuel) and vessels running on fuel cells (hydrogen) receive a 15% discount.

It is clear that there is no common policy on the port level. For this analysis it is assumed that the port dues will drop by 15% for the LNG-D compared with the CTV. Because of the assumption that the CTV has an engine that complies with the CCNR II standard, also a reduction of 7% is granted.

The rate (EUR/dwt) for an inland vessel without reduction and taxes, lies for the Port of Rotterdam between EUR 0.094 (for 7 days) and EUR 3.253 (for calendar year)¹⁴¹. For the Port of Antwerp, a basic rate is used of EUR 0.0895 for a period of 30 days and EUR 0.0707 for a stay less than 36 hours (Port of Antwerp, 2018). In 2012, port dues were in Antwerp between EUR 0.0609 and EUR 0.087 for each dwt.

The fairway dues are different between countries. Where in the Netherlands the fairway dues are a competence on the level of the local municipalities¹⁴², it is the competence of the regional waterway managers in Belgium. In the Flemish region, this was up to 2018 the NV De Scheepvaart and Waterwegen en Zeekanaal nv. The Walloon region has abolished fairway dues in 2006. The French national Voies Navigables de France (VNF) has a more complex calculation method in which the dwt of the ships is taken into account next to a variable part for every ton-kilometre of the vessel trip and special tariffs for the lock service. In 2018, the CTV would cost EUR 69.14 for each dwt and would pay EUR 0.001024 for each tkm. Lock service lies between EUR 31.57 and EUR 47.36 (night tariff).¹⁴³

The Rhine is exempted from fairway fees because of the Mannheim Convention. Because no reductions were found in the fairway fees for alternative fuels, the impact of this cost on the business case is less important. For the further analysis, only the port dues are taken into account. The estimate is adjusted to 2012 and a fixed port dues reduction is taken for 15% for the LNG-D and 7% for the CTV (CCNR stage II). The CTV is assumed to have a reduction until 2020 when Stage V becomes mandatory for new engines and ports will have less incentive to support stage II (assumption).

The share of the port dues in the operational costs is relatively small and therefore the impact of the green reductions is also expected to be relative. Based on the Antwerp rate for 2012 and 97 trips between the ports for one year, the port dues are estimated at EUR 15,288 for the CTV and EUR 13,973 for the LNG-D in the base scenario and for an average payload of 1,948 ton.

F. Insurance

The insurance cost of the CTV is estimated at EUR 78,560 in 2012 and derived from Prominent (2018). To calculate the insurance for the LNG-D, the ratio between the insurance and the capital value is derived of the CTV and multiplied with the capital value of the CTV. This approach can be debated, because of the possible perceived danger of insurance charterers towards the technology, although the crew members are assumed to be experienced and certified with proper LNG training. It is assumed that insurance companies do not regard the LNG-D as more dangerous or a higher risk than a CTV and that only capital value is of importance. Crew and cargo insurance remain the same.

As cited in the Market Observation report of 2016¹⁴⁴, insurance premiums are considered relatively constant owing to fierce competition between the insurance companies. Furthermore, the accident rate in inland navigation does not invite increasing premiums.

¹⁴¹ https://www.portofrotterdam.com/sites/default/files/general-terms-conditions-port-tariffs.pdf?token=3_0408y0

¹⁴² For the municipality of Arnhem passage costs are EUR 0.04 per ton (dwt) for a duration of 4 days.
<https://zoek.officielebekendmakingen.nl/gmb-2017-224570.html>

¹⁴³ http://www.vnf.fr/vnf/img/cms/Transport_fluvialhidden/avibat_tarif_2018_20180725115202.PDF

¹⁴⁴ https://www.inland-navigation-market.org/wp-content/uploads/2017/09/om16_II_en.pdf

G. Financial cost

A total of 70% of the capital cost is lent by a bank at an interest rate of 4.5% for a period of 15 years of payback time in the basic scenario for both the CTV as for the LNG-D. During the sensitivity analysis, the payback period will be changed to measure the impact of this value on the business case.

H. Subsidies

Subsidies are here taken into account for the private business case within the vessel model of the CBA. For a SCBA they are less relevant. Subsidies were given by the German government for low-emission engines between 2013 and 2016 with a total budget of EUR 1,5 million for German VOs which addressed a maximum of 30-40% of the costs of the new engine¹⁴⁵. In France a VO could apply for a direct subsidy of maximum EUR 70,000 if emissions were reduced by 30%. This support measure was active until 2017.

The Netherlands made it possible to cut taxes by investing in energy efficiency. The Energy-Investment Tax Cut was maximum 41.5% of the fiscal profit. The total cost of this measure was estimated at EUR 151 million within an undetermined time period. Until May 2015, it was also possible to receive a direct subsidy for projects that reduced emissions with a return on investments. This was funded with EUR 200,000 in 2015. The province of South-Holland gave a maximum direct subsidy of EUR 400,000 for each project that refitted an existing CTV into an LNG-D. In several dual fuel diesel-LNG projects, the European Union contributed half of the additional costs above a conventional diesel engine installation. In the model of this analysis, only an EU – subsidy is assumed to be granted with the value of half of the LNG installation, minus the costs of a diesel engine or

$$S_p = (COST_{DF} - COST_D)/2$$

The granted subsidy (S_p) for the individual vessel owner for the LNG-D is estimated at EUR 533,266 which can be granted during the first year of operation.

I. Charterers provisions

No impact of the innovation on charterers provision percentage is assumed. Provision is limited by national regulation but is negotiable between VO and charterer. The charterers provision is estimated at 7% of the earnings within a fixed long-term contract at one freight charterer according to EBIS clearance procedures and within a long-term charter. The earnings are explained further.

J. Crew cost

In the used model, the crew consists of a captain, an operator, helmsman, a boatman and an apprentice. All crew members have a back-up team to allow working in shifts during the full-continuous operations. For a Belgian vessel, the annual gross crew costs for the CTV are estimated at EUR 840,000 annually (RebelGroup et al., 2015). The minimum crew costs are EUR 425,000 and based on sectoral minimum wages (Table 60).

Annual gross crew costs	Belgium	The Netherlands	Germany	France	Switzerland	Luxembourg	average
Maximum	840,000	600,000	600,000	560,000	380,000	440,000	570,000
Minimum	425,000	460,000	455,000	275,000	n.a.	n.a.	403,750

Table 60: Gross crew cost in the CCNR MS and Luxembourg
Source: RebelGroup et al. (2015), n.a. = not available in original study

¹⁴⁵ <http://www.itb-info.be/files/cms1/eindrapport-binnenvaart-final.pdf>

These costs are significantly higher than the estimations in Prominent for this type of vessel because of a different methodology and a lower number of crew members. To ensure a full-continuous operation and to ensure enough resting time, the possibility to have an extra replacement crew, as RebelGroup et al. (2015) calculated, a higher estimate is assumed in this model.

Because there is no significant effect (except for training concerning fuelling and safety procedures) expected on the total crew cost by implementing the innovation, the crew cost for the model is based on an estimated average between the given data of the mentioned countries and between the minimum and maximum salary cost estimations. The crew cost is then EUR 486,875 annually for 2015 prices. The crew cost for 2012 is adjusted with an annual indexation of 1.8% or EUR 461,503. The training costs for the ADN exams and update courses are assumed to be included in the crew cost. The crew cost is not considered to have a significant impact from the implementation of the innovation. Extra examination costs and refresher classes for LNG experts (after 5 years) are not considered to have a significant influence on the crew cost.

K. Technical compliance

Because the CTV and LNG-D in this model have to comply to the ADN and technical requirements, they must be inspected every 2.5 years for inspection on water and every 5 years in a dry dock. The five years period also relates to the certificate of inspection (Rhine regulation) and the community certificate (EU-directive) that is valid for a similar length of duration. In addition, the ADN treaty requires a certificate of approval. These inspections can lead to additional costs if the vessel does not comply to ADN or technical regulation. If inspection does not show anything wrong, the average minimum costs are estimated between EUR 37,625 and 41,219 (prices of 2015) for each inspection in a dry dock (based on RebelGroup et al., 2015) for the renewal of the needed certificates.

These costs cover docking costs, docking days, inspection costs, standard preparation costs, cleaning and thickness surveys. The costs differ between countries, therefore an average is calculated to estimate the annual inspection cost and added on the estimated loss of revenue in the assumption that inspection in a dry dock takes up to eight days¹⁴⁶. This results in an annual value of EUR 14,025 for 2012. For the LNG-D it is assumed that the compliance cost will be much higher during the first years while the regulatory barrier still exists. After the removal of the remaining regulatory bottlenecks (since 2018) the compliance costs are expected to be more comparable with those of a CTV. The compliance costs are assumed to be 10% more than for the CTV.

L. Fuel Cost

Gas costs have two key components according to Rossert (1996): production costs and transport costs. Production costs depend on the technology that is used and differs between onshore and offshore production, but there are considerable differences between gas fields. The transport costs vary both with volumes and distance. Furthermore, the used mode causes differences within the costs. Pipeline and LNG transport by vessels differ, whereas shipping costs increase less with distance than pipeline costs but increase because of the liquefaction and regasification.

LNG is usually sold to end-users in kg and diesel in litres. An equivalent value is needed to compare diesel with LNG. The density of diesel is 837.5 kg/m³, while the density of LNG is 452.5 kg/m³ as shown in Table 61. Fuels are expressed in different calorific values (CV) according to their heating process. These different heating values or fuels relate to the water vapour during the combustion process in the engine. The combustion process of the fuel in the engine generates water vapour. Depending on the techniques in retrieving this vapour, fuels can be of high (vapour is recovered) or low calorific value (vapour is not recovered).

¹⁴⁶ which could add up to months since 2016 in the Flemish region

For LNG this can be between 13.4 kWh/kg with a net CV (NCV) and 14.9 kWh/kg for gross CV (GCV). For diesel, the net CV is 11.9 kWh/kg and the gross CV is 12.7 kWh/kg. To compare both, the gross value is chosen which is also the standard CV for the TTF spot market.¹⁴⁷

	Density	GCV		NCV	
Liquid fuels	[kg/l]	[kWh/kg]	[MJ/kg]	[kWh/kg]	[MJ/kg]
diesel	837.52	12.69	45.67	11.93	42.93
LNG*	452.49	14.93	53.75	13.44	48.38

Table 61: Energy density and energy Calorific values of LNG and diesel
Source: UK Government GHG Conversion factors for Company Reporting (2018)

The price for diesel is derived from the CBRB fuel circular list as published by Contargo (2018). The CBRB *brandstofcirculaire* is often used as a bunker list for fuel cost which is quoted in fuel annexes of charter contracts. The CBRB is a Dutch sector organization that gives an advisory price based on an unweighted average of all input from end users (Backer van Ommeren, 2011).¹⁴⁸

The prices for the LNG are derived from the TTF spot market in Rotterdam. The extra logistics cost and the loading fee at the gate terminal are added to the TTF spot prices. The loading fee which every truck must pay to load LNG is 8.67 EUR/mWh (PitPoint b.v., 2018). The logistics cost, to transport the fuel to the vessel by truck, is more difficult to calculate because of the strong variations between locations. It is also forbidden to drive into tunnels loaded with LNG and in most countries only 18 tonnes are allowed to be loaded in a truck. Against an LNG spot price of EUR 0.37 per kg, one bunkering operation costs between EUR 9,469 and EUR 10,154 for 40m³ LNG. Table 62 shows the total logistics costs for different locations of possible bunkering (truck-to-ship).

Origin Rotterdam LNG Gate		
Destination	Truck cost	Total logistics cost
Zeebrugge	€ 1,023	€ 9,992
Antwerp	€ 685	€ 9,654
Vlissingen	€ 780	€ 9,749
Moerdijk	€ 575	€ 9,544
Zwijndrecht	€ 525	€ 9,494
Rotterdam	€ 500	€ 9,469
Amsterdam	€ 695	€ 9,664
Eemshaven	€ 1,185	€ 10,154
Average	€ 746	€ 9,715

Table 62: Total logistics cost of LNG distribution to IWT
Source: own calculations based on PitPoint BV (2018) and monthly average quotation of TTF (2018)

For the cash flow analysis, the average logistics cost for one truck with a payload of 18 tonnes is added to the spot price of TTF which delivers an additional cost of EUR 2.76 per mWh. Together with the loading fee at the gate, this price is indexed accordingly the used inflation rate of 1,8%. The supplier fee (SF) is not included in the calculation and was not given by the interviewed company. This variable differs from firm to firm. For an annual assumed consumption of 500m³ diesel which obtains an energy

¹⁴⁷ Title Transfer Facility (TTF) Virtual Trading Point, TTF refers to the virtual marketplace in the Netherlands where gas is traded that is already in the European Union. As being the largest market place on the European continent, this is one of the most important references of gas prices (Gas Union Transport Services, 2018).

¹⁴⁸ https://www.evofenedex.nl/sites/default/files/inline-images/re/fb899df2a3abae8a0056e7862df02/Gasolieprijs_ICE_Betaald_Advies_2011-06.pdf

of 5,312,808 kWh (419 tonnes), an estimated 786 m³ LNG is needed or 356 tonnes. The explained calculation delivers results that are shown in Figure 43.

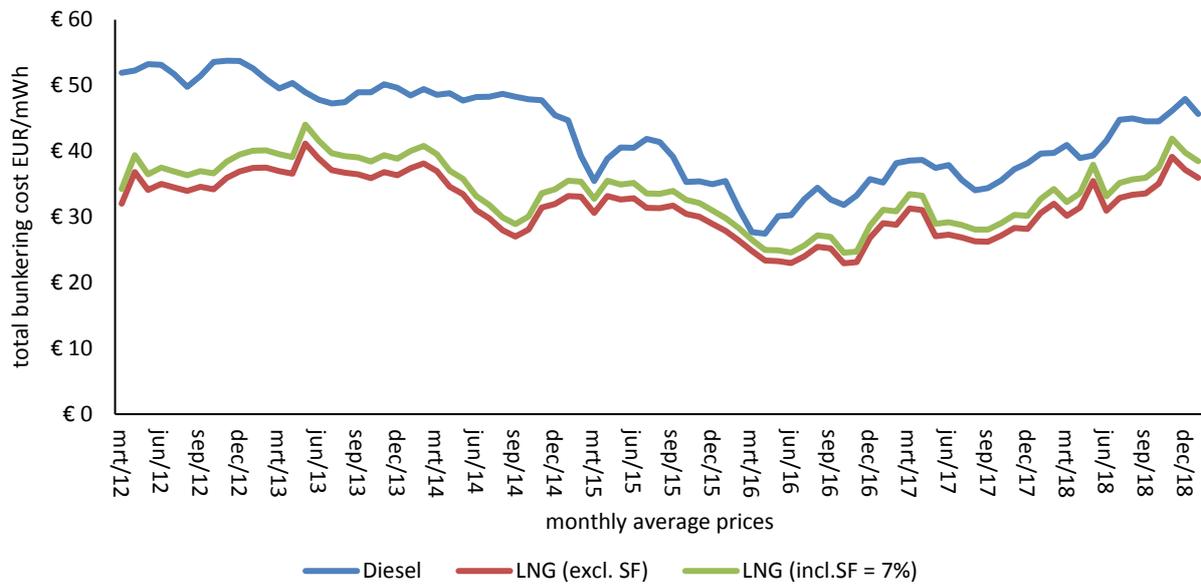


Figure 43: The price difference between LNG and diesel for TTS

Source: own calculations based on PitPoint BV (2018), monthly average quotation TTF (2018), CBRB by Contargo (2018).
SF = supplier fee

To bunker LNG at port of Antwerp, the VO must fill in a request 24hrs in advance to order the truck to come to quay 526-528. The bunkering companies need a special permit. Several ports have developed with the IAPH an LNG accreditation Audit Tool to facilitate this process for bunker suppliers.¹⁴⁹

The truck must be a special cryogenic tanker truck where low temperature of LNG (-162°C) is maintained during transport and also the hoses connecting with the vessel must be cooled down to avoid boiling off of the fuel and the methane slip. Most trucks have a capacity of 18 tons, which after regasification contains 25,600 m³ of natural gas.¹⁵⁰

The conventional way to bunker diesel is less complex and the installation of on-shore facilities or the building of conventional bunkering vessels are relatively cheaper (lower sunk costs and less uncertainty) and also critical mass of consumers is sufficient. The main reason to change and to invest in alternative fuels, are the increasing scarcity and prices of conventional fuels from an industrial-economics perspective and the increasing emissions (and regulation) from a welfare-economics perspective.

The CBA starts in 2012. The fuel costs until 2018 are monthly averages based on real market prices. Starting from 2019 the fuel prices are forecast. Because the complexity of forecasting lies outside the scope of this research, a simplified forecast is applied using trend analysis, with excel as explained in the case concerning automation.

Fuel consumption depends on the sailing profile of the ship and the number of operational hours. For the CTV in this research, annual operational hours of 4,318 hrs are assumed. The engines are not always at full power.

Table 63 shows the different consumption profiles for each CTV according to engine use which indicates that the assumptions are in line with other findings.

¹⁴⁹ <https://www.duurzamehavenvanantwerpen.be/nl/nieuws/energietransitie-de-antwerpse-haven-nieuwe-impuls-voor-lng-als-alternatieve-brandstof-voor> and <http://www.lngbunkering.org/lng/content/audit-tool>

¹⁵⁰ https://www.cryogas.pl/en/lng_facilities_-_scheme

CTV 1 diesel				
Energy output	kWh	ton	m ³	l/hrs
100%	5,708,396	450	537	124
93%	5,312,808	419	500	116
90%	5,137,556	405	484	112
80%	4,566,717	360	430	100
70%	3,995,877	315	376	87
60%	3,425,038	270	322	75
50%	2,854,198	225	269	62
40%	2,283,358	180	215	50
CTV 2 diesel				
100%	6,692,900	528	630	146
93%	6,229,087	491	586	136
90%	6,023,610	475	567	131
80%	5,354,320	422	504	117
70%	4,685,030	369	441	102
60%	4,015,740	317	378	88
50%	3,346,450	264	315	73
40%	2,677,160	211	252	58

Table 63: Annual performance of diesel engine of the CTV 1 and CTV 2

Source: own calculation based on Prominent (2018), UK Gov. GHG Conversion factors for Company Reporting (2018)

When the engine on board of the CTV 1 is used at 60%, it produces 3,425,038 kWh annually and needs 75l/hrs diesel or 270 tonnes of diesel. The calculation considers the gross heating value of diesel (12.7 kWh/kg) and a density of 837.5 kg/m³.

The LNG-D engine is assumed to offer the same energy than the conventional engine. It must be noted that fuel efficiency of the engine and loss of energy because of the methane slip, are not accounted for yet. At the end of the calculation and during the sensitivity analysis, this is closer examined.

The needed fuel can now be calculated for the LNG-D and set according to the last available prices of November 2018 (from CBRB for diesel and TTF for LNG). For calculating the fuel consumption of the LNG-D the CTV 1 is used as reference for the remaining 20% (in case of a DF with blend 80-20%). Prices are again set according to percentages of annual power for each engine. Prices for LNG include an assumed 7% for supplier fee and are delivered by TTS from Rotterdam according an average logistics cost. The results are presented in Table 64.

LNG – CTV1 (P=1322 kW)		Fuel consumption in volume		Total bunkering cost	
Energy output	Annual kWh	LNG (80%)	diesel (20%)	LNG-D	CTV 1
		ton		EUR/kWh	
100%	5,708,396	306	90	227,814	260,732
93%	5,312,808	285	84	212,027	242,663
90%	5,137,556	275	81	205,033	234,658
80%	4,566,717	245	72	182,251	208,585
70%	3,995,877	214	63	159,470	182,512
60%	3,425,038	184	54	136,689	156,439
50%	2,854,198	153	45	113,907	130,366
40%	2,283,358	122	36	91,126	104,293

Table 64: Price of bunkering an LNG-D with one 1,322 kW DF engine

Source: own calculation based on Prominent (2018), UK's GHG Conversion factors for Company Reporting (2018), CBRB cited from (2018), PitPoint (2018), TFF spot market (2018). Price LNG = 38.5 EUR/mWh and diesel = 45.7 EUR/mWh

In order to compare on a yearly basis, an average fuel cost is taken for both the diesel and the LNG cost. All the monthly averages are cumulated and divided by 12 for every year, to have an average annual price.

The forecasting part for 2019 and 2020 are based on futures as traded on the ICE ENDEX TTF, which is an industry reference for trading on long-run contracts for natural gas. The forecast for diesel 2019-2030 and LNG 2021-2030 is based on values predicted by the World Bank 2018¹⁵¹ concerning an average world price of crude oil¹⁵² and the price of natural gas for the European market¹⁵³. The percentile annual change in average price of crude oil is strongly correlated with derivatives such as diesel.

The forecast of the World Bank is expressed in constant and nominal US dollar per barrel of crude oil. The gas price is expressed in thermal unit. To fit the forecast with the data of TTF and CBRB a logarithm is used to convert the values. To change the exchange rate into Euro, an average exchange rate between US Dollar and Euro based on the period of 2014-2017 (ECB, 2018) is used with a value of 1.17 USD/EUR. The values are converted to EUR/mWh. To obtain the constant prices for the fuels, the World Bank uses the Manufactures Unit Value Index (MUV)¹⁵⁴ to deflate the nominal prices. This is applied for filling the missing gaps in the dataset. Figure 44 shows the evolution of the considered prices.

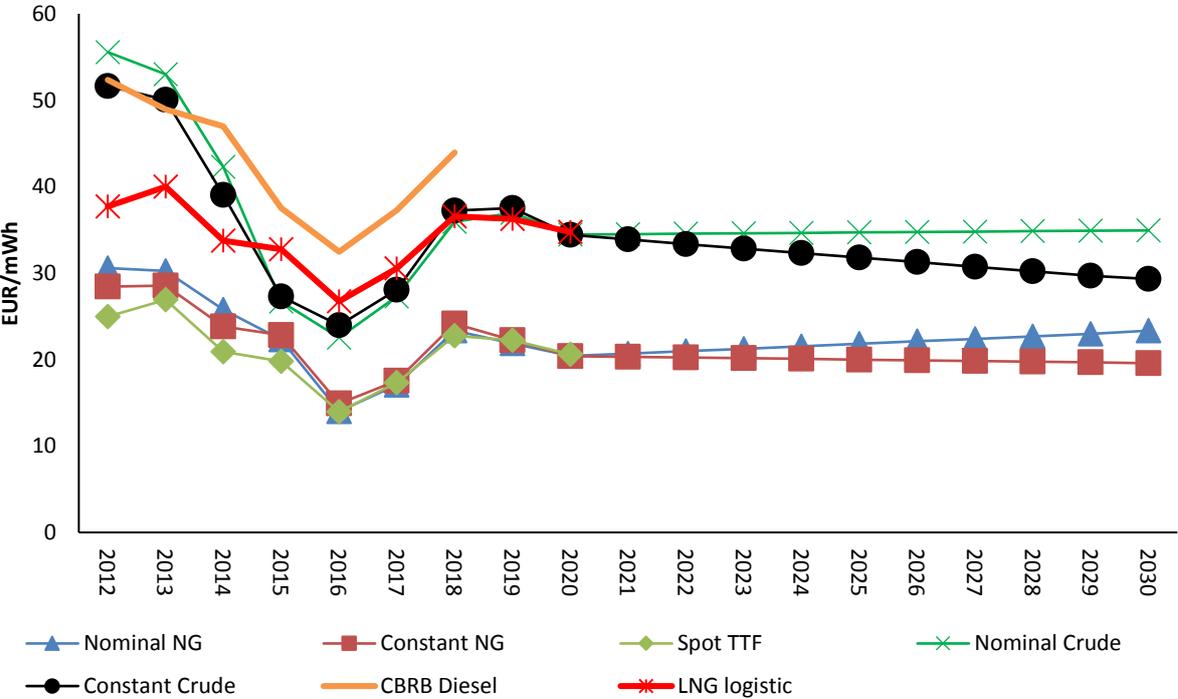


Figure 44: Forecast of fuel prices until 2030

Source: Own calculation based on World Bank for constant and nominal prices of crude oil and natural gas between 2019-2030; Gate TTF (Gasunie, 2018) for LNG between 2012 and 2018; ICE ENDEX TTF Futures for 2019 and 2020; Contargo for CBRB diesel price; MUV index of the World Bank; average exchange rate (Statista Ltd., 2018); UK Government GHG Conversion factors for Company Reporting (2018); PitPoint BV (2018)

¹⁵¹ World Bank (2018), Commodities Price Forecast (nominal and Constant US dollars), October 29, 2018 <http://pubdocs.worldbank.org/en/823461540394173663/CMO-October-2018-Forecasts.pdf>
¹⁵² Crude oil, average price of Brent, Dubai and West Texas Intermediate, equally weighed.
¹⁵³ Natural Gas (Europe), average import border price, including UK. As of April 2010 includes a spot price component. Between June 2000 - March 2010 excludes UK.
¹⁵⁴ the index is a trade-weighted average of export prices of manufactured goods for 15 major developed and emerging countries, with local-currency based prices converted into current U.S. dollars using market exchange rates.

Because of the strong correlation between the converted dataset of the World Bank and the adjusted TTF and CBRB data, these forecasts provide a basis to calculate the forecast as used in this analysis to predict the fuel price between 2019 and 2030. The same linear approach is applied for LNG and CBRB data forecast, using the same compound annual growth rate as the World Bank (2018).

As the World Bank mentions in its forecast report, the prices for natural gas and crude oil are converging as demand increases for gas while crude oil is decreasing next to an increasing crude oil supply. The developed and compiled forecast for the bunker fuel in the CBA is shown in Figure 45.

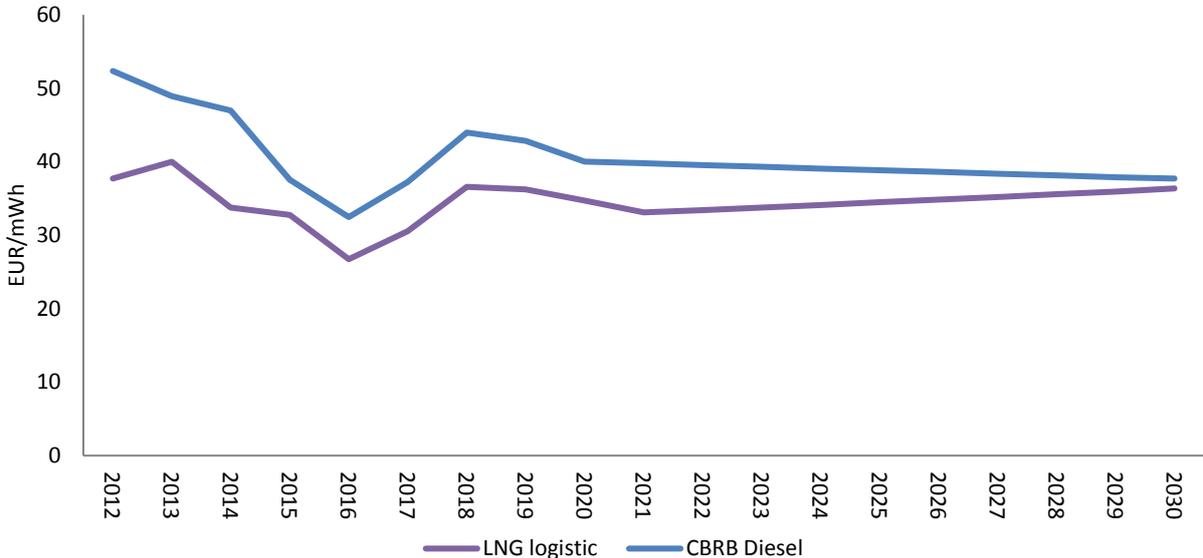


Figure 45: Forecast of bunkering price LNG and diesel
Source: own calculations derived from Figure 44

M. Taxation

Taxes imply in this analysis a similar argument as for subsidies. Taxes are relevant to view a realistic impact of the innovation on the enterprise cost structure of an IWT firm. For a future developed SCBA, taxation should be ignored. Amongst the CCNR countries and Luxembourg, taxes tend to differ (RebelGroup et al., 2015) with Belgium having the highest corporation tax (Table 65) without taking into account the Notional Interest Deduction¹⁵⁵.

%	Belgium	The Netherlands	Germany	Switzerland	Luxembourg	France
Personal income tax	50	52	45	40	44	45
Corporation tax	34	25	30	18	29	33

Table 65: Differences in taxes between CCNR members and Luxembourg
Source: RebelGroup and Van Hooydonck (2015)

Another difference is the possibility to carry back operational losses to profits made earlier. In Germany, the Netherlands and France, it is possible for VOs to deduct in such a way their losses. In Belgium, Luxembourg and Switzerland, this system does not exist, and losses can only be carried forward to the next financial year. For this model, the tax rate is chosen from the Netherlands because the majority of the tanker barges of >110m are registered in the Netherlands¹⁵⁶. Furthermore, IWT fuel costs are exempted from taxes.

¹⁵⁵ The possibility for corporate tax payers to deduct from their taxable income a fictitious interest calculated on the basis of their shareholder’s equity

¹⁵⁶ The reason why there is not chosen for an average value between the countries for the tax rate as for crew costs, is that crew costs are much more differentiated in reality. The past two decades more crew members from Eastern Europe became active in IWT on the Rhine with income taxes based on country of origin.

N. Freight rate and revenue

During this research, it was easier to find freight rate data for the tanker IWT market than for the dry bulk freight market. An often-quoted source by CBRB, CCNR and others, are the data derived from PJK international. The PJK data is used from the Market Observation of the CCNR and the European Commission of 2016 until 2018 which provided monthly freight rate data from January 2002 until September 2017. The freight rate data show a seasonal variation which is explained by changes in water depth affecting the available freight capacity of the fleet at supply side and of increased demand during fall preparing gasoil stocks for increased consumer demand during winter.

In this scenario it is assumed that the seasonal variation of low water depth periods and the demand for gasoil transport, stays stable which is even more challenging to predict and does not correspond with the forecast of the World Bank concerning the price of crude oil. Another limit of this forecast is the assumption that the supply side develops stable and that the possible increase of freight capacity meets a comparable increase in demand.

The freight rate of PJK International is based on an average month freight rate for gasoil transport by IWT bound for Duisburg, Dortmund, Cologne, Frankfurt-am-Main, Karlsruhe and Basel which are ports on the traditional Rhine (from Basel until the Dutch-German border). For methodological purposes, the monthly freight rate is recalculated according to an annual average. The seasonal variation is taken into account by including seasonal adjusting factors in the trend model forecast, which are calculated with Excel on a monthly basis before calculated as an annual average (Figure 46). This results in a freight rate that can be used for the CTV and the LNG-D model and is for both ships assumed to be the same.

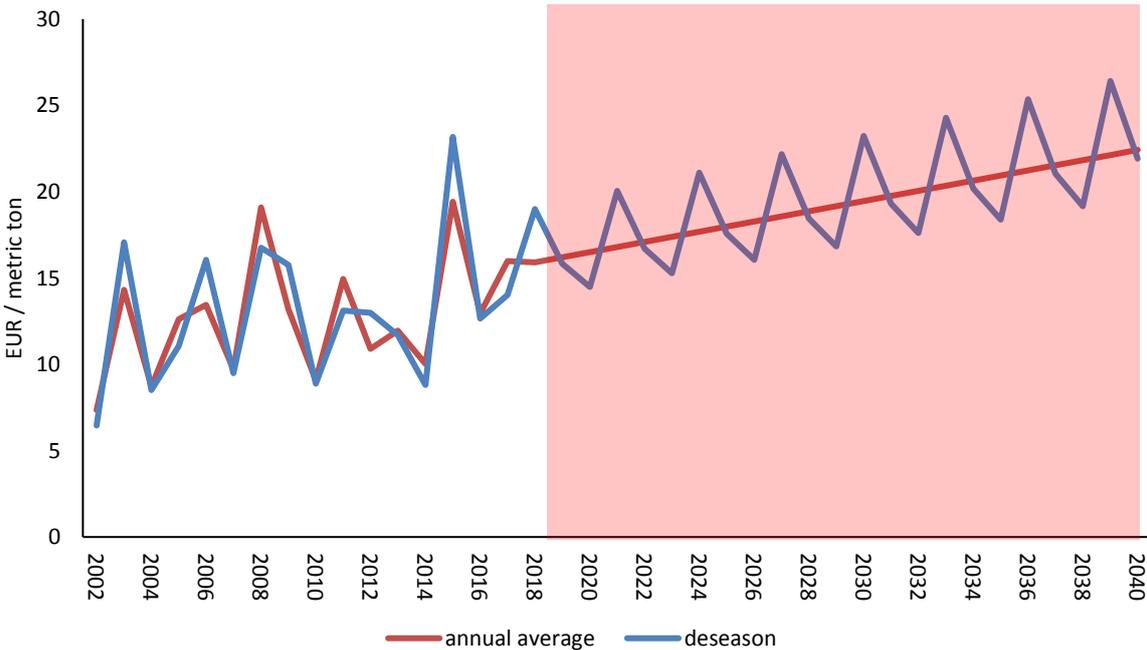


Figure 46: Evolution of tanker freight rate for the traditional Rhine including seasonal variation
 Source: based on PJK International (Jan. 2002 – Sept 2017) as reported by Market observation (CCNR, 2016 and 2018). Own forecast from 2018 (shaded area). Seasonal variation of monthly data is converted in annual averages.

The forecast is not robust and invites further research to be improved by adding other variables such as the demand for gasoil and the capacity on the market. For this research, the forecast method suffices because the innovation is not assumed to have an impact on the earnings.

To understand the seasonal variation of the freight rate, the influence of the water depth of the main rivers such as the Elbe is important. When water is low at the Rhine, fully loaded vessels can transport less goods on the river because of their vessel depth. The lower the water levels become, the lighter

the vessels must be in order to reach their destination. This results in less available vessel capacity on the IWT supply side. Consequently, skippers on the demand side must address additional suppliers with higher freight rates. Although a recurrent phenomenon, it is nevertheless impossible to predict how long these periods could last and how low the water will be. The most known and used point to measure depth for the Rhine is the Kaub measurement, which refers to the small town of Kaub at the Lorelei in the state Rhineland-Palatinate in Germany (Figure 47).

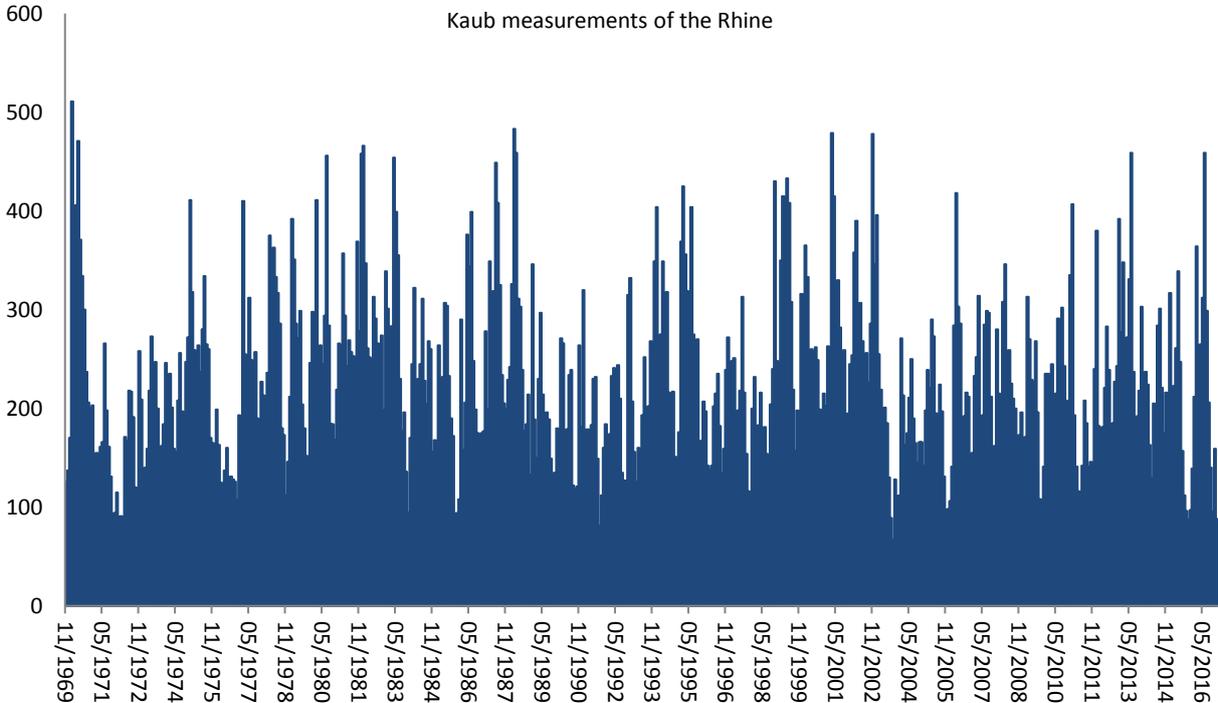


Figure 47: Water depth at Kaub between 1969 and December 2016

Source: elwis.de (2017), Kriedel N., Market Observation (CCNR, 2018)/ monthly values are averages of total days

The weight of the cryogenic tank and the LNG installation is partially compensated for by the fact that LNG is lighter than diesel. For an LNG-D with 100% performance and thus 100% annual consumption, the needed fuel weight is 396 tonnes (based on 20% CTV 1) or 464 tonnes (based on 20% CTV 2). The CTV 1 needs 450 tonnes of fuel weight and the CTV 2 needs 528 tonnes for maximum capacity. The problem lies rather in the volume. Where a 40m³ cryogenic tank only can bunker 18 tonnes of LNG for an energy content of 270,244 kWh, the CTV 1 can bunker with the same tank 33 tonnes of diesel or an energy of 425,025 kWh. This has an influence on the number of bunkering operations for each year. Knowing that not all locations allow for synchronized bunkering of diesel and LNG, the maximum number of bunkering operations at 100% fuel consumption and performance is on average 22 times¹⁵⁷ for the LNG-D (based on CTV 1 and 20m³ for 20% diesel assumed) and 13 times for the CTV 1 (with a tank of 40m³). However the tank of the CTV is smaller than 40m³. For this calculation, it is assumed to be the same. If assumed that the remaining ignition fuel (diesel) in the LNG-D is kept in a tank of 20m³, the volume of needed fuel space is then 60m³ compared to 40m³ (of the CTV).

In case of the MTS Sirocco, this problem is solved by installing two cryogenic tanks at the back and reducing living space. In case of the MS Eiger, the additional fuel tank takes the place of one container, but it is still at least 20m³ of volume that is additionally needed for fuel storage, and which reduces cargo, living space or other areas on the vessel.

¹⁵⁷ If parallel bunkering of diesel and LNG is allowed, the number of operations is still 17 compared to 13.

6.4.4. The net present value

The net present value (NPV) of both the reference case without the innovation as the project case with the innovation can now be determined and tested in different scenarios. The earnings and costs are identified and explained in the previous part. The cash flow statement is based on the revenue as explained and the different identified cost components.

Similar as in the case with the AV, the earnings depend on market behaviour and on competition with other modes. The water depth also causes a seasonal variation in annual revenue. In this case scenario freight rate data has been found for the tanker case and can be calculated and forecasted which was not the case for the AV where revenue was assumed to be fixed.

The cash flow statement is based on revenue and the different identified cost components. The net present value (NPV) of investing in the LNG-D will be determined according to different scenarios and compared to the reference case. The earnings and costs are identified and explained. The cash flow statement is based on the revenue as assumed and the different identified cost components and explained in Chapter 4. The statement of the cash-flow analysis can be found in the same Chapter. The cases and the cash flow analysis are presented in the following part.

6.4.5. The reference case: The conventional tanker vessel

The reference case describes a conventional tanker vessel (CTV) of 110m with relevant costs and benefits. The CTV is used as a comparison with the business case of the project case, the LNG-D, and shows some relevant differences in costs and benefits. The CTV provides insight in a situation where the innovation is not implemented. The inputs of the reference case are summarized as follows:

A. Inputs for the CTV

- The total capital cost is EUR 5,900,000 at the starting year of the investment in 2012. All costs are adjusted as such.
- Lifespan of the investment is assumed to be 25 years
- Gearing is 70%
- Payback period is 15 years at an annual interest rate of 4.5%
- The residual value at the end of the lifespan is estimated at 2.5% of the total investment at the beginning of the investment
- Annual operation hours are fixed at 4,318 whereas the estimated sailing hours are 1,943
- The total annual required power is fixed at 5,708,396 kWh.
- The average payload per trip is 2,908 tons at a charterers provision of 7%
- Annual trips are fixed at 97 at an average trip of 294 km
- The conventional engine has a power of 1,322 kW

B. Cash flow analysis of the CTV

The cash flow analysis with the inputs as described are shown for the CTV (reference case) by the following figure.

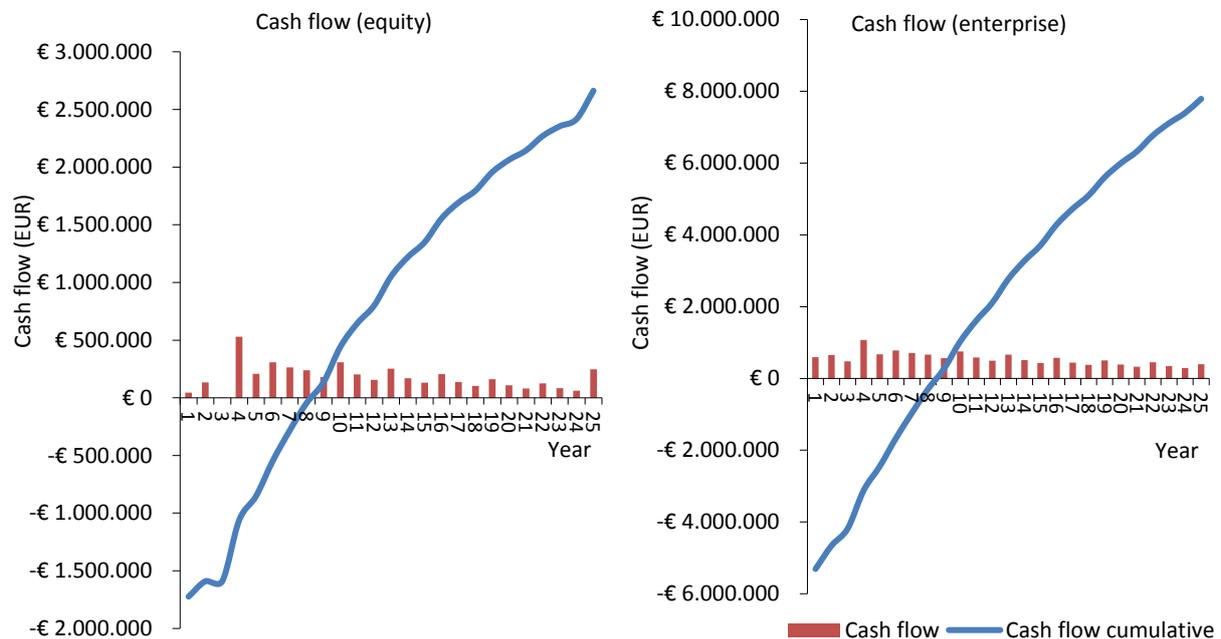


Figure 48: Evolution of cash flow of the CTV (equity and enterprise) with 15-year loan
Source: method as applied in van Hassel (2011a)

Figure 48 shows that the cash flow turns positive starting from year 8 for equity and year 9 for enterprise of the investment for the CTV. The following part shows the cash flow analysis of the project case or LNG-D. The higher value at the end of the lifespan refers to the residual value.

6.4.6. The project case: The LNG-D

The project case describes a tanker vessel of 110 m such as the CTV but with the innovation which is a dual fuel engine and a cryogenic tank. The following inputs are used:

A. Inputs for the LNG – D

- The starting year of the investment is 2012. All costs are adjusted as such;
- Lifespan of the investment is assumed to be 25 years and is EUR 6,966,533;
- Gearing is 70;
- Payback period is 15 years at an annual interest rate of 4.5%;
- The residual value is estimated at 2.5% of the total capital cost at the start of the investment;
- Annual operation hours are fixed at 4,318 whereas the estimated sailing hours are 1,943;
- The total annual required power is fixed at 5,708,396 kWh.
- The WACC is 5.36%;
- The average payload per trip is 2,908 tons at a charterers provision of 7%;
- Annual trips are fixed at 97 at an average trip of 294 km;
- Fuel price include calculated logistics, is based on Dutch spot market¹⁵⁸ for LNG and compared with BAF prices for diesel¹⁵⁹. Prices in EUR/MWh according to engine ratio 80% LNG/20% diesel
- The dual fuel engine has a similar power as the CTV (1,322 kW);

¹⁵⁸ <https://www.theice.com/marketdata/reports/80>

¹⁵⁹ <https://www.contargo.net/nl/goodtoknow/baf/history/>

B. Cash flow analysis of the LNG-D

The annual cash flow and the cumulative cash flow evolution of the LNG-D tanker vessel from private equity and enterprise perspective are shown in following figure.

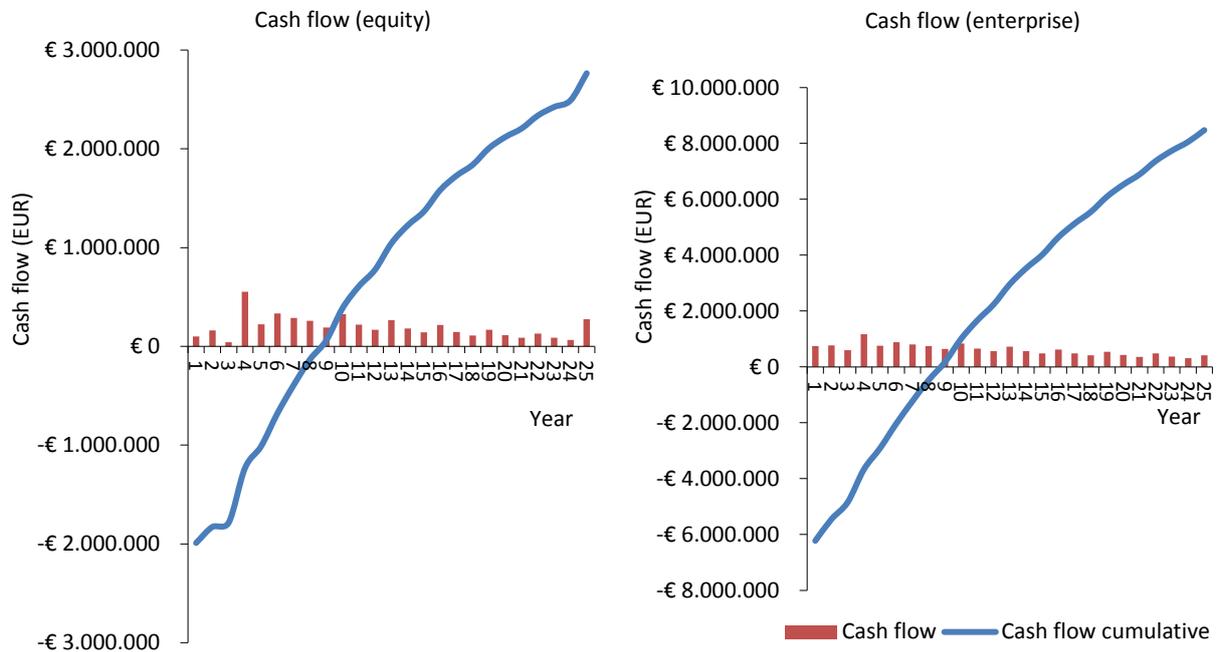


Figure 49: Evolution of cash flow of one LNG-D (equity & enterprise) with 15-year loan
Source: method as applied in van Hassel (2011a)

From an equity and enterprise perspective the cash flow analysis shows a positive result for the innovation starting in year 9. This will be examined closer in the next part.

6.4.7.Scenario-driven analysis of LNG-D

As in the AV case, this analysis investigated different scenarios where inputs are changed and how they affect the business case.

The net values for both equity and enterprise perspective are given in Table 66 together with the internal rate of return for both perspectives. The reference case has an NPV of EUR 2,662,707 which is called scenario 0.

In scenario 1, the LNG-D vessel features without other changes than only the implementation of the innovation and the expected cost changes (P&F, fuel cos, insurance, depreciation and financial costs). This is the first scenario that is compared with the null scenario (the CTV 1 without the innovation). The earnings are assumed to stay the same and the performance is assumed to be 100% of the engine power for 97 trips for each year.

Scenario 2 adds to scenario 1 a building subsidy of EUR 533,266 at the first year of investment. It shows the impact of a subsidy on the business case from an equity and enterprise perspective. Especially the cash flow of the first year of operation increases.

Scenario 3 assumes that the price of LNG increases with 1%. This has no significant influence on the business case and covers a possible loss of LNG because of a potential slip of 1% which has a similar effect than an increased price for LNG of 1%. This slip occurs in the engine or during transport where LNG could boil off and vanish in thin air.

Scenario 4 shows the impact of a price increase of 8% of LNG or in other words an 8% decrease of the spread between the prices of diesel and LNG. If LNG prices would increase more than 8%, the null

scenario scores better if the predicted diesel prices stay stable. The latter effect is shown by scenario 5 where a price increase of LNG with 10% gives a lower return on investment than the CTV.

Scenario 6 shows the impact when the price of LNG is equal to diesel. There is still a positive NPV but there is no incentive to proceed with the innovation because the CTV has a better result. A similar conclusion can be taken from scenario 7 which shows what will happen if LNG becomes 5% more expensive than diesel. The last scenario shows the impact if there were no P&F reductions for LNG and it shows the rather slight influence of P&F on the business case for this type of vessel.

Scenarios	Short description	NPV eq (EUR)	NPV ent (EUR)	IRR eq	IRR ent
0	CTV	2,662,707	392,734	19.5%	14.6%
1	LNG-D (80-20)	2,764,744	419,658	18.8%	14.2%
2	LNG-D (subsidy)	3,298,011	419,658	23.2%	14.3%
3	LNG + 1%	2,752,453	419,332	18.7%	14.2%
4	LNG 8%	2,666,416	417,047	18.4%	14.0%
5	LNG + 10%	2,641,834	416,394	18.3%	14.0%
6	LNG = D	2,505,536	421,110	17.6%	13.8%
7	LNG > diesel, 5%	2,428,859	419,550	17.3%	13.6%
8	LNG-D P&F CTV	2,750,120	418,948	18.7%	14.2%

Table 66: Net present values of LNG-D scenarios and reference case
Source: own calculations, based on van Hassel (2011a)

The scenario with the highest NPV from equity (NPV_{eq}) and second best from enterprise perspective (NPV_{ent}), is the LNG-D with subsidies. The second best is the scenario with the LNG without subsidies. The NPV_{eq} is higher than the CTV if the price of LNG does not increase more than 8%. Depending on the threshold, which is a combination of the NPV and the minimum preferred return on investment of the investors to convince them to proceed in investing, this part of the CBA identifies five scenarios that seem to score better than the CTV. It also shows that the impact of the considered port and fairway reductions are not so significant for the business case. Even if the P&F are the same as for the CTV (CCNR 2 engine, 7%), the business case still performs better than the null scenario.

As said, by applying the real fuel costs between 2012 and 2018, there is less forecast in the calculations. By doing so, the real price spread between diesel and LNG is taken into account which is an improvement of previous studies. The forecast part until the end of the lifespan which is 2041, is a linear forecast based on former time series. The earnings follow a similar approach where the PJK prices are taken for 2012-2018 and the forecast starts from 2019. The forecast takes in account seasonal variation. This is another approach than for the AV case, because detailed freight rate data from PJK has been found on a monthly basis whereas with the AV, the earnings were assumed.

The overview in Table 67 gives the inputs of the model for both the CTV as for the LNG-D scenarios for the first year of investment and the results of the cash flow analysis whereby IRR, NPV and B/C are compared.

Scenario	0	1	2	3	4	5	6	7	8
Vessel	CTV	LNG-D	LNG-D (subsidy)	LNG + 1%	LNG + 8%	LNG + 10%	LNG = D	LNG > diesel, -5%	LNG-D P&F CTV
Payback time (years)	15								
Port and fairway reduction (in % and EUR)	0% P&F costs = 15,288	7% P&F costs = 13,973							15,288
Fuel cost in year 1 (EUR)	298,836	232,021	233,744	245,802	249,247	298,836	310,789	232,021	
Compliance costs (EUR)	26,525	29,177							
Revenue	1,028,511								
NPV in EUR (equity)	2,662,707	2,764,744	3,298,011	2,752,453	2,666,416	2,641,834	2,505,536	2,428,859	2,750,120
NPV in EUR (enter)	392,734	419,658	419,658	419,332	417,047	416,394	421,110	419,550	418,948
IRR (equity)	19%	19%	23%	19%	18%	18%	18%	17%	19%
IRR (enter)	15%	14%	14%	14%	14%	14%	14%	14%	14%
B/C ratio	1.08	1.04		1.03		1.03	1.02	1.02	1.03

Table 67: scenario driven analysis of the LNG-D and CTV

The tested scenarios show similar positive results, but some are more successful than others when comparing with the reference case of the CTV (Table 68).

LNG-D – CTV	NPV in EUR (equity)	NPV in EUR (enterprise)	IRR (equity)	IRR (enterprise)	B/C ratio
1	102,037	26,924	0.0%	-1.0%	-0.04
2	635,304	26,924	4.0%	-1.0%	-0.05
3	89,746	26,598	0.0%	-1.0%	-0.05
4	3,709	24,313	-1.0%	-1.0%	-0.06
5	-20,873	23,660	-1.0%	-1.0%	-0.06
6	-157,171	28,376	-1.0%	-1.0%	-0.05
7	-233,848	26,816	-2.0%	-1.0%	-0.06
8	87,413	26,214	0.0%	-1.0%	-0.05

Table 68: Difference between the CTV and the LNG-D scenarios

From an enterprise perspective all scenarios score slightly better when looking at the NPVs, but the internal rate of return is lower. From the equity perspective the NPVs are higher for most scenario's but only scenario 2 shows also a higher IRR when compared with the reference case. This shows that the best option is the LNG-D with subsidies. Without subsidies there is less incentive to invest in LNG on an inland barge as developed in this model.

6.4.8. Conclusion industrial-economic analysis of LNG-D

The CBA measured the feasibility of the LNG dual fuel tanker vessel compared with a conventional tanker without the innovation. Although the innovation shows a higher NPV than the reference case in several examined scenarios, the internal rate of return for both equity as enterprise and the B/C ratio is rather disappointing. Only scenario 2 showed the highest return on investment. Indeed, only with subsidies the innovation is more convincing than the reference case.

The industrial-economic performance yields a too low threshold with $\Delta R_p - \Delta C_p < \times$ as visually presented in Figure 50.

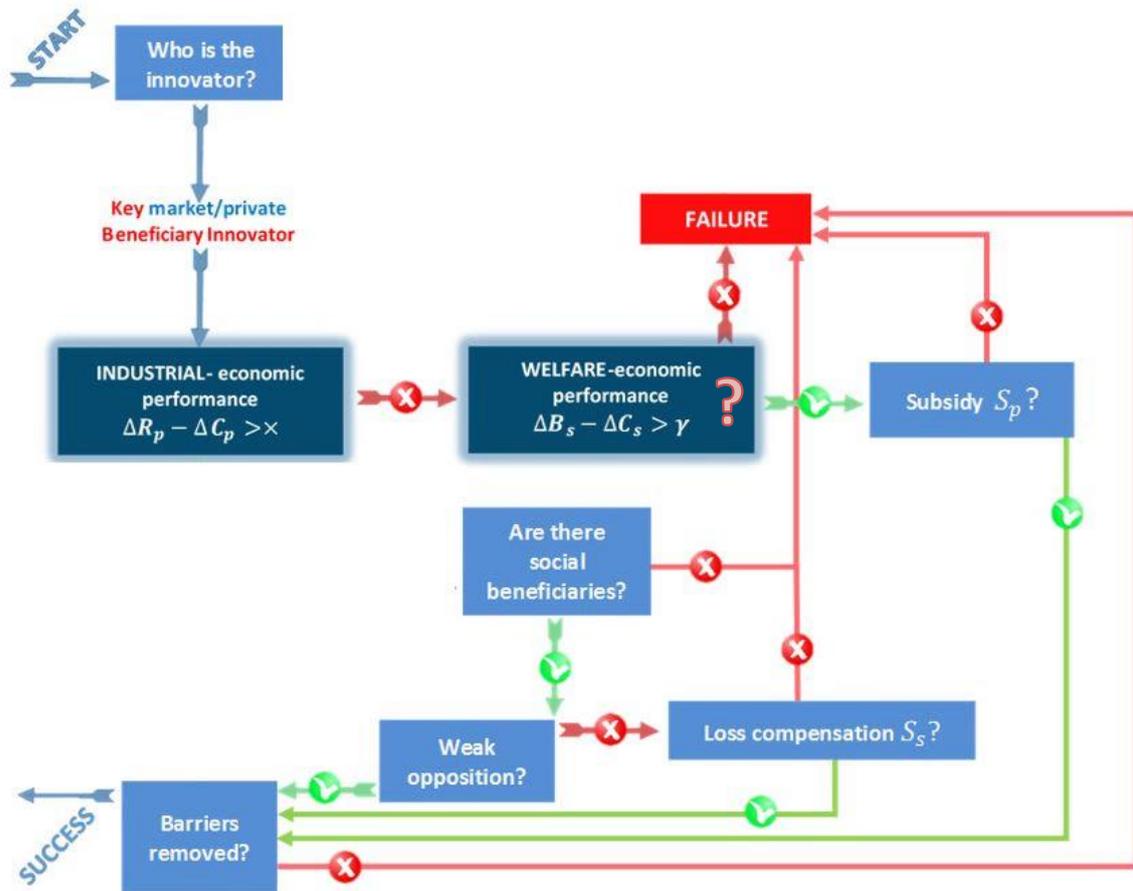


Figure 50: Innovation path of the LNG-D from welfare-economics perspective
Source: based on Aronietis (2013)

Caution is needed regarding the forecast of the freight rate and the expected earnings. They do not take in account possible changes on the market. If the service demand for tanker vessels decreases, so will the freight rate, if supply does not change. Demand is significantly more volatile than capacity supply because of the typical features on the supply side of IWT such as lack of bankruptcies, replacement rate, new building time and other aspects. Although more sophisticated calculations were developed (e.g. seasonal factors) as compared with the AV (more accessible freight rate data for tanker vessels), this is considered to be a limitation within the developed cash flow analysis.

The welfare economic performance of the vessel should justify any subsidy, but is this the case? Does the LNG-D have more benefits than the reference case from a welfare-economics perspective? This question will be answered by the following part where external costs with a special attention on the methane issue will be analysed following the developed approach of the cash flow analysis.

6.4.9. External costs of LNG-D

The external costs are reviewed and defined in sub-section 2.4.2. Concerning the emission costs, it is relevant for this case to make the distinction between climate change and air pollution. Some alternative fuel engines can have positive benefits for the environment and health, but not for climate change. The emission of CO, CO₂ or CH₄ (Methane) by carbon-based fuels still add to the global warming of the planet. In case of the LNG engines, the CH₄ waste is an important issue that invites more research or even some kind of auxiliary innovation (special after-treatment) in order to fully comply with the Paris declaration.

The main claimed social benefits of LNG are related with emission cost reduction and energy efficiency. Although, still an uncertainty, is the real incentive and engagement of the policy side, to invest in bunker facilities or to allow more of them on the main waterways. Depending on policy choice, this will have an impact on the social infrastructure cost. Except for the upcoming bunkering station in Cologne, most operations are expected to be TTS. The following part investigates first the infrastructure costs which expresses the damage that locals or the environment experience when natural habitat is destroyed to build infrastructure.

A. Emission and Climate costs

LNG is considered a transition fuel to comply with upcoming environmental regulation towards cleaner energy use within IWT. LNG is claimed to emit less pollutants in comparison with conventional diesel fuel combustion in a CCNR 2 engine. It is claimed to reduce emissions such as particular matter (PM) and NO_x. However the real impact of methane slip needs further research as real-life measurements are still not standardized and can give different readings. According to the World Energy Outlook Natural Gas report (2017), methane estimates have a high degree of uncertainty.

To estimate the emission levels, there are two key methods: “top-down”, where atmospheric concentration is measured, and “bottom-up”, where methane is measured in terms of location of the source and its volume. To estimate the effect on global warming, the ratio is estimated between the energy absorbed by a ton of the greenhouse gas (e.g. methane) to the energy absorbed by a ton of CO₂ over a given timeframe. For all GHGs, an CO₂ equivalent is calculated by using this Global Warming Potential (GWP). Most consulted literature however shows that there is no unanimity in calculating the CO₂ equivalence of methane. Values arrange from 22 to 34 which has an impact on external costs as the external cost is calculated per gram emitted CH₄. According to Ricardo/AEA (2014) as updated by Delhaye et al. (2017) the external cost of methane is EUR 2.43 / kg with a used CO₂ equivalence factor of 25.

Verbeek et al. (2011) estimated the emissions concerning well-to-tank (WTT) and well-to-propeller (WTP) for IWT in the Netherlands. This includes production, transport, purification, liquefaction, terminal storage and further distribution. They estimated this for CO₂, CH₄ and N₂O expressed in g/MJ for natural gas that is imported from Qatar by LNG carrier, from the North Sea and Russia by pipeline. Gas transport from Russia is considered less realistic for direct transport to Rotterdam. They compared LNG with heavy fuel, marine diesel oil and marine gas oil, and diesel (EN590). To calculate the CO₂ equivalent of CH₄ they used 25 as CO₂ equivalence factor. Although, the used engine data was not complete and the calculation of the inland vessel was based on several assumptions, the case study provided a method for an inland vessel of 110m to calculate the emission of methane from an LNG dual fuel engine with a slip percentage of 2.6%. This results in an average methane emission of 0.53g/MJ of the used LNG.

No other sources were found to triangulate the findings of Verbeek et al. (2011). However the values (expressed in g/MJ) can be used for the purpose of this part with necessary caution. The same is true for the values of external costs as presented by Ricardo AEA. To fit the developed engine in the LNG-D as used in the cash flow analysis, the values of Verbeek et al. (2011) are used to calculate the emitted

methane and other emissions following the used power of the engine. The values as expressed are first converted from MJ to kWh with a conversion factor of 3.6.

The external costs are calculated for LNG from Qatar and are multiplied by 80%. The external costs of diesel are multiplied by 20% and added to the external costs to fit them to the model as developed in this research. The external costs are converted into prices of 2015. For the cash flow analysis, they must be converted to prices of 2012 for the first year of operation with an annual index of 1.8%.

According to Ricardo – AEA (2014), greenhouse gasses cost EUR 100 for each CO₂ equivalent tonnes. Ricardo-AEA uses slightly other conversion factors for N₂O (290) and CH₄ (24) than Verbeek et al. which uses 25 for CH₄ and 289 for N₂O.

Table 69 shows the annual external emission costs for the CTV and LNG-D according there estimated engine power. The results are calculated for the CTV and LNG-D at constant full power and for 40% power which is more likely.

External costs WTP (prices in 2015)	EUR/kg	100% engine power (y)		40% engine power (y)	
		diesel EN590 EUR	LNG-D EUR	diesel EN590 EUR	LNG-D EUR
CO ₂	0.1	71,698	51,883	28,257	20,447
CO ₂ equivalent of CH ₄	0.1	3,650	8,030	1,439	3,165
CO ₂ equivalent of N ₂ O	0.1	0	0	0	0
Total GHG WTT		75,348	59,914	29,695	23,612
CO ₂	0.1	385,867	311,196	152,072	122,644
CO ₂ equivalent of CH ₄	0.1	0	55,337	0	21,808
CO ₂ equivalent of N ₂ O	0.1	2,086	2,086	822	822
Total GHG TTP		387,952	368,619	152,894	145,274
NO _x	11.8	592,760	279,713	233,609	110,236
PM	65.24	33,492	16,397	13,199	6,462
SO _x	14.71	288	145	113	57
Total Emissions TTP		626,539	296,255	246,922	116,755
Mechanical work kWh/y		5,708,396		2,249,703	
Energy input kWh/y		14,484,484		5,708,396	
Engine efficiency		39%			
Total external costs WTP		1,089,840	724,787	429,510	285,642
GHG WTP		463,301	428,532	182,589	168,886
Emissions WTP		626,539	296,255	246,922	116,755

Table 69: Emission costs in EUR for CTV and LNG-D in prices of 2015

Source: Own calculations with values based on Verbeek et al. (2011), Delhaye et al. (2017), Ricardo – AEA (2014)

The estimated GHG and emission costs for 2015 can now be tested according different CO₂ equivalent factors. The difference between the WTP emissions and GHG of the reference case (CTV) and the project case (LNG-D) are the benefits of the innovation.

Table 70 shows the annual nominal reduction of the WTP emissions and GHG of the LNG-D compared with the CTV, for the first 5 years and the last 2 years of the lifespan of the innovation according to different CO₂ equivalents of methane:

Index = 1.8%	CO ₂ eq. of CH ₄	2012	2013	2014	2015	2016	2035	2036
GHG + EMISSIONS	factor 25	136,371	138,826	141,325	143,869	146,458	216,853	220,756
	factor 34	128,340	130,651	133,002	135,396	137,833	204,082	207,756
Emissions		123,383	125,604	127,865	130,166	132,509	196,199	199,731
GHG	factor 25	12,988	13,222	13,460	13,702	13,949	20,654	21,025
	factor 34	4,957	5,047	5,137	5,230	5,324	7,883	8,025

Table 70: the benefit of reduction of emissions and GHG by LNG-D

The annual differences of emissions and GHG are recurrent benefits that are generated by the innovation for the LNG-D. The benefits can now be compared with the received subsidy. Imagine the subsidy was not given and put on a deposit for the same period at a low annual inflation of 1.8%. At the end of the lifespan, the net present value of the not used subsidy would be EUR 818,259.

The cumulated benefits at the end of the lifespan would be situated between EUR 154,794 (factor=34) and EUR 405,559 (factor=25) for GHG reduction. For emission reduction results are better. Here the cumulated benefit at the end of the lifespan is EUR 3,852,623.

This means that the B/C ratio for the reduction in climate change cost as benefit and the subsidy (as cost) is between 0.49 and 0.19. Only the benefit for emission reduction makes the subsidy in this case as assumed, a good investment with a B/C of 4.7.

If the policy objective was to reduce GHG as declared in the Paris declaration, the policy has failed and a scenario of doing nothing is a better option. The following figure shows the net result of the building subsidy compared with the cumulative GHG costs for methane factor 25 and 34 for only the GHG reduction benefit. In both cases, the result is negative.

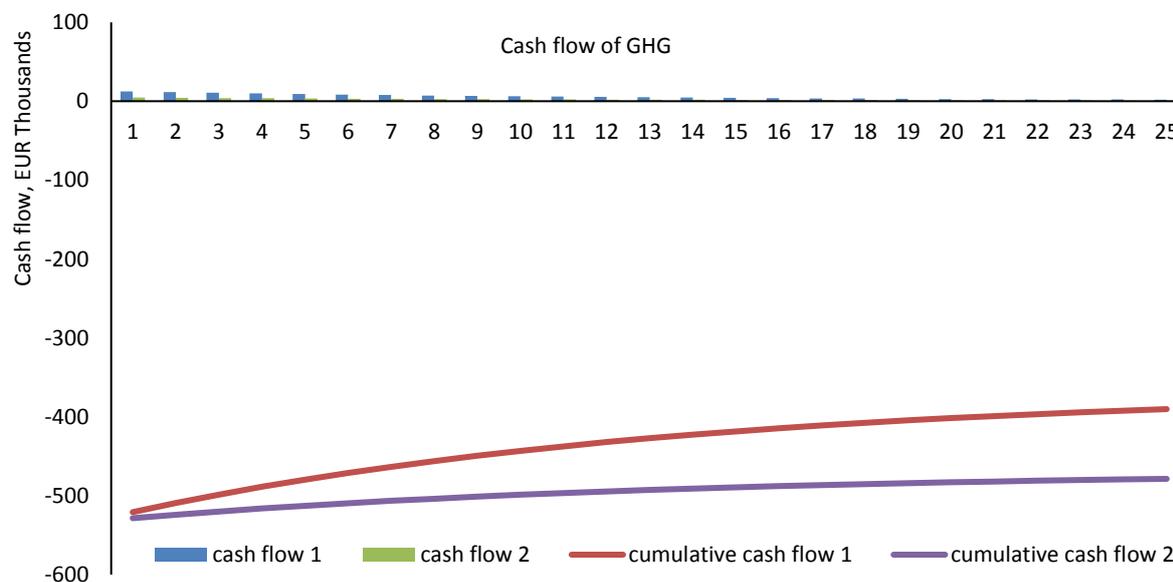


Figure 51: Cash flow analysis of subsidy targeting GHG reduction
Source: own calculations. Cash flow 1 includes CH₄ factor = 25; Cash flow 2 includes a CH₄ factor = 34

After examining the external costs of emissions and GHG, the infrastructure costs are explained in the next part.

B. Infrastructure cost

Another important challenge as mentioned, is the chicken-and-egg problem in the development of LNG bunkering but which can be generalized for all alternative fuels. Bunkering facilities need sufficient critical mass of customers (LNG vessels) to have return-on-investment. Vessel owners are more willing to invest if sufficient bunkering facilities are available, next to the potential barriers as described in the SIA part of this research.

The infrastructure cost relates to onshore bunkering but there also plans to build an offshore bunker vessel to replace the ad hoc fuelling trucks and to reduce the transport price from well-to-wheel in the last miles of the transport¹⁶⁰.

It is not in the scope of this research to look deeper in the costs and benefits of a shore-based LNG bunkering facility and to compare this with the existing diesel distribution network according to the possible differences between infrastructure costs. In further research concerning the social costs of an onshore LNG bunker station, these costs can be used to perform a complete SCBA if possible.

The costs of TTS bunkering are taken into account in the cash flow analysis as explained in part 6.4.3, paragraph L. The added logistics costs do not show a significant impact on the business case.

The analysis of the LNG-D is now considered to be sufficient to formulate an elaborate conclusion for the social part concerning external costs.

6.4.10. Conclusion welfare-economic analysis of LNG-D

The social benefit of reducing climate change cost by introducing LNG in IWT is concluded not to be significant. Only the reduction of emissions is a real tangible social benefit. LNG is still a fossil fuel which does not address the ambition of the Paris agreement (United Nations Framework Convention on Climate Change, 2015). From this perspective, better solutions need to be explored.

Caution is needed in interpreting the results within the limits of the cost–benefit model and for the analysis of the methane factor. Evidence was rather limited and not triangulated. Further research can refine this part of the analysis. Furthermore, the external costs need caution as they resemble a specific moment in time. Emissions, for example, could change by introducing new innovations or because of other dynamics that may manifest themselves such as better after-treatment systems that could recycle the emitted methane. A regular update of emission values and improved measurements (e.g. measuring the exhaust of a vessel in all situations) could indeed lead to better analyses.

Giving subsidies is in this case only justified from a societal perspective if only health objectives are the focus of the policy. The reduction of emissions could lead to a policy whereby subsidies can be used as a policy tool. When viewing the potential benefit of LNG if the main objective is climate change, the subsidy is not justified from a societal perspective. The decrease of greenhouse gases is too low to pass the threshold for the welfare-economic performance.

Figure 52 shows the innovation path so far from a welfare-economics perspective with the distinction between emission reduction (public health objective) and GHGs (climate change objective).

¹⁶⁰ During the first year of operation, the former known TMS Greenstream and Green Rhine were obliged to return from Basel directly to Rotterdam to bunker because other ports did not allow bunkering by truck and the tank capacity only allowed a round trip Rotterdam – Basel (Buck Consultants, 2015). The Port of Mannheim, for example, regulated truck-to-ship bunkering only since 2013.

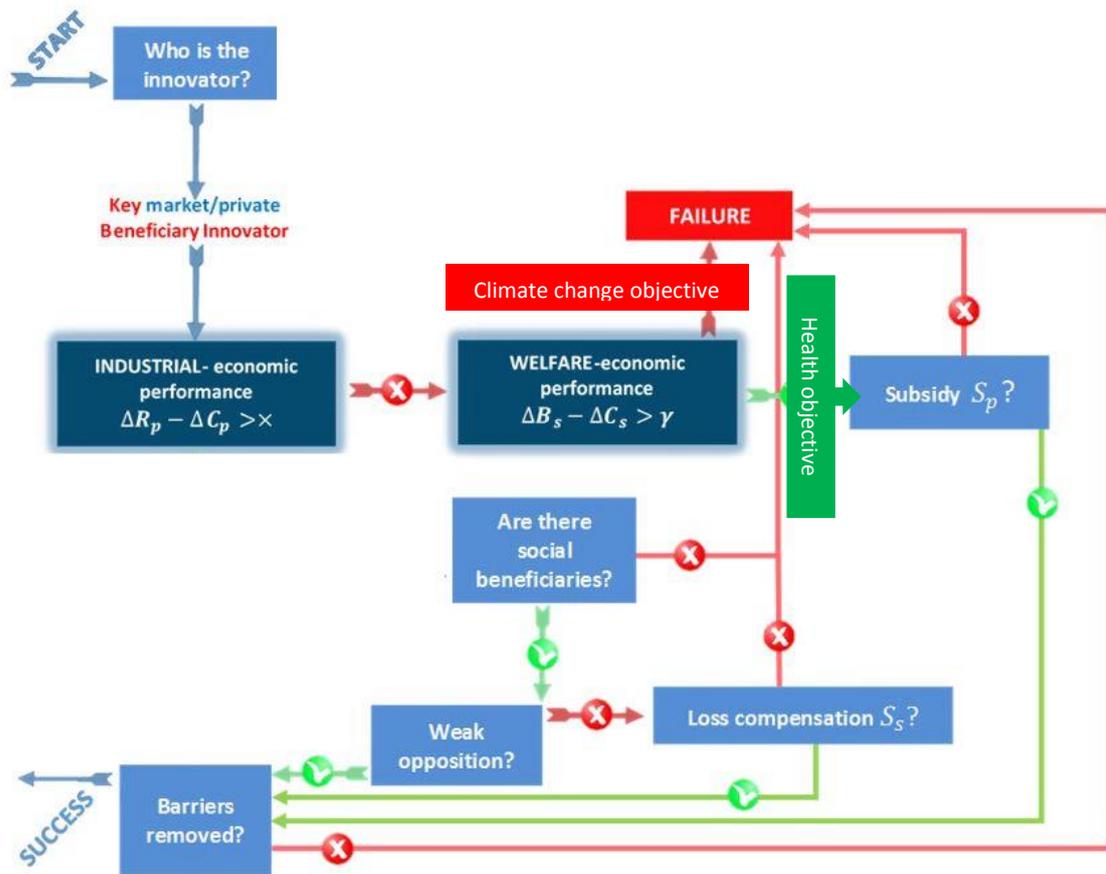


Figure 52: Innovation path of LNG-D from welfare economics perspective considering climate change and emissions
Source: based on Aronietis (2013)

Now that all the results are calculated from both parts of the CBA (private and external costs), the general conclusion can be formulated for the developed LNG-D tanker vessel model of the CBA and linked to the RQ and its sub-questions.

6.4.11.CBA conclusion of LNG-D

The following table links the results of the LNG-D cash flow analysis with the RQ.

Sub-questions Innovation	Answer
When is the innovation successful or a failure? What are the conditions that lead to failure or to success?	With too low industrial-economic performance as concluded, the innovation would fail without subsidies as investing in the conventional tanker remains more favourable according to the vessel model (reference case has higher IRR). The CBA shows that the granted subsidy costs for society is higher than the expected benefit when viewing only at climate change within the limitations of the micro-economic model. When taking into account the health-related emissions, the LNG-D shows significant benefits. Integrating the costs of TTS in the fuel price has no significant influence for the business case.
How can innovation be analysed or measured?	A similar finding applies for the AV as well for the LNG-D. The financial parameters are however mostly limited to the model. Every vessel has its own business case and special features. For the LNG-D more information for freight rates was found and to examine the unpredicted decreasing LNG/diesel price spread, the starting point of the investment was altered to 2012 which makes the CBA partly ex post.
Who are the relevant actors in IWT innovation?	The actors are the vessel owner (end-consumer who invests), ports and fairway managers (reduction of P&F); fuel bunkering firms (fuel prices, TTS); Public funding actor (subsidy); Major Shell and Total-Fina for LNG push; and engine manufacturers.

Table 71: CBA conclusion of the LNG-D

The LNG-D is not convincing for climate change as for health improvement. Policy does not have to resist the innovation if health is a more important objective. If the reduction of Greenhouse gases is more important, LNG-D does not show a convincing reduction in external costs.

The following part is developed to answer the remaining part of the RQ concerning IWT innovation policy for the LNG-D in addition to answers from the literature review and the SIA of this case. It is also the second test of this tool (after the AV-case).

6.5. PEINPA of LNG-D

As described in the Chapter concerning the institutional setting, the European IWT policy is situated within a multi-layered and multileveled policy model with competences on port, regional, national, multilateral (e.g. river commissions), European and even Pan-European level (UNECE). The past few years with the implementation of the ADN for dangerous goods and the EU-regulation referring to CESNI-standards for technical and professional requirements, the policy is slowly being reformed towards one level playing field for the entire IWT on the continent. In case of the implementation of LNG and the removal of the regulatory bottleneck, CESNI was too young to play a decisive role during this process, but it added relevant articles in its ES-TRIN concerning LNG.

The policy situation concerning alternative fuels, offers also a window of opportunity (as in the AV) because of the expressed interest of several governments, EU – funding possibilities and the fact that there is no noticeable social resistance towards these developments. Although the original aim of the research methodology of this policy analysis was to include a quantitative approach from a SCBA perspective, as in the case of the automated vessel, there was not enough material found to quantify the policy costs. Hence, the resulting analysis is more descriptive and qualitative with some exceptions.

In case of alternative fuels, it is not only from a public organizational perspective challenging to define an optimal innovation policy. Moreover, the policy objective itself, is difficult. The European Commission and other policy levels have funded and subsidized LNG and during this research it became clear that the social benefits of LNG are mostly related to emission reduction, but not to GHG reduction. From a welfare economics – perspective, the most efficient policy aims at the highest social benefit with the lowest cost.

Public actors that are relevant are also to be found outside the PEINP institutional setting that were not analysed in Chapter 3. International organisations such as the IMO also have an indirect influence on the LNG policy of the PEINP, but this is not taken further in consideration.

LNG is not only an issue for PEINP. Environmental policy is evolving to more stringent rules for engines and their emissions which probably has an impact on the development of alternative fuels. The implementation of PEINP related to LNG has therefore a strong environmental dimension with links to the upcoming and updated NRMM of the European Commission.

The next part considers the costs of policy such as the compliance and enforcement costs in relation to LNG-D. The final part of PEINPA examines different policy options for the IWT policy on LNG.

6.5.1. Costs of Policy

From the perspective of the consumer, which is in this case the vessel owner/operator, policy is considered to have an impact. Taxes, fees, penalties, port dues, and other costs for an individual enterprise could be directly linked to the government. First, the compliance costs in the business model are taken into account. Then the enforcement costs are analysed.

A. Compliance costs

Compliance costs from the perspective of a vessel owner, refers to the costs related to mandatory dry docking, inspections and surveys with respect to vessel and crew. Between the MS these required costs could differ which allows cherry picking of vessel owners/operators. Furthermore, the availability of

dry dock capacity differs between countries. There are different prices for certificates. Finally, the time between dry docks and the needed time for inspectors to perform their inspections also differs between Member States.

For the ADN treaty (dangerous goods), crews on tankers need to follow trainings in order to keep their basic or expanded certificate up to date. For LNG an extra training is also required. These additional training costs are compliance costs and are generally accounted as part of the crew costs.

The compliance costs concerning the vessel depend on the technical regulation and provisions. If the CCNR or the European Commission and now the CESNI ES-TRIN standards would require new rules of compliance such as, for example, new noise limits on-board or a standardized dinghy, this would result in increased compliance costs for the vessel owner.

With the new NRMM stage V, all VOs that have a certified engine before the implementation of the Stage V requirement, are not obliged to replace the engine with the new standard. The implementation will only affect new engines, giving a potential higher entrance price to the market through compliance costs for new starters or new engine buyers. Starters with a new vessel complying to all regulation, would have a more difficult position to compete with older market players. Especially with long lifespans, an IWT vessel of 30 years old, does often have a lighter leverage, which decreases its fixed costs compared with new starters with a loan.

In case of the first mover in PEINP for LNG-D (Daemen with the Argonon), it is not possible to quantify the efforts of the early innovator to convince the different policy makers in adjusting the regulation or grant a derogation. The innovator did not only address the CCNR in Strasbourg, but also the European Commission (Brussels) and the UNECE (Geneva) after rallying support in the MS and within sectorial organizations. Next to years of design and research of the dual fuel application on board of an IWT vessel, the compliance costs, which in this sense also include lobbying costs within the innovation network towards regulators, could be considered relatively high.

In case of an LNG-D tanker, the compliance cost is not only towards public officials. Within the tanker market, a private organization consisting of major IWT service customers and verification agencies, which is called European Barge Inspection Scheme (EBIS), also demands compliance. Without EBIS clearance, it is very difficult to operate on the tanker market.

The cumulative cash flow analysis offers a way to see what happens to the business case if compliance costs are multiplied by an assumed factor with the value of 1 until 11 (Figure 53). When the compliance costs are multiplied by a factor 11, the NPV becomes negative. The analysis is based on the project case of the LNG-D. Furthermore, the moment when the business case has a first positive cumulative cash flow, is delayed by every increase of the factor. It becomes clear that an increase of the compliance costs can cause a potential barrier for the innovation.

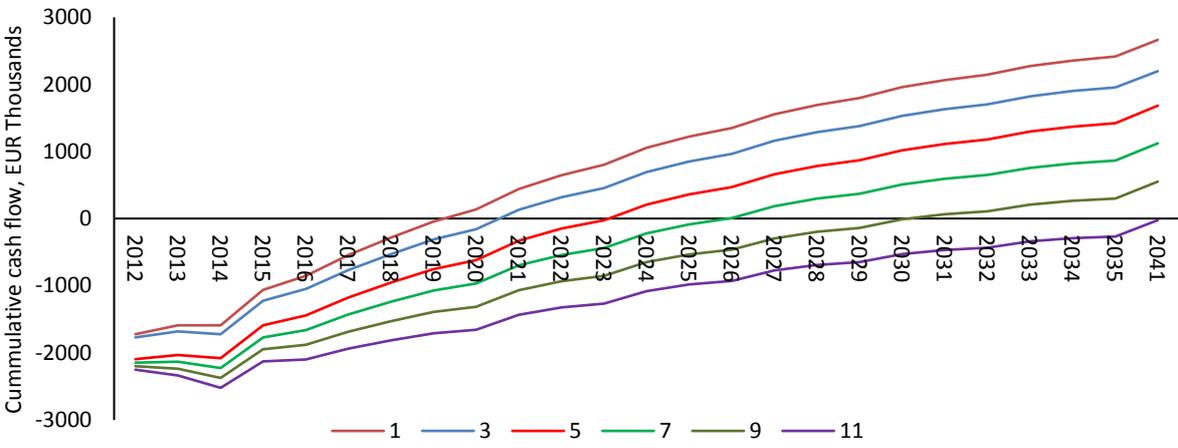


Figure 53: Cumulative cash flow analysis and the impact of compliance costs in scenario 1
The uneven numbers represent the compliance cost factor.

When an emission regulation requires a more expensive engine and exempts actors that are already on the market, the entrance fee for new vessel owners becomes higher, which could in the end limit or even slow down the market. This could be favourable for the incumbent market players with an upwards pressure on the freight rates but also could slow down the implementation of innovation.

The compliance costs from the perspective of the public actors considers the adjustment process of the existing regulation that was fragmented between the UNECE, CCNR and the EC. In order to maintain a level of coherence and maximize the level playing field, regulators had to collaborate or at least coordinate between policy levels within the PEINP. To remove the regulatory bottleneck regulations had to be adjusted before the derogation time ended of each separate vessel using LNG as fuel during this period together with other relevant PEINP actors. Standards were made or adjusted, type-approval procedures of engines and cryogenic tanks were developed and LNG vessels under derogation were inspected and judged on safety requirements to support these changes.

Verification agencies played an important role, not only for the survey of the vessel but also as lobbying experts in meetings with public actors, as well as engine manufacturers next to the first vessel owners who implemented the innovation.

On the lower levels, port authorities added safety checklists to their bylaws and some ports allowed LNG bunkering from TTS on defined locations within the port while complying on higher decided standards. Ports and MS with IWT have adjusted bylaws or policy on this topic on a differentiated way, but to coordinate these approaches, cross-border cooperation could become more necessary. For instance, bunkering with TTS differs from country to country such as the maximum LNG that a bunkering truck may carry¹⁶¹.

B. Enforcement costs

At this moment hardly any data concerning enforcement is shared between the IWT countries, which makes measurement of the effectiveness of a policy and its enforcement rather problematic concerning cross-border externalities. As the diffusion of the innovation is still quite low, no infringements surfaced yet (or not publicly) to examine the enforcement mechanism of the different levels in this case.

Concerning emissions regulation and GHG ambitions, the monitoring, evaluation, enforcement and implementation of the regulation is mainly on the level of the MS. The approaches between MS can be relatively different and depends on the means of the lower authorities. Where some countries have more means to monitor emissions (e.g. sniffers, more inspectors, ...etc.), others might have a more tolerant or permissive regime. Another problem is the lack of harmonized procedures to measure emissions in all modes of exploitation, making it difficult for monitoring authorities to perform inspections. Emissions and GHG differentiate when engines are stationary and at different speeds and this is, according to the conducted interviews, not specified enough. This is especially a problem for manufacturers. The homologation procedure of the new engine in stage V requires a relative long and expensive procedure and there are still questions concerning the type-approval procedures on-board of a vessel. This could slow down the technological innovation and can be considered as a regulatory bottleneck.

Another difficulty of the current institutional setting is the lack of data-sharing between countries. The principle of mutual recognition is based on trust and not on numbers and does not guarantee the exchange of emission data, penalties, and so on between riparian states. Policy makers are taking important steps to exchange more data such as the further development of the European Hull database or the administrative actions taken under the CDNI agreement (European treaty concerning vessel waste).

¹⁶¹ Different rules for LNG trucks with max. 18 tonnes LNG in Germany and 20 tonnes LNG in the Netherlands

Finally, the principle of proportionality in case of inspections for environmental regulation compliance, indicates that any enforcement or implementation action on a too high level would be less effective and lead to disproportional use of policy means. Indeed, appointing an agency with EU bureaucrats and use EU budget to send EU inspectors in all MS to examine LNG vessels, can be an exaggeration and not necessarily mean that enforcement policy would be more effective or even more feasible than a national one or on a lower level. This could be a disproportional method to address the challenges.

C. Credibility and asymmetrical information costs

A possible asymmetrical information cost can be situated in the context of the methane impact on climate change. In several studies a more optimistic scenario is presented related to the CO₂ equivalent value of methane and its impact on climate change which does not suggest necessarily adverse selection behaviour as methods and methane measurements improve for the calculation of these values and other literature concerning climate change. The discussion concerning the methane slip can be tracked on all explored and analysed levels of policy. Within several meetings and commissions, LNG was considered to be a transitional fuel that could be implemented rather quickly. In reality, the quick implementation was not the case for the infrastructural part, but it was relatively fast for the removal of the regulatory bottleneck by an integrated approach which can be described as a collaborative network of policy levels between public and private actors. One of the benefits of a more integrated policy approach for LNG, is the avoidance of cherry picking. Vessel owners could buy engines in those MS that have less severe emission standards if a system of mutual recognition¹⁶² is not applied rightfully.

When viewing the PEINP on LNG in IWT, the removal of the regulatory bottleneck is considered to be successful but failed in implementing infrastructure for bunkering. Although some differences still exist between the MS, the integrated approach through a collaborative network of public and private actors (vessel owners, branch organisations, verification agencies, engine manufacturers) can be considered to be successful in removing the regulatory bottleneck. The supportive policy towards LNG implementation is however rather problematic when viewing the coherence of the policy with other policy objectives (decrease of greenhouse gases).

Costs related to administration, translation, communication, employment, housing and transport are not presented here, but they do exist throughout the cycle. They are similar as theoretical developed for the AV PEINPA. No public projects are identified for infrastructure. Most of the theoretical costs of PEINP as developed in Chapter 3 are not rejected, but quantification remains an issue.

Benefits for public actors of the followed policy cycle are related to quality of policy and synergy. In this case because of the involvement of different public and private actors, the insights, knowledge of market information concerning LNG increased during the implementation.

To summarize, policy for LNG as fuel for IWT focused on a following number of policy actions so far:

- Public funding to support R&D (EU, few MS);
- Subsidies for enterprises to invest in LNG engines and cryogenic tanks (EU, few MS, provinces);
- Derogations for the first wave of LNG vessels in IWT (including inspecting and debating results of surveys (MS, River Commissions));
- Adjusting relevant standards and regulation (technical requirements, crew skills and training, bunker check list, rules on dangerous goods, type-approval) (CESNI, River Commissions, EC, UNECE)
- Assigning dedicated zones to allow TTS (ports and fairway managers)
- Discounts on port dues

¹⁶² As explained earlier, mutual recognition is explained as follows: within the rules of the internal market, standards that are implemented by a member state, are assumed to have equal objectives as in other MS and are therefore recognized by other MS.

Other policy actions to aid the diffusion of LNG were not identified to be implemented regarding LNG. These actions could involve several innovations policies, or the choice can be made to do nothing.

A fuel charge is legally not possible for Rhine IWT, the Mannheim Convention prohibits this.¹⁶³ It would be a clear violation of the Mannheim Convention which advocates freedom of navigation and forbids riparian states to tax international IWT. However as shown by the CDNI treaty, it might still be possible, if there is enough political will.

Table 72 links the public costs with the policy cycle during the removal of the regulatory bottlenecks from the perspective of public actors. The table continues on the next page.

	Input: demands and support, defining an issue	Agenda/selection of issues	Decision making	Implementation	Outcome/evaluation/feedback
costs of PEINP (LNG-D)					
Information	Input from network comprising: <ul style="list-style-type: none"> • Innovators testimonials (first vessels with LNG and engine manufacturers); verification agencies with technical studies that address national MS, River Commissions, European Commission and UNECE for the ADN; support from LNG majors • Other stakeholders are ports, sector organisations, waterway managers, knowledge institutions • Evaluation of relevant IMO regulations • Safety assessments of derogated vessels with LNG as IWT fuel • Cross-border exchange of information between Rhine countries as most LNG vessels are operational on Rhine. • Significant literature and projects, studies • Joint working group between EC and CCNR for technical requirements. No CESNI PT yet before LNG implementation. 	Identifying the regulatory bottleneck of own regulation Suggested solutions and financial complications Collaborative approach with other actors	Unanimity between MS Information on positions of MS and other relevant actors.	Monitoring diffusion of innovation and required safety standards	Not planned or identified (yet) as relevant stage for policy concerning LNG-D
Enforcement	Input from enforcement (court law, river policy, inspectors); Derogation results		Inspections, safety check list of bunkering LNG; No known infringements found		
Compliance (internal)	Consistency overview of IMO, EC, river commissions, UNECE (ADN)	Maritime and IWT legal interface, compatibility	Common PEINP approach of LNG before development of CESNI		
Project	No public infrastructure for bunkering (yet)				

¹⁶³ The convention of Mannheim prohibits charging in the Rhine fleet based on shipping. Article 1 states that only restrictions based on safety or general security. Article 3 states that all ships on the Rhine are free of duties based on shipping without forbidding port and lock fees (van Essen et al., 2004). Although the mentioned legal limitations, the CCNR started with introducing emissions standards for inland shipping in January 2002, before the EU did with the Directive 2004/26/EC when the NRMM included IWT for the first time. The first CCNR and EU standards were not similar but choose to recognize each other.

benefits of PEINP (LNG)					
Quality	Learning curve through pool of experts and consultation; private and public stakeholders	Larger evaluation capacity More funding tools	Learning curve	Output of insight and information to market	Credibility of policy
Synergy	Bringing experts regularly together can cause sustainable synergies in research and other inputs Exchange of best practices between MS No synergies related to overhead cost management across public actors				

Table 72: PEINPA of the policy cycle costs of the LNG-D

The current institutional setting of the European IWT is rather a disadvantage to successfully implement a differentiated fuel charge. MS could choose to influence the prices of alternative fuels by giving tax cuts, possibly paid by charges on conventional fuels. Of course, this is again a question that provokes rather an ideological stand point (should taxes be implemented on the Rhine?) which is not part of this research. Regardless, using a tax as PEINP tool could be quite ineffective. Especially for international IWT (e.g. Rhine IWT), it is relatively easy to avoid national taxes. This is because none of the identified higher PEINP institutions or regulators have a fiscal policy. These tools are kept on the level of the Member States, which makes it relatively easy for vessel owners, in this example, to avoid national taxes and to bunker in tax friendlier Member States, which lowers the tax revenue and could hurt the national producers that cannot delocalize the production unit in the short run, such as an on-shore bunker facility. This avoiding behaviour or cherry picking by vessel owners, despite the European internal market, could make a taxation policy less effective with the objective to decrease externalities. On the other hand, lowering indirect taxes could invite new consumers from other more taxed Member States and increase the national tax revenue.

Another option is the differentiated waterway charge (DWC). Waterway managers could charge a kilometre emission charge with the help of River Information services to provide engine emission standards information. Legally, this could require an implementation of such charges in other modes and for the Rhine IWT an amendment of the Mannheim Convention may still be needed. Differentiated port dues (DPD) are legally possible. Vessel owners in IWT are not in a position to avoid a port regardless if they do not agree with the ports policy. The disadvantage of this approach is the increased complexity for vessel owners being faced to a fragmented approach and a variety of port dues. As seen above, the different approaches between Rotterdam and Antwerp, the Green Award and the port due regulation of the Port of Antwerp, are only some of the examples that are being implemented. Besides the higher complexity which could make it more difficult for VOs to comply (higher compliance costs), the threshold of the charge, as in other policy options, determines the success. A DPD that hardly affects the business case, will only cause nuisance but not real change in behaviour.

A charging policy has the objective to change behaviour. The threshold of the charge should be high enough to stimulate investments in energy reduction. If it is too low, the VO would experience it as nuisance and policy would fail. The level of the charge is however challenging to determine and subjected to political rational.

The identified port charging rules still support CCNR II engines, but this could change in a nearby future when also CCNR II engines are charged. The usage of LNG is now supported but in a few years it could be possible that policy makers decide to charge GHGs. LNG has a much better performance for air pollutants but for GHGs it does not have such performance. If the chosen threshold is too high, shippers could choose to shift to other transport modes as lower capacity can be offered by IWT to the port. Policy also must bear in mind that charging IWT, could provoke a modal shift towards other transport modes. If this is the case, the total social costs would increase.

The investment of VO envisages a long-life span and complies with the regulation of today. This is the main reason why policy makers choose to let new emission standards only be mandatory for new engines. The main disadvantage is that the demand for CCNR II engines (still cheaper than stage III or

stage V) is expected to rise before the regulation becomes active. If the engines that are bought today would provoke the same behaviour as before (*cubanization*), it could be the case that most of the fleet will have a CCNR II or stage IIIA engine for quite a while instead of the target of upgrading the fleet to stage V.

Another option for policy makers is to do nothing and to leave the market without intervention in a business-as-usual scenario (BAU). The main benefit to choose for alternative fuels or other technologies is then solely given by the price difference between conventional fuel and alternatives. If complementary engine manufacturers could offer a relatively cheap technology and price difference becomes high enough, more vessel owners would see the benefits of change. A problem here is the size of the market. IWT in Europe is a niche market which could slow down developments of new technology. When expected profit margins are too low for a developer, the opportunity cost is too high when money and means could be allocated for more profitable innovations from the perspective of the innovator or in this case engine manufacturers.

Capacity policy as during the nineties, could modernize the complete fleet according to new regulation. But, for now, there is hardly any support of the sector or from policy makers to enrol such a policy. A capacity policy, such as the old-for-new policy could stimulate the scrapping of old ships and introduce new ones but could lead to overcapacity in certain segments. One of the disadvantages of the old-for-new regulation and scrapping funds, was that most of the new built vessels were larger vessels, leaving more of the European waterways (below CEMT III) less supplied with capacity and larger waterways more or even oversupplied with lower or less increasing freight rates as consequence. Another challenge is the difference of institutional setting. Where the EU policy of old-for-new regulation was implemented in the EU-15, it would now be the case for the EU-28.

Where the Rhine fleet has a lot of similarities in business structure, the companies on the Danube are mostly multiple vessel owners and more push&tug combinations or push convoys are active. An old-for-new regulation would have to deal with this new institutional reality but could provide significant incentives for the modernisation of the Danube fleet and their engines if desired by policy but again, the answer for the need of such a policy is subjected to political rational.

As the analysis of the PEINP concerning LNG as a fuel for LNG comes to an end or pause, as no relevant LNG related issues seem to come on the agenda anymore, the conducted policy approach so far could have been identified. Therefore, an additional part as in the PEINPA of the AV to examine different potential PEINP approaches, is here not needed. The similar is true for the final part of the PEINPA which examined policy actions (e.g. derogation impact in the AV case). The potential impact of actions such as subsidies are already explained during the cash flow analysis of the CBA of the LNG-D.

6.5.2. PEINPA conclusion of LNG-D

The PEINPA examined if there were possible transaction costs during the different stages of the policy cycle and explored the actions that were taken to remove the regulatory bottleneck. Although still significant theoretical and descriptive, the tool could not be rejected as it shows a closer understanding of the policy actor. The quantification challenge remains impossible for all costs and invites further research and more detailed cost collection on the level of the public organization.

The innovation is in the implementation period which also has a consequence for policy. The regulatory bottleneck was removed within five years of the first LNG inland vessel. During that period, vessels that used LNG as a fuel, were granted a derogation. The PEINP resembled a collaborative policy network between the identified policy levels within the institutional setting as analysed in Chapter 3. Although the main driver behind alternative fuels is environmental policy with increasingly stringent emission rules such as required by the NRM, next to an influence of other organisations (IMO), the institutional setting of the PEINP still stands.

Finally, Table 73 shows the linkage of the PEINPA on the case of the LNG-D with the RQ.

Sub-question	Answer
<p>What is (IWT) innovation policy, how is it organized and which role plays IWT innovation policy?</p> <p>Which policy measures are applicable for IWT?</p>	<p>PEINP for LNG as fuel for IWT, followed a collaborative network approach between institutions where all relevant policy actors aligned to remove the regulatory bottleneck. Between the first derogation in 2012 until 2017 this process took place.</p> <p>Environmental policy from the EC (NRMM) is considered as the main innovation push behind alternative fuels and the transition fuel LNG.</p> <p>Only policy measures that were identified were derogations (first wave of LNG vessels), public funding and subsidies from different policy levels.</p> <p>Enforcement is mainly at national and port level. Compliance between public actors was considered significant because the objective of removing the regulatory bottleneck took place on several levels.</p> <p>No synergies between levels were identified to reduce transaction costs. The implementation of CESNI is an attempt to develop synergies between EC and the CCNR but is too young to evaluate.</p> <p>Compliance costs: the first movers offered knowledge for adjusting the regulatory bottleneck. Asking derogation, legal uncertainty, lobbying for regulatory adjustment increased compliance costs in the initiation phase of LNG-D. Using LNG as fuel for IWT increases the cost of compliance for the vessel owner, also administration costs increased. These increases were not considered as problematic for the innovation to be implemented.</p> <p>Overhead costs, administration, translation, transport, housing, are similar with the AV. Efficiency gains are possible, but this requires further research and more quantitative data. This is a general remark for the PEINP and not only within the limits of this case research.</p> <p>Ports could offer discounts, but these have hardly an impact on the business case so far. It could be expected that as emission zones within ports are being implemented, an extra incentive arises for IWT to convert to innovation to meet the requirements.</p> <p>The regulatory bottleneck was removed for LNG within five years. In the broader sense, there is inconsistency with climate change objectives and the impact of methane on climate change. From health perspective, LNG offers more benefits than diesel.</p> <ul style="list-style-type: none"> • For implementing public or support private bunkering infrastructure, all policy levels failed and only TTS is possible at the moment. The decision-making process is situated on higher levels of the regional or national level. Infrastructural funding is partial national and from the EC. This is not necessarily only a public function. Cooperation with private actors is also possible and is in the case of the Port of Antwerp authorities an objective. Private actors also can take their own initiatives (e.g. bunkering vessel). • The diffusion of LNG in IWT during the implementation phase is limited. If it was the target of PEINP to stimulate diffusion, policy is not successful yet. • Public funding for R&D is mainly situated on the national and European level. • Subsidies for firms are given by national (in the Netherlands also provinces) and European level through public funded projects and pilots. • Standards were updated by River Commissions (RVIR, RPR) and the EC. The UNECE with ADN for LNG as fuel.

Table 73: PEINPA conclusion of the LNG-D

Now that all analyses are performed, the case study can be concluded, and all sub conclusions can be integrated and linked for a higher level of understanding. The SIA, the CBA and the developed PEINPA together with the analyzed institutional setting of PEINP, make it possible to perform a detailed case study of this IWT innovation so far.

6.6. Case conclusion

The LNG-D innovation offered a subject in this research that could be analysed partially ex post and ex ante. The methodological framework is replicable on other IWT innovations and the institutional setting of PEINP as developed in Chapter 3 still stands. The SIA approach delivers in-depth insight of the introduction of LNG as a fuel in IWT and gives a strong foundation for the business analysis and the PEINPA.

The following main findings emerged during the first case analysis:

- There is variety of alternative fuels and propulsion systems, but LNG has received the most attention and funding the past years by stakeholders and regulators
- Infrastructure such as bunkering facilities are critical to stimulate market uptake but seem to have their own barriers.
- Further dissemination of best practices of the pilots is necessary to convince new potential users
- Subsidies are mainly given to a few larger companies. Smaller companies (majority of the fleet) seem to find their way more difficult in the possible public funding.
- The focus is on the tanker market which is already a relatively small niche in IWT (engine builders consider IWT already as a niche). Furthermore, the tanker market just had a cold phasing out of single hulls. The consequence is that most ships already have significant leverage and young engines with relatively long lifespan.
- Cultural barriers include cubanization of engines and perception of LNG as dangerous
- Lock-in effects refer to fixed contracts with major refineries and could pose a threat for the innovation if major players change their strategy (e.g. Shell).
- There is an important issue concerning the methane slip and its potential impact on climate change. There is a need for further research into methane slip and possible solutions. Methods to recover or reuse the methane (e.g. heating) can also be considered.
- It is possible to calculate the external cost of methane from a welfare-economics perspective.

The analyses were performed after the removal of the regulatory bottleneck as described by literature as the main failure factor next to the lack of bunkering infrastructure. From an industrial-economics perspective, the results from the economic analysis are not convincing to invest in LNG engines without subsidies for the considered vessel type as developed in this model. The economic analysis gives insight in the cost structure of a tanker vessel of 110m and developed a fuel price forecast from 2019 until the end of the lifespan of the vessel next to real spot-prices and CBRB averages from 2012 until end 2018. The unpredicted and surprising decreased price spread between LNG and diesel during the implementation phase is considered in the analysis. The cash flow analysis considers external costs and showed that LNG as a fuel has a significant benefit in reducing emissions but is not convincing in reducing greenhouse gases. The latest findings of the latest IPCC Assessment Report (CO₂ equivalent factor of methane = 34) are taken into account and result in a more significant impact on climate change.

The return on investment depends on the spread between diesel and LNG which makes the business case vulnerable. In the case analysis, it was shown that if the spread was smaller than 8%, the innovation offers a lower NPV than the reference case (without innovation) with a very high price forecast of diesel. Another novelty compared with existing literature is the integration of the cost of the TTS in the fuel price. Analysis showed that if prices evolve as expected in the ex-ante part of the model, the added logistics costs on the bunker price, do not show a significant impact on the business case. Adding the TTS bunkering cost still allows a significant distance between the prices of diesel and LNG. However when the spread narrows or prices converge, the logistics costs can become a more significant burden.

For the PEINPA, it is also in this case impossible to quantify the transaction costs and the benefits of the different policy levels. The developed analytical tool is in its initiation period and needs more refinement and relevant detailed cost data. Further application can improve the analytical tool. In case of LNG, no synergies to decrease policy transaction costs were identified. The development of CESNI could offer some kind of synergy benefit but is too young to evaluate in this sense. Although some links to the institutional framework could be added such as maritime policy (e.g. IMO) and environmental policy (e.g. NRMM) which showed influence on the development of LNG as a fuel for IWT.

The following Chapter presents the final cases. I decided not to apply the full methodology on the final cases as explained in the cases.

7. SIA of e-BC and the SBC

This Chapter contains the remaining cases that were subjected to a SIA. Not all methods were applied to analyse these cases any further. All innovators behind these cases were interviewed.

The third case concerns electronic barge chartering (e-BC) and is aimed at the innovation of the chartering business. For this case study hardly any available cost-related literature was found. Cost data was therefore limited and the potential effect on the business case of a vessel owner was considered not to be significant (yet). Relevant policy for this case lies beyond PEINP and addresses other policies such as e-commerce and GDPR. Only indirectly the CMNI can be relevant as explained later in the analysis.

The final case study concerns innovation on the small waterways. Cost data of the case of the latest variation of the SBC (concept of Watertruck+) was largely kept confidential which did not allow to create a CBA as in previous cases. The current variant of the small barge convoy (SBC) is mainly led by a public innovator with EU funding. The focus on this research lies until now on private innovation in IWT.

For the cross-case analysis important findings can be compared for the SIA part with the main cases of AV and LNG-D. Finally, the case of the e-BC provided inspiration for the case development of the AV because of the automation potential of e-barge chartering. The potential effect on the business case of 1% chartering provision is integrated in a number of cash flow scenarios of the project case of the AV. The innovation does not require a significant investment of the private VO which makes a case related CBA quite unnecessary.

The following part starts with the SIA of e-BC and shows a similar structure as the SIAs of the AV and LNG-D.

7.1.SIA of e-Barge chartering

Electronic barge chartering (e-BC) relates to the chartering of a vessel by an online platform or application (*4Shipping*) and should not be confused with the online market place (e.g. *Bargelink*). Both are explained and are complementary but have different approaches.

The differences between e-barge chartering and conventional chartering (currently dominating the market) are examined. The focus of this case analysis lies on the application of 4Shipping which goes further than a virtual market place such as Bargelink. It offers shippers and skippers not only to match their needs but also to receive all required documents through the application for a relatively small cost. The subscription and chartering provision fees are significantly lower and regarded to be more competitive than conventional ones. Past similar (but failed) attempts to develop this kind of B2B applications for inland navigation were identified during this research together with familiar initiatives in maritime.

In reference with the typology as explained in previous Chapters (Arduino et al., 2011; Roumboutsos, 2015), the innovation is presently implemented with the aim to change the inland vessel chartering business. The innovation (as shown in Table 74) is considered to be:

- Technological: ICT development with a digital and online platform.
- Managerial: changes the way of managing a trip with e-documents and real-time information.
- Organizational: the shipper looks for a match online and requires another internal organisational approach than with conventional chartering. Moreover, on the side of the vessel owner, who is looking for a match, the innovation requires another organisational approach. The vessel owner looks more actively for a matching offer while in conventional booking, the freight charterer organizes this for a chartering fee or provision.

- Cultural: it demands a mental shift of changing old habits and trust that confidential market sensitive data is only used for the claimed purpose.
- Private: although some public innovators were involved at the earlier development stages with failed attempts, this innovation is pushed by private initiative.
- Semi-open: only business actors are allowed on the application. Programming and market data are kept confidential.

Type of innovation	I TECHNOLOGICAL	II TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - BUSINESS CHANGE	III TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	IV MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	V POLICY INITIATIVES (MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE)
Implementation level	Initiation		Development		Implementation
Degree of Innovation	Incremental	Modular	Systemic		Radical
Level of Success	Success		Failure		Not Available

Table 74: Innovation typology of e-BC

Source: applied typology derived from Arduino et al. (2011), Roumboutsos (2013) and Sys et al. (2016)

The innovation is used as an addition to conventional chartering. The number of registered vessels is growing but the dominance of the conventional charterer still exists. The innovation is successfully diffused in a more incremental way, but it is not clear if critical mass is reached as explained further during the analysis. Moreover, it is not known how many registered users actually use the application. In the past, several attempts were made to digitalize the process of chartering a vessel and to replace or to support the intermediary function of the charterer. In other sectors, such as travel agencies, the emergence of platforms such as *Booking.com* were quite disruptive, as were *Uber* for the taxi business and *Airbnb* for the hotel industry. The comparison with these examples of collaborative economy¹⁶⁴ and the innovative tools in IWT is not completely accurate¹⁶⁵ and lies outside the scope of this research.

In the maritime sector, several online platforms emerged the past few years, such as *vesselbot.com* which brings vessel charterers and vessel owners together¹⁶⁶. The vessel owners (VO) have the benefit of meeting new customers, of having a rating mechanism of their service, lower commission costs, less time in searching for customers and possibly less administration. Such a platform makes it easier for maritime vessel charterers to make more informed decisions, to lower the search costs for an appropriate vessel for a certain load and trip and to discover new vessels. *Vesselbot* is more than only a digital market place, it also provides e-signed charters and advisory services such as market insights,

¹⁶⁴ “Collaborative economy” refers to business models where activities are facilitated by collaborative platforms that create an open marketplace for the temporary usage of goods or services often provided by private individuals. The collaborative economy involves three categories of actors: (i) service providers who share assets, resources, time and/or skills – these can be private individuals offering services on an occasional basis (‘peers’) or service providers acting in their professional capacity (‘professional service providers’); (ii) users of these; and (iii) intermediaries that connect – via an online platform – providers with users and that facilitate transactions between them (‘collaborative platforms’). Collaborative economy transactions generally do not involve a change of ownership and can be carried out for profit or not-for-profit” (European Commission as cited by Zadnik, 2017:7)

¹⁶⁵ *Booking.com* also rents hotel capacity and resells it. *Uber* and *Airbnb* compete with the taxi and hotel industry but often operate without complying to taxi and hotel taxes or other administrative requirements (although, this has changed in a number of countries the recent years).

¹⁶⁶ *Vesselbot* (2018), company’s website on <https://www.vesselbot.com>, Athens, Greece, Rotterdam, Netherlands

route freight rate indications, negotiation facilitation and charterer party terms. It also posts fixed operations for both charterers and vessel owners. Other maritime digital platforms are *opensea.pro* and *btscoasting.com*. Most of these platforms provide an online market place but have different roles when it comes to the contractual trip planning. In the maritime sector, several liner companies also offer e-chartering through their websites (e.g. Evergreen).

In IWT sector, only *4Shipping*, *Bargelink* and the *Imperial Freight Management System*¹⁶⁷ were identified for the Rhine countries, Belgium and Luxembourg. An attempt of the charterer company Transito, with the digital platform *Shippport.eu* in 2012 failed, as did other older attempts. The following table gives an overview of identified chartering tools.

Online chartering tool	IWT	Maritime
Market place	<i>Bargelink</i>	<i>BTS Coasting, Vesselbot</i>
Digital charterer	<i>4Shipping</i>	<i>ShipmentLink</i> (Evergreen), <i>Axsmarine</i> (BRS Groupe), <i>Opensea.pro</i>

Table 75: Overview of identified online chartering tools and virtual market places
 Source: based on companies 'website (non-exhaustive)

Bargelink is a virtual market place for the European IWT where charterers, shippers and VOs find each other. It was originally intended by founders BP, Vopak, Petroplus, Marquard & Bahls and Booz & Company in Rotterdam, as a marketplace for liquid bulk. Dry bulk showed very soon much better opportunities. For using the modules on *Bargelink*, a monthly subscription is demanded of minimum EUR 30 for VOs and EUR 55 for shippers. *Bargelink* is not involved as a market player and only provides a telematics ecosystem with modules requiring registration to match cargo with transporters. Negotiation and actual contracts happen outside the platform.

4Shipping is the youngest in the identified applications and online tools. It provides online chartering services whereby the needed documents (e.g. contracts) are also generated inside the system, after the shipper and the VO agree on a price for the transport service. *4Shipping* is an online chartering tool developed by a VO which has the potential to replace the role of the charterer. Freight rates are negotiated through the platform between VO and shipper with a relatively low provision of 1% for *4Shipping*. The trip contracts are valid and exchanged through the platform. Because of the lack of e-government, it is still mandatory to print the trip documents and send them by conventional mail. Despite the latter, more than roughly 1,400 market players are already registered in the system (since the interview with the innovator in 2018). The focus lies on the spot market, but *4Shipping* also competes with relatively small charterers. In this case analysis the focus lies on *4Shipping* and *Bargelink*. Cost data of the application development was kept confidential, which makes a cost benefit analysis more difficult. For the policy analysis, the main relevant regulation is the international CMNI and the national regulations on chartering.

The SIA in this case highlights the barriers that could prevent the innovation uptake and identifies the success conditions of the innovation with a focus on interactions between a variety of actors and institutions. The innovation that is highlighted is a potential market-disrupting innovation that could weaken the dominant position of conventional charterers, especially small ones, at start in the spot market and in the longer run perhaps in the entire market. This online application for customers (shippers) and service suppliers (VOs or skippers) gives an additional marketing instrument next to more conventional ways and has a potential organizational impact on the market by disrupting the conventional charterers.

¹⁶⁷ More information on <https://ifms.imperial.systems/#/login/> and on http://www.binnenvaartkrant.nl/wp-content/uploads/2016/01/krant_201615-krant.pdf

The results are obtained from literature review, interviews with the innovator, customers and experts. The innovation of 4Shipping is already implemented with more than 1,400 registered application users, which is relatively significant and successful after two years of operation.

The innovation is now described, defined and placed in the typology. The SIA in the following parts helps the researcher to dive in the different phases of development, the innovation network and to identify failure and success factors of e-Barge Chartering with the focus on *4Shipping*.

7.1.1. Current situation

The company *4Shipping* reported more than 1,400 vessels registered. The strategy to demand 1% provision seems to be fruitful. The company reported some resistance from especially small charterers who feel threatened. The main target for *4Shipping* is the spot market of dry bulk. According to Bargelink, every month 2,000 barges offer their services for a volume of 500,000 tonnes (2018). Quite recently, they tried to export the innovation to railways, but the first attempt failed.

The conventional process of chartering a vessel is still dominant in all segments of IWT, but it reveals quite archaic components. Freights and negotiations are mainly through telephone and on-board fax machines. There is hardly any digitalization except for a confirming email from the charterers dispatch without much legal value. Several attempts were made, mainly by charterers, to establish a digital online booking platform to reduce transaction costs and to give customers the opportunity to charter much easier and quicker a vessel. However most of those initiatives failed.

7.1.2. Initiation period

According to a study of the former *Promotiebureau Binnenvaart Vlaanderen* (PBV, 2015) about the use of ICT on-board between 2005 and 2015, approximately 98% of the responding VOs (n=175 VOs) had a personal computer or tablet on board; 96% had internet access; 96% in Belgium used mobile network, only 26% used WiFi; in France 49% used mobile network and 36% had no internet connection; concerning the internet coverage on the waterways, 22% in Belgium experienced insufficient coverage, 5% in the Netherlands, 12% in Germany and 17% in France. While in 2005, only 54% of the total respondents had internet on board. This number increased significantly, although complaints still exist concerning full network coverage.

Several early failed attempts of digital innovations with the focus on bringing supply and demand together can be identified from desk research (Dullaert et al., 2005; Nieuwsblad Transport 1997). In 1998, publisher Wolters Kluwer started with Teleship¹⁶⁸, following the example of Teleroute for road haulage (the latter is still operational for road since 1985). The web-based intranet offered a supply and demand system for the inland navigation. The innovation failed within two years. Hardly any VOs, even if they had internet connection, felt the need to participate in this system.

A direct competitor and other failed innovator was *Just-In-Time Bevrachting*, which was an initiative of VOs. Coming from the very popular Dutch IWT internet forum at the end of the nineties and beginning of this century Vaart.nl¹⁶⁹, the VAART-VRACHT was created and failed. Another failed attempt was BIVAS (Binnenvaart Intelligent Vraag en Aanbod Systeem¹⁷⁰) which was an INDRIS project¹⁷¹ from the Flemish government. The latter public-driven innovation failed despite special training courses for VOs. All these developments came at the eve of the upcoming liberalization of the

¹⁶⁸ More information can be found on <https://www.nieuwsbladtransport.nl/archief/1997/11/22/teleship-volgend-jaar-van-start/> and on <https://www.agconnect.nl/artikel/binnenvaart-mist-kansen-zonder-it>

¹⁶⁹ The former popular website Vaart.nl showed a record number of captures in 2004 (16.7 thousand). In 2018 there were 53 captures. The webpages of the mentioned failed innovations disappeared from the internet.

¹⁷⁰ Inland navigation intelligent demand and supply system

¹⁷¹ INDRAS, Inland Navigation Demonstrator for River Information Services. European 4th RTD Framework Program, between 1998 and 2000, final report (ten Broeke, A., 2001)

sector and the abolishment of the system of chartering by rotation (EC, 1996) and were developed within the European implementation of River Information Services which was started in 1998.

A number of reasons why these innovations failed are identified as the lack of intelligent components and ‘real-time’ decision support; sufficient actors that were willing to share confidential business data; standardization and harmonization of systems and data exchange, trust on the side of the VOs and the lack of a ‘trusted third party.’

In retrospect, during this research and with the findings of the PBV study, other general reasons why these digital innovations failed could be added:

- The required subscription fee while internet cost was relatively high, especially international
- Not even half of the VOs had internet on board during this period;
- Network coverage and GPRS were not everywhere available;
- Communication costs were relatively high;
- Incompatibility with other existing systems;
- Cultural: privacy-aspects in the exchange of confidential data with government.

In the initiation phase the needed infrastructure was not sufficiently available on the side of VOs, of which only half was reported to have a personal computer and internet connection on board as shown in Table 76. In parallel to the ICT – infrastructure, connection speed was relatively slow and 3G coverage was not everywhere accessible. Subscription fees to participate in the first systems above the relatively high communication costs, was an extra barrier (financial capability). Sector organizations were aligned and in favour of these developments, European and national funding were available and research at knowledge institutions was conducted within the first RIS activities. Shippers and forwarders are considered to have the capabilities to use the digital platforms but did not find sufficient loading capacity on these platforms.

Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties’ lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Institutions				
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 76: System of innovation matrix in the initiation phase of e-barge chartering
 Source: based on Aronietis (2013): Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

7.1.3. Development period

During the development of 4Shipping and Bargelink, the digital infrastructure improved drastically. With the further enrolment of the 3G network, the upcoming 4th generation (4G), the broad market uptake of tablets and smartphones, the further liberalization of the telecom sector with more relatively cheaper telecom operators and the new European roaming policy gave incentives to the entire economy and certainly international inland navigation. Better systems, more compatibility, faster data sharing, more accessible interfaces and mobile applications, gave more fertile ground for new attempts. The company combines and builds on more advanced technology and knowhow but also shows (as *Just-In-Time Bevrachting* and others tried) a genuine link with the sector to gain trust and credibility. The software development made it possible to charter a vessel in real-time and allows to automatically generate the needed documents. Learning from failed attempts, improved technology

and digital infrastructure, and more vessels with at least a basis ICT equipment (minimum a personal computer with internet access), made it possible for these new attempts to further digitalize the business. The further implementation of RIS key technologies such as Inland AIS and Inland ECDIS (supported by Directive 2005/44/EC) provided indirectly more possibilities for these B2B IT solutions.

The digital infrastructure with more than 90% of VOs connected, are identified as success factors during this development period (Table 77). The economic crisis of 2008 reduced the offered volume on the spot market. The crisis had as effect that more VOs tried to have a fixed contract with a conventional charterer. Capability is therefore considered as a failure factor. Roaming costs are still relatively high during this stage. Network effects are monitored because of the low interest of container and tanker fleet. Mostly the dry bulk spot market is the main target. The tanker fleet still seems too strongly linked with conventional charterers.

Institutions \ Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 77: System of innovation matrix in the development phase of e-barge chartering
 Source: based on Aronietis (2013): Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

7.1.4.Implementation period

Skippers use the innovation as an additional service above conventional ways of doing business. This shows that the digital charterer has not reached enough critical mass of sufficient supply and demand (yet) to become the dominant charterer on the market. However as *4Shipping* experiences market uptake, the conventional charterer systems could be significantly disrupted over time.

Most failure factors are considered to be removed in this period (Table 78), except for the lock-in effects (as explained in the methodological framework) in other segments of the IWT market such as the tanker fleet. The interaction conditions are not fully installed, and it is not certain if critical mass can be obtained by the innovation with only focusing on the dry bulk spot market. The detailed analysis will further explain these findings.

Institutions \ Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 78: System of innovation matrix in the implementation phase of e-barge chartering
 Source: based on Aronietis (2013): Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

The applications and databases are kept confidential and are only visible for registered users. This corresponds with the vital target of building trustful relationships within a closed market structure which is unlikely to give confidential business data that easy.

Of course, not all tasks of charterers can be replaced by an internet service (yet). As mentioned, mostly relatively large charterers add more value on their basic service of chartering a vessel towards a VO. Often they provide loans, co-investments, administration and compliance support to VOs. Trust, genuine link and accessible and affordable sufficient infrastructure on board and on shore, low admission costs, an easy interface and basic internet knowledge at users' side, sufficient critical mass of service supply and demand (freights, market actors), are so far identified as factors that could lead towards success or when absent towards failure. The factors or conditions as mentioned in the SIA matrices are more detailed analysed in the following paragraphs.

7.1.5. Innovation conditions

The innovations still face potential failure or success factors that could possibly prevent further market uptake. These factors are now grouped by three conditions as explained in the methodological framework.

A. Infrastructural conditions

Main concerns are the data safety and quality within the digital infrastructure. Data breaches can scare new and old users to work with such applications. Any lack of these factors damages trust and could even lead the innovation towards failure.

One of the elements that led to failure of comparable e-barge chartering systems at the beginning of this century, was the lack of sufficient digital infrastructures and connected users. At the end of 1998, less than half of the VOs had internet on board and telemetric advancements were too limited. Connections were slow and network coverage was insufficient to reach critical mass. Prices for wireless data (second generation GSM/GPRS/EDGE and WAP technology¹⁷²) were relatively high, especially with international roaming which was often the case during trips. Until the European Union made it possible to abolish the roaming costs within the Union, VOs carried and used several SIM cards of German, Dutch, French and Belgian operators to lower these communication costs.

B. Institutional conditions

There is no dedicated international regulatory framework for this type of business in the European inland navigation. The relationship between charterers and VOs is still mostly regulated at national level and is based on a conventional freight charterer with paper documents.¹⁷³ The differences between national regulations concerning chartering are solved by the binding nature of the State flag where the contract is made. However the innovation can pose practical concerns to identify the genuine link of the contract to the State.

In the European context, the CMNI (Treaty of Budapest concerning the contract for transport of goods on the inland waterways) is relevant to consider in this analysis. Article 11 of Chapter 3 of the CMNI describes the required transport document and demands them to be original copies but it does not rule out electronic ones. For inland navigation, the VO is obliged to prepare a transport document. This original transport document needs to be signed by the transporter or the representative of the transporter. The transporter can require the sender of the goods (shipper) also to sign the transport document. The CMNI does not rule out electronic signatures if the procedure is not in conflict with the

¹⁷² An interesting paper that describes the development of the digital infrastructure is Wang, C. X., Haider, F., Gao, X., You, X. H., Yang, Y., Yuan, D. & Hepsaydir, E. (2014). Cellular architecture and key technologies for 5G wireless communication networks. *IEEE Communications Magazine*, 52(2), 122-130.

¹⁷³ For Belgium, this is the law of the inland navigation chartering (Wet op de binnenbevrachting/Loi sur l'affrètement fluvial) from 1936.

national regulation of the State where the transport document is published. A bill of lading¹⁷⁴ is only mandatory if required by the sender of the goods and if this was included in the contract prior to receiving the goods.

In 2000, the European Commission published a directive concerning electronic trade (European Commission, 2000a)¹⁷⁵ that required MS to consider electronic documents or contracts as equal with paper ones. However according to Gobel (2015:27), not all courts seem to accept an electronic bill of lading for maritime transport. Moreover, the electronic signature is not everywhere accepted as legally equal with an authentic signature on paper. Although Gobel studied the maritime bill of lading, many of the bottlenecks for the electronic transport documents for inland navigation could relate to comparable concerns. Another aspect of the regulatory framework for this type innovation is the policy according GDPR (European Commission, 2016c) and data security, but also this lies outside the scope of inland navigation policy. The applications will need to comply to rules of GDPR and data security.

As the CMNI is still rather easily avoided if agreed on by contract parties (Kroos, 2011), national regulation remains dominant. The contractual parties replace the intermediary conventional charterer by a one percent provision digital chartering platform and agree on the content of the contract, within the legal boundaries, which is automatically formed by the platform. There is no proven cross-border legal certainty of the digital contracts in courts. Leaving the paper document requirement behind facilitates the further development of e-barge chartering applications.

After studying the CMNI and the national legislation, it is not clear whether a complete digital system without paper documents already has the same legal value in court as original paper has. This uncertainty makes VOs and customers still to prefer paper documents, which makes a full digital application without paper prints not yet possible, but which is considered merely as a small discomfort in the use of the application according to the innovator. Even though the identified regulations require several original transport documents in paper such as the bill of lading, they do not form a significant barrier for a digital booking platform to facilitate market transactions.

Resistance of existing charterers was reported by some respondents during the interviews. It can be assumed that conventional charterers could convince VOs not to use these platforms. It could be the case that this conservative resistance influences the further implementation of e-barge chartering. The level of conservatism could delay and, in some cases, endanger individual companies (innovator and customers). The potential resistance and impact need further research. Another strategy, contributing further to e-barge chartering implementation, is that conventional charterers embrace this technology and develop their own systems (e.g. *Imperial Shipping*) or look for ways to adapt to the existing ones.

In the case of e-barge chartering, it is not always clear if the legal basis is at hand for this kind of collaborative economy (Zadnik, 2017) in international transport. This juridical question lies out of the scope of this research and should be answered by international or national case law, if there would be a juridical incentive to do this. The reported resistance is still rather individual but as market uptake increases, resistance could become more organized.

Chartering a vessel electronically has the potential to make IWT more transparent for shippers. Transport service offers can be compared and the additional costs of a conventional charterer as an intermediary are replaced by the lower chartering provision. Resistance of shippers is therefore not expected as the use of e-barge chartering is beneficial for them. By replacing the conventional charterer by the innovation, chartering a barge has the potential to become relatively cheaper for a

¹⁷⁴ The bill of lading, as in maritime, is a transport document that is part of the transport contract and is an important proof of receipt of the goods and of the state that they are in before, during and after the transport. The owner of the goods is the one that owns the bill of lading. In inland navigation, a bill of lading is not mandatory but if it is included in the transport contract, it is also considered an important document of value, as in maritime law.

¹⁷⁵ EC (2000a), Directive 2000/31/EC of the European Parliament and of the Council of 8 June 2000 on certain legal aspects of information society services, in particular electronic commerce, in the Internal Market ('Directive on electronic commerce') <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32000L0031&from=EN>

shipper. Skippers have the benefit to pay less chartering provision costs than with a conventional charterer.

Furthermore, in general, the social benefit of a competitive, modern and sustainable inland navigation, lies in the potential modal shift from less sustainable modes of transport with higher external costs such as congestion, emissions, energy, infrastructure and accidents. If the B2B application of the e-barge chartering can make IWT more accessible, transparent and even relatively cheaper, more shippers could be attracted to use this more sustainable mode.

This potential social benefit was one of the incentives¹⁷⁶ behind the development of a similar competing public driven innovation. It inspired Dutch members of Parliament to explore the possibility of a mandatory and public online auction platform as some literature suggests¹⁷⁷. The Dutch parliament accepted a motion¹⁷⁸ to support the launch of a two-year pilot project for a public auction system for the spot market which was called AGORA. The Dutch government finally rejected the motion in June 2017 and referred to the existence of *4Shipping* and *Bargelink* which would be threatened in their existence and to the European market regulation¹⁷⁹ that does not allow such a regulated IWT market.

C. Interaction conditions

Network effects as Shapiro (1999)¹⁸⁰ describes, are clear in this case. The more users that are registered on platforms such as Bargelink or 4Shipping, the more value the services will receive. Critical mass is reached when the number of registered users (both VOs as forwarders) is at a point that the obtained value of the service becomes higher than the actual price to register and to use the service. Early adopters have the advantage to gain knowledge and experience on how to use the technology but also to have more market insight in offered freight rates directly from the customer.

A lock-in effect is identified outside the spot market. According to several VOs, it is not always easy to switch from a charterer to another one. Particularly in the tanker fleet, the system of the European Barge Inspection Scheme (EBIS) requires that the vessel and the conventional charterer are regarded as one unit towards charterers. Switching to another charterer often means that the vessel needs to be inspected for a new EBIS report, which can take several weeks (FBB, 2013)¹⁸¹ of non-activity and makes it less likely to easily use new ways of chartering.

The incentive to participate in the spot market is for most VOs in the tanker fleet relatively low. The level of complexity in dealing with EBIS, ADN requirements and negotiating with sizeable actors such as BP, ESSO, TOTAL-FINA and others directly, explains partially why most VOs in the tanker fleet depend on specialized charterers that divide the compliance and overhead costs on several ships and have more experience with dealing with such relatively large customers. The services or added value of these charterers is not to be underestimated in this segment.

Despite being originally intended for the tanker fleet, Bargelink therefore quickly shifted its activities and started focusing on the dry bulk spot market as did 4Shipping.

¹⁷⁶ Other incentives related to the economic crisis and claims of skipper organisations that the transport pricing was not transparent and sufficient to cover operational costs of the VO.

¹⁷⁷ Van Dijk (2012:22-23) describes the need for an e-market for auctioning freight contracts and for cooperation, but leaves the details of the suggested auction system open for debate.

¹⁷⁸ Motion for parliament, Smaling & Jacobi, 22 February 2017, Tweede Kamer, nr. 140

¹⁷⁹ Schultz M.H.(2017), Letter of the Minister of Infrastructure and Environment, Den Haag, 6 June 2017, nr. 158

¹⁸⁰ Carl Shapiro and Hal R. Varian (1999). Information Rules. Harvard Business School Press.

¹⁸¹ As discussed in the meetings between the European Commission, the Federal government of Belgium and the sector organizations, Federatie Belgische Binnenvaart, Nota EBIS-problematiek, Binnenvaart tankschepen Overleg EC – FOD – FBB, 27 november 2013, 7p.

C.1. Capabilities

The registration at *4Shipping* is free and chartering happens with 1% provision cost. At Bargelink, the use of the modules costs a relatively low monthly fee. Only internet access is needed. As PBV (2015) shows, the penetration of basic internet connection and necessary devices on board is a nowadays a fact on most ships.

Capacity can be understood broader and can refer to the intellectual or organizational capacities of the potential users. Even if a website or an application is as user-friendly as can be, it is possible that some potential users still find it difficult to enter. Not only basic knowledge is needed (e.g. using an internet browser or a mobile app), but also sufficient time and valid incentives to learn to use these kinds of applications is crucial. Continuously investing in digital education can broaden the capacities to participate in digital innovation much more easily.

From an innovator perspective, the support of major companies behind the development of Bargelink had a positive influence on the innovation to survive where others failed. Nowadays, there are several examples in other modes which are quite advanced and give a supportive knowledge based on further developments for IWT.

C.2. Market

Most registered VOs on the e-barge chartering platforms that actively use these applications, do not depend only on digital chartering. The tool is considered for the moment to be rather additional next to conventional ones.

The innovation must deal with the limitations of the spot market and with existing (sometimes long-term) ties between conventional charterers and VOs. The ambiguous relationship between VOs and charterers is still dominant and as existing charterers are looking for new ways to make their core business more efficient with digital applications, such as Imperial Shipping, it could be more difficult to disrupt the dominance by one of the mentioned firms. Nevertheless, the possible disruptive features of companies such as the *4Shipping* application and the resistance of conventional dominant charterers can evolve comparably with the emergence of online booking platforms such as booking.com and the travel agencies, whereas many of them failed in adapting to the new reality. Only travel agencies that offer added value or more service than the digital booking platforms manage to survive. In a comparable scenario, only the charterers that offer additional services (such as credit lines, co-investor in VOs new investments, overhead and administration or others) and use digital applications could maintain their position on the market. The comparison with the tourist sector should be understood with necessary caution. Indeed, the hotel sector has a significantly high number of service suppliers and a global consumer market whereas the numbers are much smaller in IWT.

Only in the Western-European fleet a high number of VOs are active. In the Danube basin, most vessels are owned by former state companies and these are still relatively large in size. The charter system differs between the Danube and the Rhine: whereas charterers offer an intermediary branch in Western Europe, in the Danube basin, customers usually call the owner directly, which usually has multiple vessels.

Next to market size, other innovations are finding their way to inland navigation, which could influence the business case of digital platforms. For example, if vessels become fully automated or perhaps autonomous, the entire business structure and market could change. As automated vessels are relatively high investments, only larger companies could be able to build them in the first phase of the development. Smaller companies such as the described VOs will find it more difficult to compete. In this scenario, customers could be the ones that build and own these vessels, leaving any *e-barge chartering* application for VOs obsolete.

As the supply chain becomes more digitalized (e.g. by block chain technology), applications such as *4Shipping* and Bargelink can support inland navigation to become a more optimized component in the future transport block chain, which invites further analysis and goes outside the scope of this research.

Another possible scenario is that 4Shipping and Bargelink, having all the data of all the registered vessels and market intelligence of real price setting and negotiation or bargaining power of different actors, would develop itself in to the new dominant charterer of the IWT market with market power over the fleet.

7.1.6.Conclusion of the SIA of the e-BC

It is unavoidable that e-barge chartering could eventually experience market uptake. Most conditions are in place. Some remaining barriers are however essential to overcome for the market uptake of the innovation: the market structure, which is still dominated by conventional charterers, the limited size of the spot market in the inland navigation dry bulk, the necessity for critical mass of registered supply (number of vessels) and demand (tonnes of cargo from different shippers) and potential public innovation (e.g. AGORA).

The SIA matrix as developed for the AV and the LNG-D shows several limitations. Most usual actors in IWT are less relevant for this innovation case. The relevant regulatory framework lies outside the PEINP. Only in reference with the CMNI, there are some connections to be made, but IWT regulation does not seem to be a failure factor.

Before the more innovation specific conclusions are presented, the RQ can be linked with this analysis and can be partially answered (Table 79 which continues on the next page).

Sub-questions Innovation	Answer
When is IWT innovation successful or a failure? What are the conditions that lead to failure or to success?	<p>The e-BC is successful as it is being used by a growing number of registered users. However it is not successful (yet) in overthrowing the business dominance of the conventional charterers (so far) as it is used as an addition to business as usual.</p> <p>There is a lack of e-documents, but which does not provide a bottleneck for the business case. Potential issues related to GDPR and data security were not identified.</p> <p>To be successful, end-users only must be linked with the internet and need basic skills to work with the application. The future implementation of 5G and the increasing coverage is beneficial for the innovation. The abolishment of EU roaming costs is also beneficial.</p> <p>Some lock-in effects were observed as the tanker sector is usually framed within the EBIS structure which makes the tankers less flexible in changing the charterer.</p>
How can innovation be analysed and how can it be measured??	<p>The SIA proves to be a powerful tool to explore, identify, categorize and qualitatively analyse the case of the e-BC. More data could improve the analysis. The number of registered users provide a way to measure the diffusion, but recent numbers of the actual usage of the application are not given. The share of e-BC within the business case compared with conventional chartering can be a good indicator.</p>
Who are the relevant actors in IWT innovation?	<p>Actors are identified within the innovation network such as a small number of innovating firms, knowledge institutions, public actors, some VOs and large vessel owners, regulators, but only a few of them play a role during the development of the e-BC. At the earlier stages of development, more IWT actors were involved and even led pilots to develop the innovation, but all those initiatives with significant similarities with the e-BC failed.</p> <p>Infrastructure relates to the network coverage and the future implementation of 5G networks. This lies outside the IWT policy setting.</p>

Sub-question policy	Answer
What is (IWT) innovation policy, how is it organized and which role plays IWT innovation policy?	Most policy lies outside the scope of the PEINP and refers to GDPR and data issues. Only indirectly with the CMNI regarding the legal certainty of electronic freight documents. The RIS policy seems less relevant for the further development of this type of B2B innovation. In this case IWT policy is not needed to stimulate or resist the application.

Table 79: SIA conclusion of the e-BC, answers for the RQ

The first attempts to offer online charterer systems came at the eve of the liberalization of the sector but failed for several explained reasons. The failed attempts, private and public driven, offered a knowledge base for later developments. Major events for IWT such as the liberalization of the sector stimulated the kick-off development of virtual market places and *e-barge chartering*. The enrolment of river information services stimulated VOs further to get connected on board and invest in basic ICT but had no direct influence on the innovation. The rapid development in devices (smartphones, tablets, etc.), the improvement of the network (coverage and quality), the abolishment of EU roaming and the further steps in implementation of e-documents with necessary legal basis, are identified success factors for this innovation to experience further market uptake.

Chartering a vessel can become relatively cheaper with the one percent of charterers provision compared with the offered freight rate of conventional charterers and makes the e-BC competitive. The price difference can attract new customers on the IWT market and can push disruptively conventional dominant market players aside. However this did not happen yet.

An additional service of charterers is that they have more experience in negotiating with customers and often have more bargaining power than most VOs. A direct contact between VOs through an *e-barge chartering* system does not mean that the VO will gain better rates in the long run, which depends fully on supply and demand or the available ship capacity and the volumes of cargo on the market. Furthermore, complex trips such as project cargo or dangerous goods, could perhaps need a specialized charterer while more straightforward cargo (e.g. sand) will find its way easier to digital solutions. A digital chartering platform will not offer any added services in the short run. The further diversification of the services of charterers will give added value on merely chartering which can easily be replaced by a digital application.

If the digital application becomes more diffused and perhaps market dominant, with all the gained market knowledge and price evolutions, even larger charterers that did not adapt on time, could lose market share. Conventional charterers that refuse to adapt to these changes could lose customers because of the cheaper rates and could also lose VOs that see more freight and trips coming through these online platforms.

After diving in the online booking of a vessel, the innovative concept of the small barge convoy to reactivate the small waterways is analysed in the following sub-section.

7.2.SIA of the small barge convoy

The innovation considers the development of a small-sized barge convoy including an adjusted pusher with a single headed crew. The small barge convoy (SBC) concept does not only represent a technological innovation but also aims at a market and organizational change. Indeed, the innovation tries to reactivate the small waterways and change this segment of the IWT market. It also reduces costs (less required crew in day shift combined with shared overhead benefits over a few vessels). The convoy configuration allows larger volumes and less fuel use, compared with a conventional vessel on the small waterway. It is an innovative way to compete against road haulage. The innovation is therefore:

- Technological: small convoy configuration allows larger transported volumes on small waterways. The innovation includes the possibility for every component to detach from the convoy and sail independently.
- Organizational: The end-user has a more complex configuration than one vessel. This requires another organizational approach.
- Cultural: it leaves the traditional family life on-board behind and focuses on single crews with more regular hours of activity.
- Public: the main innovation leader is the Flemish waterway manager with EU funding.
- Open: private actors such as ship yards develop the innovation during the development period.
- At the moment of research, the innovation is at the end of its initiation period. The first components are being built as we speak. The following table shows the typology of the SCB innovation.

Type of innovation	I TECHNOLOGICAL	II TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - BUSINESS CHANGE	III TECHNOLOGICAL, MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	IV MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE	V POLICY INITIATIVES (MANAGERIAL, ORGANIZATIONAL, CULTURAL - MARKET CHANGE)
Implementation level	Initiation		Development		Implementation
Degree of Innovation	Incremental	Modular		Systemic	Radical
Level of Success	Success		Failure		Not Available

Table 80: Innovation typology of the SBC

Source: applied typology derived from Arduino et al. (2011), Roumboutsos (2013) and Sys et al. (2016)

7.2.1.Definitions of the SBC

Before the analysis starts, the innovation is defined as a small barge convoy that consists in the coupling of barges in one convoy which is designed for service on small waterways. The following parts explain the SBC further.

A. Push Convoy

A distinction can be made between a pushed convoy and a convoy (Figure 54). While a convoy is made up only of barges of the same or different types, a pushed convoy is made up of a convoy together with a pusher (Škiljaica et al., 2015)

According to article 1.01 (2.1) in ES-TRIN¹⁸², a convoy is defined as a rigid or towed convoy of craft. Art. 1.01 (2.2) defines a formation as the manner in which a convoy is assembled, while a rigid convoy is a pushed convoy or side-by-side formation. A pushed convoy is a rigid assembly of craft of which at least one is positioned in front of the craft providing the power for propelling the convoy, known as the 'pusher(s)'. A side-by-side formation is an assembly of craft coupled rigidly side by side, none of which is positioned in front of the craft propelling the assembly. Finally, a towed convoy is defined as an assembly of one or more craft, floating establishments or floating objects towed by one or more self-propelled craft forming part of the convoy (ES-TRIN, 2017).



Figure 54: Difference between convoy and pushed convoy
Source: Škiljaica et al., 2015

The push convoy originates from implemented concepts on the rivers Mississippi and Ohio in the U.S. where the MS Sprague in 1902 pushed barges towards Pittsburgh for the first time. This concept, although with a diesel engine and with less push barges, came to Europe in 1957 with the building of the pusher Wasserbüffel. This German pusher had a length of 36.4m and a width of 8.4m and was able to push convoys on the Rhine. In the same year, the French tow boat *Président Herrenschmidt* was refitted as a pusher¹⁸³. Before the introduction of these pushers in Europe, small *opduwers* or *opdruckers* were used to push or two barges (Martens et al., 1977).

One of the unique selling positions of a push barge service is the feature of decoupling the actual sailing from loading and unloading. The pusher boat pushes a convoy to a usually fixed destination and decouples the configuration of the convoy. It is comparable with a flat-belt conveyor on water that guarantees a constant relatively high-volume flow of production goods for manufacturing. The push barge can start loading or unloading procedures while the pusher sails away with other push barges to a next destination. When the push barges end these procedures, another pusher reassembles the convoy and sails away.

With a conventional motorized barge, operational costs could be higher because of the waiting time until the vessel is full or empty. The conventional system has the advantage that the captain and crew can be involved during the loading and unloading procedures in checking all safety procedures and the cargo. Especially with tankers loading dangerous goods, this can be preferred by the customer, although tanker push barges are also used

Push barges exist in different sizes. They can be motorized or not, with or without a bow propeller. One distinctive feature is that they do not have accommodation or a wheelhouse. They can be pushed by a pusher or by a conventional ship (with an adjusted flatted bow). Another variation of convoy or configuration is a barge pushing another barge. The first container push barge convoy was the Laurent/Laurens in 1987 of the DANSER group which sailed 351 TEU towards Basel.

¹⁸² ES-TRIN European standards laying down technical requirements for inland navigation vessels of the European Committee for drawing up Standards in the field of Inland Navigation (CESNI)

¹⁸³ More information can be found on <https://www.binnenvaart.eu/motorsleepboot/13090-president-herrenschmidt.html> and on <https://nl.wikipedia.org/wiki/Duwboot>

B. Small waterways classification

The small waterways (SWW) are defined in this research as waterways of CEMT- class II and below which builds further on the findings of van Hassel (2011a) as explained in sub-section 1.1.4. Looking at the data concerning small waterways infrastructure, the classification has remained mostly stable during the past decades. Nevertheless, slight changes are noticeable due to the upgrading of part of the network to higher classes.

Table 81 shows the length of waterways of the CCNR members, Luxembourg, Austria and Poland for 2011. The small waterways are estimated to be 31% (class I and II) of the mentioned waterways (total of 43,686 km).

COUNTRY	I	II	III	IV	V	VI	VII	TOTAL
BELGIUM	533	484	127	6,936	792	591		9,463
FRANCE	6,692	580	149	194	2,891	200	196	10,902
GERMANY	1,012	395	388	2,989	4,396	3,292		12,472
THE NETHERLANDS	240	1,567	306	1,197	1,581	1,337		6,228
LUXEMBOURG					37			37
AUSTRIA						360		360
SWITZERLAND					17	5		22
POLAND	110	1,761	1,905	275		151		4,202

Table 81: CEMT classification of waterways in km
Source: NEA (2011) as referred in BVB (2018)

C. Small waterway business of push barges

When looking on the small waterway business in Europe, it can be observed that the main sector where these small vessels are being used, are dredging, building materials (including cement, stones, sand and gravel) and agri-bulk. The companies that are described as “divers” in Table 83 offer capacity to several customers such as containers, dry bulk, tanker push barges and project cargo.

The main geographical areas also show interesting differences. The companies with the highest DWT capacity of small push barges for building material have their vessels mostly registered in France and the Netherlands. Inland navigation companies that own several small push barges in diverse segments are mostly located in the East of Germany, Czech Republic, Poland and France as shown by the following table.

Segment	Number of companies in top 25	DWT	Area
Building	6	69,183	F, NL
Divers	7	58,065	D, CZ, PL, F
Agri-bulk	3	48,758	RO, NL
Dredging	6	40,368	B, NL, D

Table 82: Main segments of activities on the small waterways
Source: based on IVR, 2018 and company websites, fleet data for 2017

Dredging is mostly done by companies that have their vessels registered in the Netherlands and Belgium. The IVR database did not show if these vessels are only used on the small waterways. It is perfectly possible (and which is often the case) that these small push barges are also used for larger waterways for transport of dredging or other cargo. Furthermore, small vessels have relatively lower payloads and have therefore less advantages, even if they have less crew members on board than a larger ship.

Company	CR	Number of SWW PB	DWT	Products & service
Lafarge granulats seine	F	69	37,439	Cement
Agrium-Agroport Romania SA,	RO	13	13,831	Agricultural products
Deutsche Binnenreederei AG	D	30	12,984	Divers
Euro Maritime	D	25	11,465	Divers
L.M.P.S.	F	25	9,707	Divers
De Heus Veevoederfabrieken B.V.	NL	15	8,686	Animal food
Algemene Onderneming R. De Roeck	B	20	8,498	Dredging
Plattard Granulats,	F	15	8,114	Stones & building material
GRANULATS VICAT	F	19	8,079	Stones & building material
Möbius, Josef GMBH & CO.	D	16	8,068	Dredging
CFT	F	9	7,858	Divers
KALIS SA	B	22	7,295	Dredging
Agrifirm Feed	NL	8	7,117	Animal food
Baars AZN BV HOLDING A,	NL	19	6,559	Dredging
Mannekus B.V.	NL	13	6,545	Chemicals
CSPL A.S.	CZ	11	5,915	Divers
Reederei ED LINE GMBH	D	15	5,788	Divers
Aannemingsmaatschappij de Vries & van de Wiel B.V.	NL	16	5,600	Dredging
Thaumas BV	NL	30	4,961	Vessel equipment
Heyrman – De Roeck NV	B	10	4,508	Dredging
CEMEX	F	10	4,438	Cement
Odra Lloyd Sp.z.o.o.	PL	10	4,348	Divers
Povodi Labe, Statni podnik	CZ	17	4,232	Public waterway manager
Ballast Maatschappij De Merwede B.V.	NL	15	4,202	Building material
Niba Beheer NV	NL	11	3,809	Sand and gravel

Table 83: Top 25 of European push barge firms (DWT capacity with push barges with length = 10-50m)
Source: own calculations based on IVR, 2018 and company websites. With CR = country of registration; D = Germany, RO = Romania, F = France, NL = Netherlands, B = Belgium, CZ = Czech Republic, PL = Poland

D. Volumes on the small waterways

Data on volumes transported by push boats on small waterways is not available. However data on total traffic volume is available and is shown for some of the Flemish small waterways in Figure 55.

The volumes on these waterways show since 1977 an overall decrease. Several reasons for such a decrease have been identified (based on van Hassel, 2011a:101-132):

- modal shift towards road haulage,
- decrease of the SWW fleet where investors are more interested in higher revenue vessels for the larger waterways which are not able to access small waterways,
- lack of interest of youngsters
- lack of banks/investors (which prefer to invest in larger vessels with higher expected return),
- relatively high entrance and exit barriers on the market.

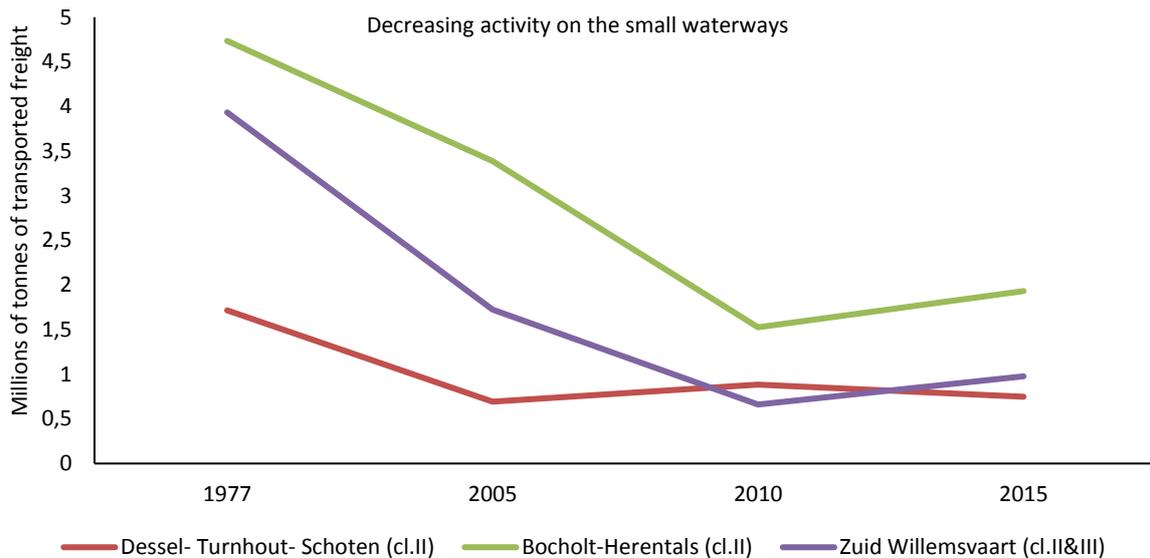


Figure 55: Overview of the transported tonnages on the Flemish small waterways
Source: update of van Hassel, 2011; Flemish Waterway Managers 2016 (nv DS and W&Z NV), according to available data and compilation from different sources. 'cl' refers to CEMT class. Zuid-Willemsvaart includes a Dutch part

The following entry barriers are identified:

- a new vessel (including a loan if one is found) must compete with old vessels that are usually free of loan, which makes it harsh to enter the market;
- the requirements to become a captain, are much higher than for a truck driver. In the case analysis of the automated vessel, these training requirements will be further elaborated on.

Furthermore, there are also exit barriers for the existing vessels:

- demand on the second-hand market could be relatively low;
- resold vessels after bankruptcy usually remain operational against lower freight rates;
- financial restraints

To exit the market, other options are also possible such as demolition or conversion to a complete house on the water.

E. Small waterway fleet data

The IVR Ships Information System for the year 2017 was used next to several sources on the national state level and the market observation of the European Commission and the CCNR. However it was not possible to retrieve company data of all small ships (class I & II) from the data set of IVR. Moreover, national (Germany and the Netherlands) and regional (France and Belgium) data are not collected in a uniform way (different classification of fleet).

The category of push barges between 10 and 50m across Europe that are still registered, according to IVR (2018), are presented in Figure 56. The average dead weight of this segment is estimated at 545 tons on a total number of 1,130 push barges or 607,077 tonnes in total. The average depth is 1.95m. Vessels operating in this segment are mostly registered in the Netherlands, Germany, France, Belgium, Romania and Czech Republic. The tank push barges (TPB) represent only a small percentage of this segment (3.9%) and of the total fleet of push barges (5.2%).

There are no small push barges reported by the United Kingdom, Switzerland, Serbia, Luxembourg, Hungary, Austria and Slovenia. The self-propelled dump barges (SPDB) are not taken into account in the analysis, but a number of 16 vessels are accounted in the database whereas only two have a length beneath 50m. The SPDBs are all registered in the Netherlands.

Fleet share of small freight & tanker push barges in number of vessels

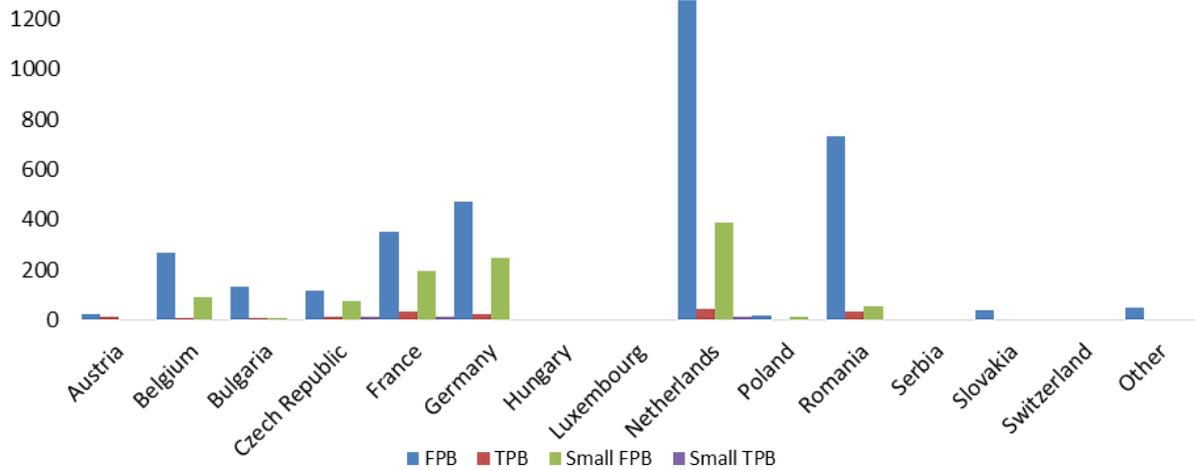


Figure 56: Fleet share of small freight (FPB) & tanker push barges (TPB) across Europe
 Source: own calculations based on IVR (2018), small PB's are filtered by length (between 10-50m).

The number of pushers (including tugs with push bow, push tugs and push boats) in Europe are estimated at 1,309 (IVR, 2018) whereas 209 vessels have a length beneath 12m and a draught¹⁸⁴ beneath 1.6m. Figure 57 shows that the Netherlands have the highest share on pushers for all waterways, followed by Germany, Romania, Belgium and France.

Fleet share of small pushers in number of vessels

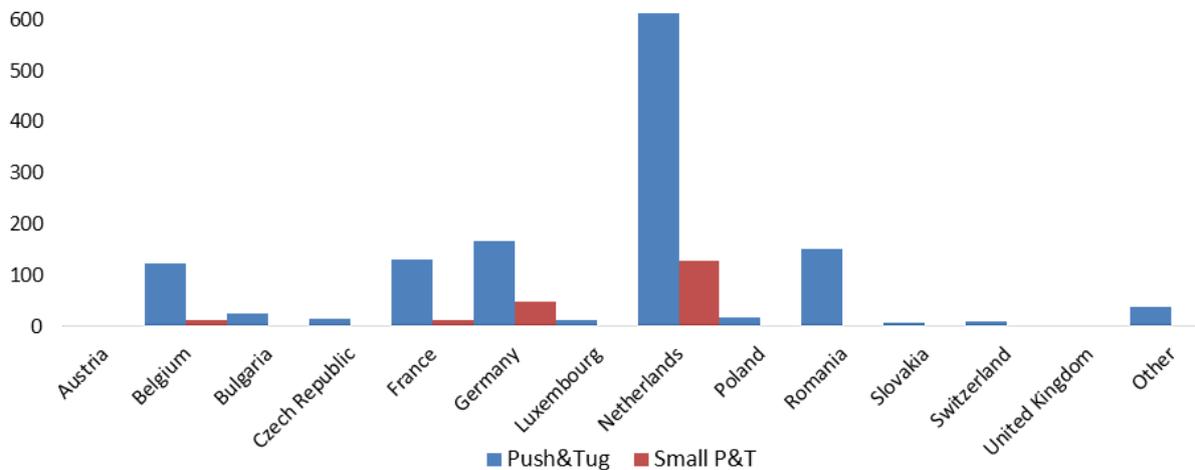


Figure 57: Fleet share of small pushers in Europe
 Source: Own calculations based on IVR (2018), pushers include push boat, push tug and tug with push bow. Small pushers are pushers with a draught beneath 1.6m and a length beneath 12m for CEMT I&II waterways

The *Spits* (maximal length of 38.5m, width of 5.05m and payload between 250 and 400 tons) and the *Kempenaar*¹⁸⁵ (length between 50-55m, width of 6.6m and a maximal payload between 400 and 650 tons) are designed for the small waterways in particular and comprise the main part of the small waterway fleet in the CCNR MS. These vessels are an essential part of the market on the small

¹⁸⁴ Draught is defined by European Directive 2017/2397 as the vertical distance in meters between the lowest point of the hull without taking into account the keel or other fixed attachments and the maximum draught line

¹⁸⁵ van Hassel (2011a) refers to the Neo-kemps as a possible concept as an example for the first mentioned concept but this lies outside the scope of this research.

waterways that competes mainly with road haulage. These small vessels of CEMT-class I and II, are known on the Flemish and Dutch waterways and correspond with the French *Péniche* (for the *gabarit Freycinet*) and Campinois. In Germany the Spits is also called a *Groß Finowmaß* called after the *Finowkanal* between the *Zerpenschleuse* in Brandenburg and *Niederfinow*. The volumes of these ships are relatively small, which results in a higher cost per tonnage or TEU, especially for small distances.

As new vessels enter the market, they tend to be larger in loading capacity and dimensions while the number of smaller vessels is decreasing. The average loading capacity of the fleet increases, which is shown for France (Figure 58) and Belgium (Figure 60). The evolution of the fleet in the segment of the small waterways is also shown for France and Belgium (Figure 59 and Figure 61).

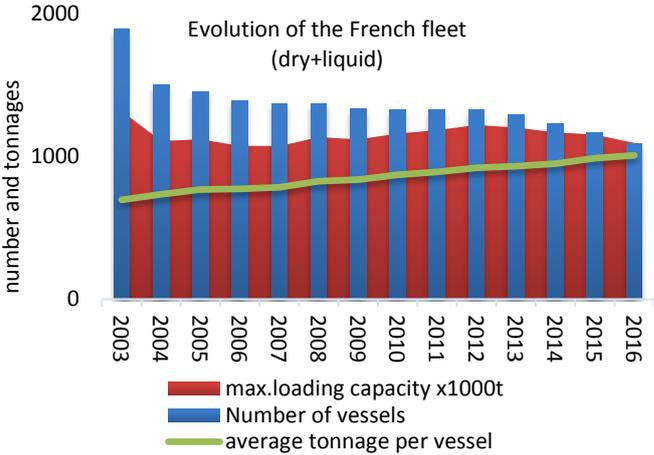


Figure 58: Evolution of the French fleet

Source: Own calculations based on VNF and market observation (CCNR, 2018) for motorized small vessels

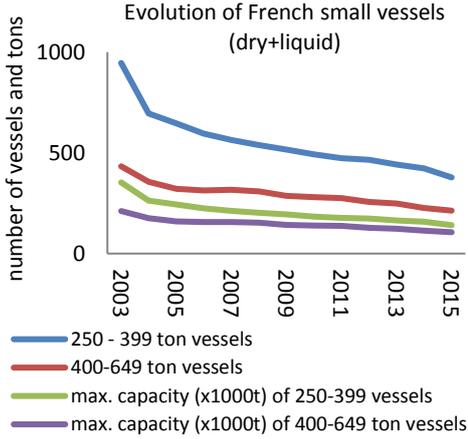


Figure 59: Evolution of small vessels in France

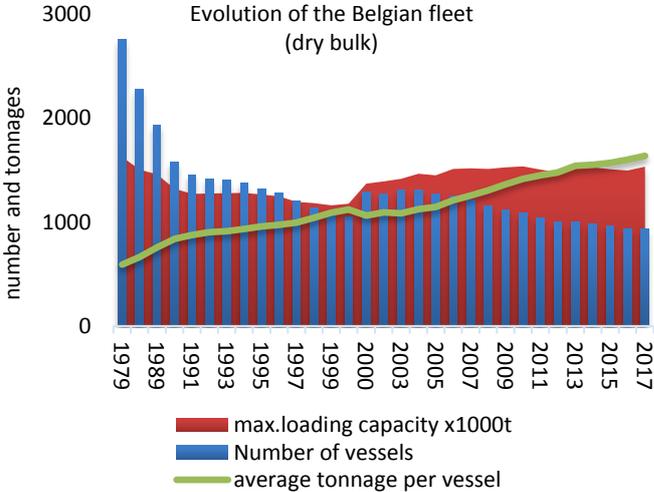


Figure 60: Evolution of the Belgian fleet

Source: Own calculations based on ITB and market observation (CCNR, 2018) for motorized small vessels

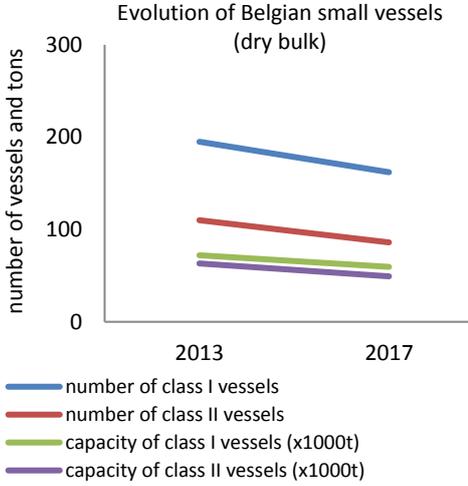


Figure 61: Evolution of small vessels in Belgium

The average age of the push barges owned by the top 25 companies on Europe’s small waterways is 53 years, with building year 1965. This indicates that the average age of this segment of the fleet is relatively old. Since 2000, 52 push barges of this type have been built, mainly in Belgium and the Netherlands, of which 40 are dedicated to dredging activities and the rest for transporting building materials such as cement and stones (own calculations based on IVR, 2018).

F. Concepts to reactivate small waterways

After defining the used terms and examining the available data, the analysis will now focus on the innovation of the small barge convoy. In the past twenty years, several innovative concepts were developed to reactivate the small waterways (based on the findings of van Hassel 2008, 2011):

1. A first concept¹⁸⁶ consists a small push barge that can pass a lock on its own, pushed by a conventional inland vessel towards a terminal in a port. However this concept faces several challenges:
 - a. The first challenge is that the push barges need a solution at the end of their voyage by recoupling with another conventional vessel.
 - b. The second challenge is the distinction of liability between two companies (push barge and the inland vessel) within a two-party transport.
 - c. The third challenge is the decreased availability of the number of potential pushing conventional inland vessels of this class. The push barges must be sailed on the small waterways, from the drop point to a terminal or another destination independently, after the pushing vessel leaves, and before loading or unloading.
2. The second concept consists a push barge convoy of small motorized push barges designed to fit into the locks on small waterways and to sail independently further after decoupling for the last miles of the convoy. The push barges can be equipped with electrical batteries that are charged by the pushing vessel during sailing and before uncoupling. The push barges can be remote-controlled by the pushing vessel and could have propellers on both sides (front and end) to facilitate manoeuvring on the small waterways.
3. In a third concept, the convoy is pushed by a small pusher that can sail on the small waterways. Passing a lock where decoupling and coupling activities will be necessary, offers the main challenges. On the small waterways, there are numerous locks.

An important advantage of the convoy system in general, is that the pusher or pushing inland vessel is not needed during loading or unloading, which is innovative for the small waterways. A round trip improves the efficiency of the system in most concepts. When the convoy reaches the terminal, the pushing vessel needs to decouple from the loaded vessels and to couple with waiting push barges that are full. The terminal does not need to provide shifts depending on the arrival of the convoy or to pay waiting time in case of a conventional inland navigation vessel such as a Spits. The main challenge here, is that the reduction of empty trips depends on the number of available push barges that must be relocated and are waiting for a pusher, preferably in the proximity of the earlier destination.

To achieve sufficient round trips, sailing between water bound industrial clusters or distribution centres offer the most optimal operations. The small barge convoy offers economies of scale of which larger ships have a clear advantage compared to small vessels. Figure 62 shows the cost reduction of the ratio of transported volumes as payload and the costs of the ship.

¹⁸⁶ This concept finds its origin in Waterslag (2006-2008) as explained during the SIA.

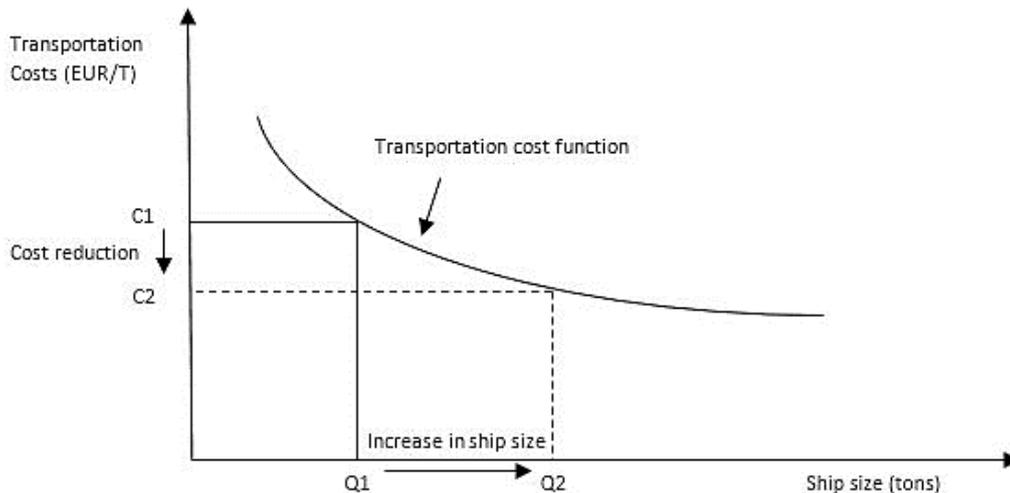


Figure 62: Theoretical concept of economies of scale for the SBC
Source: van Hassel 2011a

Now that the different concepts and the challenges on the SWW are known, the SIA can commence. The SIA goes deeper into the combination of concepts two and three as developed by van Hassel (2011a & b), which is also the basic concept (although with a slight variation) of the European funded project Watertruck+. Components of this SBC project is currently being built at the time of this research.

The analysis starts with a description of the current situation of the innovation. The different innovation phases of the small barge convoy are analysed, which leads to initial conclusions and a more detailed analysis of the identified factors.

7.2.2. Current situation

As explained before, the innovative concept of the small barge convoy, has several variations. Some of these are already being implemented, such as the coupling of two existing small vessels where one is pushed or pulled alongside by another in different configurations. A variation of the combination of the third and fourth mentioned concepts is still in the development phase.

The most well-known project for the moment is the public driven *Watertruck+*, which has announced to start with the building of the small push barges even though no private partner is found yet to operate the vessels (at the moment of research). This project was preceded by more than a decade of initiatives to revive the small waterways.

7.2.3. Initiation period

The initiation period of the small barge convoy concept starts within several European funded projects such as the Enhancement of Containerized freight flows over Small Waterways (ECSWA, also known as Waterslag), Barge Truck, Innovative Inland Navigation (INLANAV) and Watertruck.

The INLANAV project (Innovative Inland Navigation) which was a spin-off of ECSWA, included the focus on pallets and big bags with pilots and support for on-board installation of cranes. One of the developed concepts within the framework of INLANAV was a two-stage tug and barge concept. In the first stage, the tug and barge concept sails on large waterways with several barges pushed by a single tug from seaports to the small inland waterways and in the second stage, the convoy uncouples at the entrance of a SWW and the small barges continue autonomously (van Hassel 2011a).

The actual blueprint of the small barge convoy was designed during the Barge Truck project but was abandoned. The business case was not convincing enough to continue for the involved stakeholders.

Watertruck identified several causes why the small waterways experience problems: skippers aspired larger ships with more revenue and there was a low intake of labour where the labour supply did not meet labour demand. A proposed eight-hour shift system in which people go home after a day’s work was examined if it would make the SBC more attractive to work on. This also allows reducing the accommodation area and to increase loading capacity.

During these projects, R&D and test cases were done in partnership with universities, stakeholders, sector organizations and government officials. Despite several pilots and surveys amongst potential charterers to identify necessary volumes (critical mass), no private investor has (yet) been found to take up the innovation in co-partnership with public shareholders. More than EUR 5 million has been spent on R&D with all the preceding projects to develop a small barge convoy, before the last project *Watertruck+* that aims at really building and implementing the concept. An overview of projects is shown in Table 85.

During this initiation period, the infrastructure of the SWW needs more maintenance to reach enough critical mass of potential cargo flows the more industry is linked with small waterways with a good navigation status, the more critical mass becomes available with a higher market potential and the higher the chance the innovation becomes successful. The infrastructure is nevertheless considered as sufficient available to commence the development, but not (yet) for market uptake of the innovation. In the SIA matrix, this is considered as a failure factor.

Actors	Demand: VOs, vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties’ lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, verification agencies
Institutions				
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 84: System of innovation matrix in the initiation phase of the small barge convoy
 Source: based on Aronietis (2013). Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

The small existing competition is not considered a failure factor because of the public funding behind the project and because of the official objective to attract new cargo flows outside the existing market. Attracting ‘new flows’ could also mean that existing shippers and forwarders on the small waterways are exempted from the *Watertruck +* concept but this is not certain.

At the side of the private market, no vessel owners or industry with own vessels are interested or capable to invest in small barge convoys so far. For market uptake, this is an essential requirement. Both in hard and soft institutions, several factors are identified, such as insufficient labour force and manning regulation. At this stage, interested ship yards could not be found. Therefore, the lack of infrastructure on the side of manufacturers (in this case ship yards) is a failure factor.

A lock-in effect is noticeable to the extent that the focus lies on the unimodal approach of the project and does seem to include intermodal concepts and fully-integrated logistics concepts (failing factor linking shippers with strong networks lock-in effect).

Knowledge increased during the initiation period but besides pilots, no real ships were built as shown in Table 85.

Period	Description	Results	Scope	Funding/main actor	
ECSWA	2006-2008	Trunk-feeder inland navigation system for the SWW. Trunk-feeder entails that containers or bulk are loaded on the SWW to be transported (feeder), to an inland terminal (trunk) that is located at a main waterway and where the freight is bundled towards a seaport	Showed technological and operational feasibility of the usage of coupled barge convoys for the small waterways for container and bulk transport. Test runs in Flanders and the Netherlands. Consumption of gasoil was reduced. More competitive freight rates, lower CO ₂	Flemish Region and Southern Netherlands	Total budget EUR 999,095 EU funding EUR 479,566 Main actor: Waterwegen en Zeekanaal NV
SBIR	2007-2010	Small scale Business Innovation Research (SBIR) pilot program asked inland waterway operators and shippers to come with promising ideas to stimulate and strengthen IWT on the smaller waterways.	Two ideas were selected for further research and development: Small inland waterway vessel and barge truck.	The Netherlands	Total budget: EUR 900,000 Main actor: Dutch Ministry of Transport, Public Works and Water Management
BARGE TRUCK	2008-2010	Spin-off of SBIR: a combination of push barges and push boats. The smallest unit, a single barge in combination with a small pushing boat, for the smallest navigable waterways	Need to involve private sector from beginning of project Only feasibility studies and first design small pusher/small push barges	North-Holland and North Brabant region	Concept development EUR 425,000 Push boat EUR 0.8-1.0 million Push barge: EUR 0.25-0.3 million Main actor: MARIN
INLANAV	2009 - 2012	A spin-off of ECSWA, including pallets and big bags with pilots and support for on board installation of cranes. Development of a two-stage tug and barge concept (van Hassel, 2011a & b)	Research if second generation ECSWA-barges could cover the freight market. Including palletized cargo and big bags together with a crane barge concept by transnational test runs of pilots. Innovative concepts from University of Antwerp, Schipco bv, Research Small Barges BV, such as electrical push barge concepts with automatically guidance and a composite ship		Total budget: EUR 956,671 European Union funding (INTERREG IVB): EUR 478,335 Main actor: Waterwegen en Zeekanaal NV
WATER-TRUCK	2010-2014	Introduction of a sailing concept with a small pusher and small push barges adjusted on the dimensions of the SWW with decoupling of sailing and (un-)loading	Pilots in real life environment Feasibility studies Optimizing design Identify operational advantages	France, The Netherlands, Flemish Region	INTERREG IVB NWE and EFRO funded 50% of EUR 1.78 million Main actor: Flemish Institute for Mobility (VIM)*
WATER-TRUCK +	2014-2020	Incremental implementation of the Watertruck concept	Test phase; search for private investors and new cargo flows; building of the Watertruck		Total budget: 23,014,800 including EUR 11,507,400 (CEF, EU funding)

Table 85: Overview of Small Barge Convoy concepts and investments in R&D

Source: Platina (2011), HBCB (2013), EVO (2010), Vanelslander (2010), van Hassel (2011a, 2011b), Macharis et al. (2011)

7.2.4. Development period

The *Watertruck* project prepared the way for the succeeding project *Watertruck+*. During the follow-up project the first push barges are planned to be built, although it is not clear yet who the private partner will be.

The development of the small barge convoy, according to the *Watertruck+* project, will end in 2019 and relates to the building of the vessels and exploitation of several pushers and push barges. With an overall budget for the development of the small barge convoy estimated at EUR 23 million (EU pays 50%) another EUR 9 million should come from private partners. The leading innovator (The Flemish waterway manager) pays EUR 2 million for the administrative support of the project (Ministry of infrastructure and Environment, 2016).

The European Commission, through the Connecting Europe Facility programme, supports the innovation with funding. This support is also shown by an official letter of the EC towards branch organisations who were concerned for market disturbance caused by this public innovation. This letter (Schultz, 2016) stated that *“Even if any public subsidy inevitably causes some market interference, we consider that this interference is acceptable in view of the potential gains the project can bring to the inland waterway sector. It should be noted that the project targets new markets which were not served by inland waterway transport when the project was conceived. We consider that the potential gains of opening up new markets for inland navigation outweigh the risk of interference with the existing trades carried by inland waterway.”* The EC recognizes the possible disturbance but weighted the potential benefits higher than the costs of disturbance.

The building of this public driven innovation was not welcomed by the sector organizations. Although high resistance is unlikely at the moment. Most stakeholders agree with the need for innovative concepts to reactivate the SWW but the concern for the remaining small vessels¹⁸⁷ still exists.

Most of the vessels on the SWW have a low equity (payed off loans, depreciated vessels) which makes them more competitive towards new entrance of small vessels that must pay off loans. They are sailing until they are completely worn out and sold for scrap. The latter is one of the reasons why this segment does not show a lot of innovation. When a necessary investment is needed to comply with technical requirements, and funding cannot be found, the ship is often scrapped or converted to a living boat.

The small barge convoy concept still needs more research to be optimized into a complex logistical chain. However this does not prevent the vessels to be built according to the *Watertruck+* concept. The concept of ‘new flows’ also still needs a clear definition from the innovator during this stage.

Public funding is available for 50% of the investment (soft institution) and the public innovator is shareholder. The concept is composed of several partners including research institutions and has gained knowledge from previous projects, test pilots and surveys. Vessel owners and industry with vessels do not show interest (yet) to invest in the innovation and are not aligned. This could be due to a lack of funding capabilities but also to the fact that higher economies of scale with larger vessels show other opportunities. A weak network effect is therefore identified as potential investors have not yet been found.

During the development period a ship yard and private partner was found to build the SPDBs but a partner for the small pusher is yet to be found. Nevertheless, the innovation can continue its development.

Table 86 shows the SIA matrix in the development period of the SBC while linking the identified and analysed failure and success factors with the relevant actors which supports pattern recognition.

¹⁸⁷ which show a decrease of an annual 10% for Spits type and 6% for Kempenaar type in Flemish region

Institutions \ Actors	Demand: VOs, vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, verification agencies
	Infrastructure			
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 86: System of innovation matrix in the development phase of the small barge convoy

Source: based on Aronietis (2013). Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

The following sub-section analyses the innovation more detailed by investigating the innovation conditions in relation with failure factors concerning infrastructure, institutions and interactions.

7.2.5. Innovation conditions

The following detailed analysis relates to the development period of the (mainly) public driven innovation.

A. Infrastructural conditions

Accessible infrastructure is vital for the reactivation of small waterways. Frequent dredging to maintain sufficient depth and width of the fairway is the responsibility of the MS and Port Authorities.

Maintenance of mostly relatively old locks and of the small waterways was reported insufficient during the interviews and surveys that were done during the *Watertruck* project. The question of the infrastructural conditions does not only concern navigable waterways. Sufficient load- and unload facilities need also to be taken into account in order to reach a critical mass of volumes to develop positive business cases. An upgrade of class II waterways to class IV or V is also possible. The Dutch government, for example, decided to upgrade the Zuid-Willemsvaart from class II to class IV to allow ships to sail on the waterways with a carrying capacity of 1,000-1,500 tonnes by replacing seven locks. This operation cost EUR 573 million (MIRT 2009 as mentioned in Platina) through public private partnership but does not affect the business case of the small barge convoy.

B. Institutional conditions

The social benefit to reactivate the small waterways is expressed by the potential modal shift from road haulage towards smaller canals. The innovation needs to compete with road and must take in account costs concerning the additional transshipment and the last mile delivery (if sender and final receiver are not water bound). The SBC will not only be active on small waterways. The concept is that the convoy is pushed on main waterways until it reaches a small canal where it can detach the SPDB. The SPDB is then able to sail independently on the small canals to its destination with only a captain on board. To increase the potential market, entrance to the main waterway of the Rhine, is important.

The Rhine regulation for crew requirements (as the ES-TRIN) demands for convoys with a pusher first to comply with Standard S1 and to have in addition a bow thruster that can be controlled from the wheelhouse. For convoys with a length under or equal to 70m, the convoy needs at least two crew members (boat master and boatman) in exploitation mode A1. For exploitation mode A2, at least two captains are needed, while for mode B, two captains and two boatmen are required. As the convoy gets longer, more crew members are required (article 3.15 of ES-TRIN).

The following cases are exempted from the CCNR and EU regulation:

- The Directive EU/2017/2397 (EC, 2017b) concerning crew requirements, does not address *the situation of persons navigating on MS' inland waterways without a link to the navigable network of another Member State and who are exclusively navigating limited journeys of local interest within a trip distance of maximal 10km. Nor does it address seasonal navigation in the same way as personnel navigating on the interconnected network, whose professional competence are harmonised.* Seasonal navigation refers here to navigation that is only exercised for not more than six months each year. The directive does not cover minimal manning requirements which are found in the Rhine crew regulation (RPN) and in national regulation when traffic is conducted only in the national state and possibly exempted (e.g. Dutch *Binnenvaartwet*).
- According to the Directive EU/2016/1629 (EC, 2016a) concerning the technical requirements, vessels that transport less than 350 tonnes payload do not have to comply (are exempted) if safety standards are proven (art. 24) and if no cross-border activity is done.

Ships with a higher payload than 350 tonnes such as convoys, formations with pushers or motorized barges must comply with regulatory limitations. The regulation for push barges without steering systems or engines have less requirements¹⁸⁸. Furthermore, in order to sail in standard S2 (art. 31.03, ES-TRIN), the pushers that propel a pushed convoy need hydraulic or electric coupling winches if the foremost craft in the pushed convoy is not equipped with a bow thruster which can be operated from the steering position of the pusher.

The institutional limitations concerning manning requirements, are considered by the innovator as a bottleneck in order to achieve market uptake because of the less possibilities in crew cost reduction. Another barrier is the ambiguous resistance of branch organizations which are fragmented in this case. When the innovation would also attract existing market flows, it could be the case that existing vessel owners will be pushed outside the market. At this moment, it could be perfectly possible that social resistance will lead to juridical actions because of the perceived unlawful public intervention on the remaining market (e.g. *Blue Line Logistics* and its pallet shuttle barge¹⁸⁹ vs *Watertruck+*). Social resistance is nevertheless too low to prevent market uptake.

The private investor who will be responsible in operating the vessel for three years, needs to pay half of the budget up front, while the Flemish waterway manager remains shareholder (estimated at EUR 15 million) as already briefly explained. After three years, the operator can decide to stop activities and return the SBC to the waterway manager or proceed to buy the vessels completely. Not all private investors could find this agreement appealing. Furthermore, the subsidies weaken the negotiation position in upwards pressure on prices (relatively) and the relatively small expected revenue (small distance, low volumes, transshipment and convoy (de-)formation costs) makes the small waterway business less appealing for private investors. Finally, it can be assumed that the continuity of the small vessel fleet will be jeopardized without change or innovation aimed at renewal of this part of the waterways.

C. Interaction conditions

The network of the innovator is strongly connected with a framework of stakeholders, research institutions, policy makers, waterway manager and other relevant institutions. The SBC can be viewed as a part of a complex logistics system. Indeed, charterers need complete solutions to be able to sell the service of a small barge convoy, which requires a fully-integrated approach (EVO, 2010). This approach needs to offer a door-to-door service and requires a full analysis of every business case, including other modes such as last-mile road haulage or even trains, with or without bundling of flows in distribution centres. If the *Watertruck+* concept shows too much focus on IWT and perhaps not

¹⁸⁸ Chapters 5 to 7 and 15; article 8.08(2) to (8), article 13.02 and article 13.08(1) as mentioned in the RPN 2018

¹⁸⁹ As described in Verberghet et al. (2019)

sufficiently on the entire supply chain, the development could lead to a lock in-effect and prevent market uptake.

D. Capabilities

As mentioned in the definition part, the small waterways still face significant challenges such as both public as private funding. Large companies that could invest with own equity are rather scarce on the market of SWW which is true for the entire IWT.

Financing problems also arise in the private market because of low interest from financial institutions, relatively high private equity needed to receive loans, uncertain business return of investment (lack of data and market intelligence), need for critical mass and a relatively high investment cost (to achieve economies of scale where several ships are needed).

The typical structure of small businesses, especially on the small waterways, makes the business structure vulnerable to shocks in demand. The risk spread of the average SWW enterprise is completely integrated in the vessel. Sometimes, also a house on-shore is used as a guarantee for the investment structure of these companies. Other owned business activities to back equity are rarely the case. This low risk spread generates only revenue from the activity of the vessel within the firm and is highly dependent on a relatively small number of charterers and charterers. The number of SMEs show a vulnerability where small family businesses decreasingly succeed in convincing financial institutions to invest in the vessel.

A reliable and efficient part of a full logistical service with enough critical volume needs to be able to ship a certain amount of goods with several ships. The flexibility of the concept and the cost reduction can be reached if sufficient volume is found and if the necessary freight capacity is offered (van Hassel, 2011a; EVO 2010).

E. Market

According to van Hassel (2011a:244) the concept could have presented a positive business case with 'acceptable' fuel prices (or more fuel efficiency), under a single crew regime and in a scenario by internalizing external costs in road haulage. Of course, this study is written in 2011 and today there are perhaps other market conditions. Nevertheless, internalisation of external costs in road haulage is only being implemented in some countries, there has not been any impact on IWT identified.

The initial investment presents a high risk to provide sufficient components within a network of small barge convoys. The small barge convoy with specially designed push barges needs several of them to perform round trips. Between two destinations, at least six are needed for each pusher in the assumption that the pusher would always push at least two push barges while the other four barges are being loaded and unloaded.

The business case of the concept as further developed by *Watertruck+* provides private investors building subsidies of 50% of the total initial investment. The concept has a relatively high scale of economy with the intended first building wave of 28 push barges. It can offer a competitive advantage against road haulage but also against the remaining market players on the SWW. Although it is claimed to be one of the objectives to attract 'new' cargo flows (that do not yet exist on the market), it is not guaranteed what happens when the innovation would fail. Chances are real that the half-subsidized pushers and push barges will not disappear from the market. The public shareholder can decide to continue despite the failure or to sell with a loss on the market.

When successful, it cannot be guaranteed that the vessels will not be used for existing flows, thus disrupting those who already have difficulties to maintain market share. Furthermore, if the vessels fail and are sold as second hand, they will compete at lower prices. However this claim invites much more research and assumes a failure in the future implementation period.

7.2.6. Conclusion of the SIA of the SBC

The supply on the small inland waterway network is decreasing because of several reasons such as the ageing of the ship (technical decline) and crew, the significant absence of new build vessels, the reduced labour force, the absence of young successors or labour inflow and the insufficient maintenance of these waterways (van Hassel et al., 2011a:131). Moreover, water bound companies turn to road haulage causing higher external costs following this negative mode shift.

Because of this situation the public actor decided to invest in the development of a new concept to reactivate the SWW. A public innovation as such, can however disrupt the existing and remaining SWW market instead of attracting cargo away from road haulage. In the best-case scenario, it can help the SWW grow with new cargo flows and attract new players to join the SWW market. If the concept becomes successful, the innovation could be followed, also in other countries, and could lead to market uptake of the innovation.

Sub-questions Innovation	Answer
When is IWT innovation successful or a failure? What are the conditions that lead to failure or to success?	<p>The innovation of the SBC is not successful (yet) despite being a public innovation with significant EU funding. The infrastructure of SWW is a potential failure factor. Other factors were the lack of private funding or involvement of sufficient private partners. The suggested equity structure of the SBC with a dominant role for the public actor is perhaps also not really inviting for private investors. Although a private partner was found to build the SPDB during the development period, there is no private partner (yet) that will build the small pusher.</p> <p>The business case aims at attracting new flows without disturbing the existing market, which is rather vague. Without knowing the targeted flows, it is difficult to analyse the possible position of the vessel within the supply chain. This reveals traces of lock-in effects whereby the innovator looks too much at the SWW of IWT and less at the logistics reality.</p> <p>There is no real regulatory bottleneck identified, only the European crew regulations that require minimal manning for these small vessels and for convoys can narrow down the sailing distances and potential market. The vessel can sail with one person on-board within the limitations of the regulations and not on the Rhine, Westerschelde and parts of the Seine, but this does not prevent the innovation to come on the market.</p>
How can innovation be analysed and measured?	The SIA proves again to be a powerful tool to explore, identify, categorize and qualitatively analyse the case of the SBC. The diffusion of the SBC cannot be measured yet. Data collection and quality on the small waterways can be improved. A measurement of the current situation before implementation can be useful to measure the later impact of this innovation.
Who are the relevant actors in IWT innovation?	Actors are identified within the innovation network such as the Flemish Waterway as public innovator. Several knowledge institutions, ship yard, and EU as source of funding. In the initiation period several R&D projects were identified with several actors that contributed to the development. Infrastructure manager is the main innovation leader and remains co-owner during the implementation period.
Sub-question policy	Answer
What is (IWT) innovation policy, how is it organized and which role plays IWT innovation policy?	The conducted innovation policy is regional and leads the innovation with public funding. Public actor is the main innovator. As the SWW is not reactivated yet and the innovation is not implemented yet, it is too soon to answer this question. The pan-European dimension is limited to EU funding and regulation on crew requirements such as the Rhine RPN, CESNI QP and EC. The latter could limit the potential market but does not prevent the innovation to be implemented.

Table 87: SIA conclusion of the SBC, answers for the RQ

The innovation is currently at the end of the development phase as the first components are being built at the moment of this research. The SWW network is an important part of the European waterways with 31% identified as class I and II. However it needs sufficient investments to improve maintenance. More maintenance is needed to shift volumes to small waterways, as well as the necessary equipment such as systems for traffic control, ship guidance and resting places. An upgrade to higher classes is an option and does not disrupt the business case of the small barge convoy.

European funding was identified throughout the development phases in R&D. The funded projects offered insights and even new innovative concepts. The innovation policy was mainly regional.

The regulatory bottleneck relates to the vessel manning that requires at least three persons on-board, which could jeopardize the initial business case that aims at larger economies of scale and a reduction of crew costs.

It seems quite challenging to find private investors to reactivate the small waterways or to join the further development of the Watertruck+ concept of a small barge convoy. The future and final implementation of the innovation will have to show to what extent the public innovation will disturb the remaining market on the small waterways and how much new volumes will be shifted from road haulage.

Success of the innovation could lead to larger market diffusion and copying of the concept by private investors. Failure of the innovation could mean that the barges are sold to the highest bidder and perhaps come in operation in existing and remaining markets on the small waterways. Nevertheless, it is at this moment uncertain if the innovation could lead to reactivation on the small waterways by attracting new cargo from road haulage or perhaps decrease the existing market on these waterways because of imposing unfair competition, which is not the objective of the public actor. Both scenarios are difficult to predict, because of other more important determinants such as growth of market demand and supply. Introducing the Watertruck+ barge convoys, will perhaps only have a relatively small influence on market demand and supply of the freight capacity of small barges.

Finally, the case studies have been analysed. The following Chapter compares and analyses the results of all cases in a cross-case approach.

8. Cross-case analysis

In this Chapter the results of the SIA, the CBA and the PEINPA are compared between the cases. Not only the case related findings about IWT are important in this Chapter, but also the test of the used methodologies is investigated. The analysis ends with suggestions how to deal with generalisation and replicability of the case study approach.

First the SIAs are compared between the cases while taking into account the periods of development of the innovation. Second the cash flow analysis with private and external costs within the developed vessel model are compared where possible. Third, the PEINPA is compared and analysed on differences and similarities between cases. This part of the cross-case analysis gives more insight in how to further develop this tool.

8.1. Cross-case analysis of the SIA

When looking at the development periods, it becomes clear that because of differences between the cases, only the initiation period can be analysed for all cases. Some cases are further in their development. The following parts look at failure factors and investigates if any patterns can be recognized.

8.1.1. Failure factors in the initiation period

When comparing the pattern recognition with the different SIA matrices of the initiation period of all cases, several differences become clear. Infrastructure is in all cases identified as a potential failure factor for the innovation. Of course, infrastructure has a different explanation in every case:

- AV: referred to the mooring problem of an unmanned vessel and to the digital infrastructure (e.g. within the RIS environment);
- LNG-D: the lack of on-shore bunkering facilities;
- e-BC: lack of digital infrastructure (e.g. internet coverage);
- SBC: maintenance on small waterways and access to water bound customers.

Institutions	Actors Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Legend			

Table 88: SIA Matrix of failure factors of initiation periods of all innovations

Another frequently identified failure factor in the initiation period, relates to capabilities whereas next to financial capability, also capabilities referring to knowledge and skills. The regulatory framework (hard institution) has proven in this period to be a failure factor for the AV and LNG-D but is less significant for the SBC. Without adjusting the regulation to accept unmanned fully automated vessels or allow LNG to be used as a fuel, the innovation fails. In case of the SBC a limiting regulation on crew requirements only reduces the potential market which indirectly could lead to a fail innovation.

8.1.2.Failure factors in the development period

Only LNG-D, e-BC and SBC have reached the development period but without any significant changes which is possible, but also could imply a limitation in SIA. The recognition of failure factors in each case depends on identified factors. It could be the case that not all factors were recognized through interviews or they remained hidden. Replication of the case study could lead to further refinement as more knowledge and data comes available. The same is true for some debatable network effects. In the case of the SBC there was a weak network effect found in this period because of the failure to attract other investors. This is also perhaps related to capability where investors could not be able to invest. The SIA pattern recognition approach does not always reveal this and some of the factors are free for interpretation. Most of them were found to be obvious such as infrastructure, regulation (hard institutions) and funding (soft institutions). For the moment, this does not show any problems to answer the RQ. The following table shows the SIA matrix of all identified and analyzed failure factors of the development period. As said, the AV is not in this phase yet.

Institutions	Actors Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Legend			
AV	LNG-D	e-BC	SBC

Table 89: SIA Matrix of failure factors of development periods of all innovations

The strong network effects stay in place during this development phase. For the e-BC this relates to the lock-in effect on the tanker market which does not show sufficient flexibility in changing charterer as explained in the case. The LNG-D showed a lock-in because of the fixed contract with the major such as Shell as important part of its business plan. The SBC suggested that shippers and forwarders often rely on their already developed logistics and that the concept of SBC which requires a number of SPDBs are to be left in the proximity of destination during operations, could generate too many transaction costs for potential customers to integrate the SBC in their logistics. This potential failure factor remains unaddressed in this phase.

The implementation period is discussed in the next part of all cases that are currently in this period.

8.1.3.Failure factors in the implementation period

It becomes clear that only two cases are left to analyse. This is because the selection conditions did not only look at similarities between cases. It could be that in other research the development periods are more important to analyse and that innovations that are situated in the same development period should be preferred. In this research this was one of the selection conditions, but not a decisive one.

In case of the LNG-D the lack of infrastructure for bunkering on the side of shippers and forwarders is not regarded as a failure factor anymore as TTS becomes more possible. The regulatory bottleneck has been removed and new LNG vessels do not require (anymore) a derogation on existing regulation and standards. The e-BC only shows the remaining failure factor of strong networks considering the market dominance of conventional charterers outside the spot market.

Institutions	Actors	Demand: VOs, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties' lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies, regulators, verification agencies
Infrastructure					
Hard Institutions					
Soft Institutions					
Weak Networks					
Strong Networks					
Capabilities					

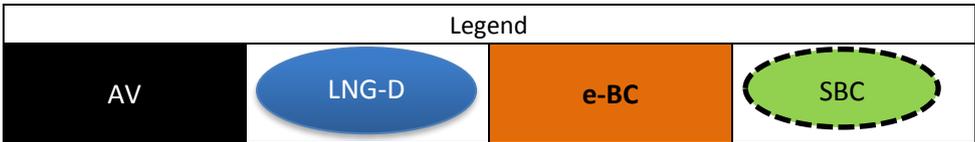


Table 90: SIA Matrix of failure factors of implementation periods of LNG-D and e-BC

The following part analyses the different cases according to their typologies.

8.1.4.Differences in innovation typology

The first typology categorizes the innovations according to five possible changes. All of them are technological, managerial, organisational and cultural changes, except the SBC which is a policy initiative. The AV and the SBC are the only innovations that aim at a market change, while other cases target business changes. The typology referring to the level of implementation, is already analysed in previous parts.

Comparing the degree of innovation shows that AV is systematic, LNG-D and the e-BC are incremental, while the SBC was defined as modular. This indicates that the cases show several differences after analysis.

All innovations were not successful (yet). Only the e-BC is successful in being diffused as an additional chartering tool, but the necessary critical mass of registered users is not known, and the level of actual usage is also not shared. Therefore, the level of success for the e-BC is mentioned as not-available.

At the beginning of the research it was not known during the selection which innovation could be successful. This finding does not mean that there are no successful innovations in IWT.

Although all innovations are private (except the SBC), all of them showed public funding for R&D (AV, e-BC and LNG) and even building subsidies (LNG).

Cases according to typologies		AV	LNG-D	e-BC	SBC
Timing	Past				
	Present/future				
	Future				
Degree	Systematic				
	Radical				
	Modular				
	Incremental				
Source	Public				
	Private				
Access	Semi-open				
	Open				
	Close				
Level	Initiation				
	Development				
	Implementation				
Change	Technological unit				
	Technological – market				
	Technological, Managerial, Organizational, Cultural – Business				
	Technological, Managerial, Organization, Cultural – Market				
	Managerial, Organizational, Cultural – Market				
	Policy Initiatives (Managerial, Organization, Cultural – Market)				

Table 91: Comparing the typologies of the analysed innovations
 Source: Applied typologies derived from Arduino et al. (2011), Roumboutsos (2013) and Sys et al. (2016)

The following cross-case analysis is applied on the CBA of both the LNG-D and AV.

8.2. Cross-case analysis of the CBA

The analysis investigated if the innovation is a sound investment for a vessel owner and for society. For both the AV as for the LNG-D a vessel model that represent the main end user of the innovation. This approach, although replicable, causes limitations for generalisation:

1. Different vessel models (dry bulk and liquids)
2. Time span of investment: 40 years for AV; 25 years for LNG-D
3. Starting year of analysis differs between cases: LNG-D = 2012; AV = 2018
4. Several case related assumptions concerning fuel cost, engine power
5. Revenue considered to be fixed freight rate (forecast), although more refined approach in LNG-D was possible. Available and accessible freight rate data for LNG-D in tanker market was identified
6. Nature of innovation: LNG is a transitional fuel, while AV consists of ICT innovations
7. Push behind innovation: LNG = fuel price and environmental policy; AV = reduction of crew costs, fuel consumption and accidents
8. AV has social benefits for society (claimed safety and fuel efficiency benefit) but is only more attractive for private investors if economies of scale are integrated and several vessels are built. LNG-D showed without subsidies to be worse than the reference case for private investors. The social benefits depend on what is more important, climate change or emissions.
9. For the AV only the total external costs of all emissions and GHG are calculated. For LNG-D the distinction has been made between GHG and emissions which was relevant for this case. For the AV there is no reason to make this distinction.

Both business cases should be interpreted with caution and have their own particularities such as average trip distances, volume, fuel consumption and required engine power. Furthermore, there is hardly any standardized vessel design in IWT which also adds to the identified generalisation problem.

It was not always possible to triangulate data for the AV as it was the first analysis for IWT according the consulted literature. The LNG-D findings however, can be compared with other sources. Different findings are explained by the removal of the regulatory bottleneck while in most consulted literature this is still considered as a problem. More important is the calculation of the external cost of methane and the converting of methane to CO₂ equivalent values according to more recent findings. Changing the CH₄ factor to 34 instead of 21 or 25 as in earlier LNG IWT studies, shows a significant difference. When 25 is used, similar outcomes are found as in Prominent and other studies whereas 5% reduction of GHG is claimed. Adjusting this factor increases the GHG external cost significantly and decreases the reduction. This part of the analysis can be improved by further testing and if possible, by triangulation of other (future) data or evidence.

LNG-D cannot be successful if no sufficient bunkering infrastructure is available. The TTS provides a solution but is sub-optimal from a societal perspective. The added logistics costs do not influence the business case significantly for private investors. Both LNG-D and the AV need infrastructure although the first generation of automated vessels could do without major infrastructural investments¹⁹⁰.

In the LNG-D the business case depends fully on the price spread between diesel and LNG which is very difficult to predict during the lifespan of the investment. By altering the start year of the lifespan in the analysis to 2012, the unpredicted narrow price spread around 2016 could be taken into account. Furthermore, the CBA of the LNG-D calculated equivalent prices per mWh of both fuels and converted it from kg LNG and litres diesel. As explained, LNG and diesel are usually compared between euro per kilogram and euro per litre in previous studies and in business, but which does not explain the difference in energetic caloric value of both fuels.

¹⁹⁰ with parts of the vessel becoming automated and crew is still required to be on-board

The inputs for the first year of analysis are shown for the AV and the LNG-D in the following table:

Comparing vessel models		dry cargo (current prices of 2015)		chemicals (current prices of 2012)	
		CV	AV	CTV	LNG-D
	Capital value (EUR)	2,000,000	5,900,000	5,900,000 ¹⁹¹	6,966,533
	Lifespan vessel (years)	40 years		25 years	
	Leverage (70% of capital value, EUR)	1,400,000	4,130,000	4,130,000	4,876,573
	Payback period (years)	15 years			
	Number of crew (persons)	4	0	Not applicable	
	Maximal loading (tons)	3,000	3,300	2,908	
	Residual value (scrap value)	80,000		147,500	174,163
Fixed	EUR	493,159	677,006	485,034	568,752
	Maintenance & Repair	50,000	26,586	47,394	
	Insurance	28,000	67,850	78,560	92,762
	Salaries (gross)	272,800	0	461,503	
	Technical compliance (certificates)	9,000	6,750	26,525	29,177
	Administration & communication	3,000	300	Not applicable	
	Financial cost	130,359	384,560	384,560	454,076
	SCC service	0	190,960	Not applicable	
Variable	EUR	247,230	163,945	921,541	856,064
	Charterers provisions	67,760	10,861	71,996	
	Fairway & port dues	15,154	19,002	15,288	13,973
	Fuel costs	164,316	134,082	298,836	232,021
Total	EUR	740,389	840,951	1,406,575	1,424,816
Revenue	Fixed freight rate AV (EUR 2.15/ton, first year)	968,000	1,086,096	Not applicable	
	PJK from 2012-2018 and linear forecast	Not applicable		1,028,511	

Table 92: Comparing the costs and earnings of the first year of AV and LNG-D

The most significant reduction in out-of-pocket costs is in AV related to the reduction of crew salaries, but the results show that in every scenario for one AV, the original reference case always has a higher NPV for equity and higher IRRs. Only when economies of scale (5 AVs) are implemented in the model or when the reference case has more crew members (e.g. ≥ 6 FTEs), the project case scores better. The NPV for equity also becomes negative when the project case (or AV scenario 1) has a more conventional chartering provision above 5%¹⁹². In case of 5 AVs (scenario 5) the NPV for equity becomes negative if the charterer provision is $>3\%$. In the LNG-D case there are no benefits related to reduction of crew costs and the chartering provision rate stays fixed at 7% for every scenario.

Table 93 shows the highest scores according to 3 categories of scenarios. The group with the analysis concerning economies of scale where 5 AVs are compared with a comparable reference case of 5 CVs, must be considered as a separate category. Because the investment is 5 times higher than in the other AV cases. The other two categories are investments regarding LNG-D or an AV. The reference cases are also showed. The differences between the developed cases for the innovations are quite significant which does not allow judgements in which investment would be better, the LNG-D or the AV. Not only the developed model differs significantly, also the target of the innovation attracts other investors.

¹⁹¹ Similar capital values for the AV and the CTV are a surprising coincidence. Where the capital value for the AV is the sum of the automated mooring devices on board, capital value of the CV and next to one-time costs of AV - equipment, the costs of a CTV comes from literature.

¹⁹² It was assumed that the AV will have a lower provision for the charterer as the charterer would also be significantly automated and could be provided by e-barge chartering

The NPVs, IRRs and the B/C ratios in all scenarios for both the LNG-D and the AV are ranked according to the highest NPV for equity in the following table:

Scen	AV	NPV _(equity)	NPV _(enterprise)	IRR _(equity)	IRR _(enterprise)	B/C ratio
8	5 AVs (low SCC p)	7,625,181	33,781,136	14%	12%	2.48
6	5 CVs	6,922,750	18,708,837	22%	15%	1.45
5	5 AVs (1% prov)	5,968,490	30,789,368	13%	11%	2.28
2	LNG-D (subsidy)	3,298,011	419,658	23%	14%	1.03
1	LNG-D	2,764,744	419,658	19%	14%	1.04
3	LNG + 1%	2,752,453	419,332	19%	14%	1.03
8	LNG-D P&F CTV	2,750,120	418,948	19%	14%	1.03
4	LNG +8%	2,666,416	417,047	18%	14%	1.02
0	CTV	2,662,707	392,734	19%	15%	1.08
5	LNG + 10%	2,641,834	416,394	18%	14%	1.02
6	LNG = D	2,505,536	421,110	18%	14%	1.03
7	LNG > diesel, -5%	2,428,859	419,550	17%	14%	1.02
0	CV (4 FTEs)	1,384,550	3,741,767	22%	15%	1.47
7	AV (low SCC p)	1,239,261	6,240,154	13%	11%	2.31
10	AV (lower fuel cons.)	718,094	5,304,682	12%	10%	2.05
3	AV (small increase fuel p)	642,768	5,301,749	11%	10%	2.09
2	AV (25yrs loan payback)	565,859	4,889,342	12%	10%	1.85
1	AV	410,915	4,744,270	11%	10%	1.92
11	CV (6 FTEs)	201,202	1,604,795	11%	10%	1.22
9	AV (7% provision)	-154,436	3,723,318	10%	9%	1.72
4	AV (low trips)	-2,143,143	139,807	5%	5%	1.45

Table 93: Comparing the NPVs, IRRs and B/Cs of the AV and the LNG-D (including reference cases)

The AV is analysed within the dry bulk market and has more uncertainties which are not only related to the assumptions and limitations within the model, but also to the innovation as such. The innovation is a future innovation that includes several components and systems that are innovations by themselves. The LNG-D is already in the market and more knowledge has been gained concerning the innovation.

The environmental part of the analysis compares the total external costs which are cumulated at the end of the lifespan of the investment. The following table shows the differences between the reference cases and the main innovation or project cases.

Scenario		External costs (cumulative) in EUR					
		Accidents	Infrastructure	Emissions+GHG	Emissions	CH ₄ CO ₂ eq. = 25 GHG	CH ₄ CO ₂ eq. = 34 GHG
1	LNG-D				6,307,663	11,274,451	12,110,810
0	CTV				18,496,710	11,980,831	12,017,198
0	CV	433,734	7,983,454	24,731,353			
1	AV		8,981,386	19,785,083			

Table 94: Comparing the external costs of the AV and the LNG-D (including reference cases)

The cumulative external costs at the end of the lifespan of each investment show differences the AV and the LNG-D. First, this is explained by the difference in investment lifespan in each analysis as explained. Both cases only have emission and GHG reduction in common. The analysis of the AV did not focus on the difference between GHG and emissions in contrast with the LNG-D.

It is not possible according to these two case analyses to judge which innovation would be better for the environment or climate change. Moreover, the use of external costs has limitations because these costs represent a certain moment in time. The economic and environmental damage of accidents, infrastructure, emissions and GHG, are influenced by the method in how they are calculated. The calculation methods can improve and when tomorrow more accidents happen (or are better measured) in IWT, the external cost values of the mode need to change.

Despite these limitations, one of the most important findings of the LNG-D analysis still stands. That is when analysing Greenhouse gases, the factor that is used to express the CO₂ equivalent values is decisive for the impact on climate change. The LNG-D is in best scenario (factor = 25) slightly better for climate change and according to the latest findings worse than the reference case. For the AV the result is positive for society but rests on several assumptions as described in the case study.

The cross-case analysis of the SIA and the CBA gave insight between the cases. The following part analyses the differences and similarities between the PEINPA of the LNG-D and the AV.

8.3. Cross-case analysis of the PEINPA

The PEINPA of the AV and the LNG-D tried to identify the IWT innovation policy from a Pan-European multilevel policy setting as developed and described in Chapter 3. The paradigm of NIE and the transaction cost theory as described in the policy literature review, are combined with theories concerning European integration and policy cycle.

After the development of the institutional setting, the PEINPA starts with identifying compliance costs, information costs and enforcement costs in both cases. Through this process, traces of asymmetrical information, adverse selection and credibility are noted and examined although theoretical. Throughout the analyses it is important to identify political bias which is often referred to. When analysing policy in a more detailed way, it is unavoidable to come across the political rational which is throughout the business cycle present. The researcher needs to realize and identify this without taking the risk of taking political sides on issues. The PEINPA does not show any clear-cut method in avoiding political bias. Through sound cognitive reasoning¹⁹³ in close collaboration with other views (e.g. peer reviewers, stakeholders, or validation jury) and in a transparent way, this can be significantly avoided. Furthermore, the information gathering is important. Not only interviews and extended desk research had been done, also the role of participant-observer can have a significant contribution.

In both cases there was a problem concerning quantification of the transaction costs within policy between public actors and between public and private actors. Both cases reflected a risk for fragmentation at the beginning of the policy. Regarding the institutional setting as developed in this research of PEINP, the influence of private verification or classification agencies and international actors such as IALA and IMO are not taken into account and need further research.

A difference in policy setting was also observed between the cases:

- **Situating:** The AV is situated in the RIS environment and relates to technical, crew requirements and police regulation. The LNG-D is nested within technical regulations (e.g. engine design) and the ADN (dangerous goods). The LNG-D is strongly related to environmental policy and needs to comply to emission standards.
- **Initiation:** Not only the innovation of the AV is situated in its initiation period, also policy just started to develop legal concepts and definitions. In case of the LNG-D all regulatory bottlenecks are removed but public nor private on-shore infrastructure was implemented.
- **Public funding:** The AV receives public funding for R&D. LNG-D received building subsidies, port due discounts.

¹⁹³ Mental process in which information, such as arguments, data or facts, are applied to decide or conclude.

- First mover advantage: possible to track the path of the innovator within PEINP. In case of LNG-D the first mover advantage was that the first LNG-D vessel provided a test case which was the basis for the adjusted standards. This not yet the case for the AV but can be expected.

Looking at the benefits, potential but missing synergies were identified in cost management regarding translation, administration, housing and transport. It could be reasonable to explore how to reduce these costs. Every public actor on the higher level has these costs. From an economic point of view, these policy costs can be reduced by centralizing at one location for all IWT related meetings or to use more modern communication tools.

Despite quantification problems and limitations, both developed PEINPAs cannot be rejected as they are still in their own initiation period and require further testing and refinement. As a method they fit in the developed institutional setting of PEINP, but in theory this method can be adjusted to analyse other innovations or policies.

For now, together with Chapter 3, the PEINPA raises awareness for different issues that have to be taken into account and it could be used as an updated pan-European IWT policy guide for policy makers, stakeholders and innovators that are interested or involved in building a PEINP for AV, LNG-D or other innovations in IWT.

After this cross-case analysis, a general conclusion can finally be drawn not only for the case studies, but also on the applied and developed methodological approach.

9. General conclusion, future research and policy recommendations

In this research a multidisciplinary approach is developed to analyse innovation in IWT within a detailed small-sample multiple case study. The approach consists of elements from welfare economics, system innovation and policy analysis through a lens of new institutional economics combined with the theory of transaction cost economics. The developed methodological framework is replicable and gives insight into a lesser explored field of research. It is the first attempt to conceptualise IWT innovation from a policy and welfare-economics perspective in detail according to the scarce and available literature consulted.

The system of innovation analysis, especially in combination with the developed CBA and vessel model, provides thorough insight into the business case of the IWT innovation. The SIA reveals important conditions that could lead innovation towards success or failure. Together with the literature review and in-depth interviews with stakeholders, innovators and end-users, it also reveals whether or not sufficient cost data could be retrieved to perform a SCBA or a CBA. In all the innovation cases examined, it is not feasible to gain sufficient insight into the closed cost structure or relevant R&D investments of the different innovating firms that produced the innovation involved (such as engine builders). For this reason, a complete SCBA is not performed. Instead, a CBA is developed and applied from the perspective of the end-user which is, in this case, the innovative vessel owner. The CBA reveals if the innovation is attractive for investors or not. By taking into account the external costs from consulted literature and calculating them according to the emissions and performance of the vessel model, it is possible to analyse the differences between the reference case without the innovation and the project case with the innovation. Nevertheless, caution is required because of the lack of unanimity in quantifying these external costs and little is known about the IWT statistics behind them to calculate these costs for IWT (e.g. lack of high-quality accident statistics, emissions measurement in real life).

For both the AV and the LNG-D, it is possible to apply the developed CBA, but a full calculation of the social cost of the innovation is not possible without sufficient information concerning costs such as the infrastructure cost (e.g. bunkering infrastructure for LNG-D) or costs related to the innovation developer (e.g. development costs of all AV devices and scanners).

The developed CBA vessel models can be used for further research and are replicable. However caution is required when generalizing the findings of both cases as the decision was made to perform a detailed small-sample case study using two different vessel models which were each relevant to the case and adjusted accordingly. Furthermore, if future researchers were to use the vessel models to conduct a SCBA, components such as taxation, depreciation and subsidies should be dealt with according to the rules of the SCBA to avoid double counting. The CBA vessel models will have a closer fit to vessels that have a similar exploitation mode, size, average payload and average fuel consumption, however a number of components can use further refinement such as revenue (including the freight rate) which depends on cross-price elasticities and developments in competing modes derived from the more general demand for transport. Moreover, the fuel cost depends on several variables outside the model (global demand and supply of both LNG and diesel). The residual value is also difficult to forecast at the end of the lifespan of a vessel which can be easily more than 30 years. Despite these concluding refinement remarks, the models are adjustable for inputs from other vessel owners and vessel types.

In contrast with other research from the literature review such as Prominent, the vessel model in this research is based on an entirely newly built inland vessel which allows for more detailed insight of the impact of the innovation on the enterprise than if only the fuel costs and the innovation are taken into account. Furthermore, the updated methane factor shows other results concerning greenhouse gases. The partial ex-post character of the CBA of the LNG-D also allows to analyse the unpredicted price change of LNG and diesel which decreased the price spread and which is the main argument to invest in LNG. It shows that the business case of LNG-D is vulnerable for a private vessel owner.

Although all parameters of the CBA of the LNG-D are positive, which means that the NPVs in most scenarios are positive with a B/C ratio higher than 1 and with an IRR that met the requirements (higher than the minimal preferred return on investment in both equity and enterprise), the reference case still shows better results. The project case with LNG-D shows more improvement only when subsidies in the project case were added. The model related external costs decrease in total because of the convincing emission reduction but does not convince at all when climate change is considered.

This research gives innovators and potential first movers in inland navigation insight into how to analyse their innovation and to identify potential barriers for market uptake. It also provides an updated institutional map of the pan-European inland navigation policy with a focus on innovation which is useful for lobbyists and policy makers, especially if they are new to PEINP. In addition to the map, the research shows how policy makers can judge if an innovation should be supported or opposed from a welfare-economic rationale. It recommends that cross-border externalities must be taken into account and links this to the institutional setting. This research also raises awareness about the fragmented IWT PEINP and demonstrates that it needs to be reformed to allow for more synergies and a decrease of compliance costs for both the public and for the private actor.

As IWT is still considered to be the most sustainable mode of transport, stimulating innovation, and therefore potential growth of the sector, could lead to social benefits which relate to a potential modal shift. Research in IWT innovation adds to that social benefit. In this regard, it has become clear that the very slow diffusion of alternative fuels or automation could weaken the performance of IWT and even lead to IWT losing its position as the most sustainable mode as other competing modes may improve their performance relatively faster than IWT. This invites further research.

The integrated method of SIA, CBA and the developed PEINPA make it possible to determine which policy level or collaborative policy network could do what and what potential failure factors are to be removed in order for an IWT innovation to avoid failure. The advantages of the integrated methodological approach offer a thorough in-depth insight into each selected innovation case and help innovators to identify failure factors such as regulatory bottlenecks or lack of infrastructure. An important challenge within this approach is to avoid any bias towards a policy level. Therefore, it is not advised to use the integrated method to make normative statements about which policy level or configuration is the most optimal for IWT, while assuming this would be possible. Viewing policy through a lens of transaction costs helps to identify potential synergies within and between public organisations, yet this approach needs further development, testing, quantification and cost data. Applying transaction costs to public actors is, as yet a relatively unexplored field.

Regarding the research question, the following part of the conclusion divides the answers into two parts. The first part relates to the factors that determine innovation success or failure in inland navigation. The second part refers to the role of policy concerning IWT innovation in (pan-)Europe. After the answers to the research questions, issues concerning generalisation are addressed, followed by an invitation for further research and some policy recommendations.

RQ: What are the factors that determine innovation success or failure in inland navigation and what is the role of policy?

9.1. Success and failure factors in IWT innovation

The IWT fleet consists of relatively old vessels and scores rather low on the community innovation survey. Furthermore, the growth in modal share of the sector has been relatively consolidated on the EU level for the past decade. The European IWT fleet consists of a significantly large group of small and medium-sized enterprises with usually one or two vessels. The vessel owner is in most cases the actual operator who lives on-board with his or her family. IWT is generally perceived as a sector that lacks innovation. There is also no custom-made definition of IWT innovation. The general findings of the case studies provide the possibility to elaborate on a definition of IWT innovation and to add elements to the developed synthesis between Hekkenberg and Liu (2017) and Arduino et al. (2013) as given in the literature review:

An IWT innovation is a technological or organizational (including cultural as a separate sub-set) change to the vessel (or IWT service) that either lowers the cost of the vessel (or IWT service) or increases the quality of the vessel (or IWT service) to the vessel owner and is mainly directed at reducing fuel consumption (e.g. AV with removal of domestic areas or the usage of LNG), maximization of scale (e.g. larger ships or the SBC concept), entering niche markets and digitalization (e-BC, AV and RIS developments) while facing mainly infrastructural, regulatory and network challenges but with public funding in at least one period of innovation development.

Indeed, public funding is found in every case in at least one period of development. Public actors are even found to lead innovation development in case of the SBC or in some automation pilots. LNG diffusion is stimulated by public funding in R&D, subsidies and in LNG masterplans. In case of e-BC, public actors funded several similar (failed) attempts during the initiation phase.

Public funding hardly seems to find its way to the numerous SMEs and is given mostly to public actors or the few larger private companies in IWT. This has to do with the lack of general awareness that public funding is possible or of sufficient knowledge in how to apply for funding in a very complex institutional setting.

The end-user in this research is not the consumer of the IWT service such as forwarders or shippers; the focus lies on the vessel owner. The vessel owner does not produce or develop innovations but decides to invest or implement the innovations or not. Failure factors at this level, are related to capabilities such as skills and training, financial possibilities, knowledge and even culture. Skippers may be reluctant to choose an innovation because of a conservative attitude and a strong belief in the effectiveness of old habits or routines. They might prefer to wait for others to move first, they expect the price of the innovation to go down in the future or that more subsidies may become available. In the case of engine innovation, the phenomenon of cubanisation where old engines are renovated for a longer period than their lifespan, does not stimulate innovation diffusion in this area. The market shows lock-in effects in several segments such as the tanker segment where it is not easy to change a freight charterer (e.g. EBIS) or in case of the LNG where the investment relies on fixed contracts with significant large LNG distributors such as Shell.

Of course, if automated and unmanned vessels become successful, the market could radically change making the mainstream business model of small family SMEs with on-board domestic areas a thing of the past. However the analysis does not allow for such a prediction. The AV is concluded to be a systematic innovation where the number of systems and components are all innovations on their own and that these components will gradually appear on the market. The applied typology still leaves room for debate as some of the innovations examined are still in the development period. For professional freight transport, it is far too soon to call the AV radical despite its believed potential, as this innovation is in its initiation period.

The identified innovation actors show collaboration in the innovation network and the considered innovations are all open which means that the innovators develop the innovation in partnership with other firms which can be ship yards, verification agencies, knowledge institutions or public actors.

Shippers and forwarders however do not show significant involvement. However because of the small-sample multiple-case-studies design, it does not mean that all IWT innovations are open and collaborative without the involvement of shippers and forwarders. Nevertheless it is an interesting conclusion that might indicate a lack of interest in innovation development in IWT from this side which invites further research.

The main failure factors throughout the periods of development of the examined innovations relate to the lack of sufficient infrastructure, the presence of regulatory bottlenecks, network effects and lack of capabilities. Although the innovations analyzed are at different stages in their development and none of them are successful (yet) in that they pushed the market dominant actor away, it can be concluded within the limitations of the SIA in this small-sample multiple case study, that the identified failure factors require the alignment of a linked innovation network of actors and that it is not only a case of money. If regulatory bottlenecks are not removed on time or mitigated by measures such as derogations, the innovation will fail. Yet even if regulatory bottlenecks are dealt with (e.g. LNG-D), and affordable solutions are provided for the lack of on-shore bunkering infrastructure (truck-to-ship), there may still be a relatively slow market uptake.

In examining the regulatory bottlenecks, it becomes clear that a complex pan-European institutional setting lies behind these bottlenecks and that different public actors need to collaborate and be aligned to adjust standards and regulations or to provide public funding and infrastructure. Although infrastructural factors are not necessarily related to public actors, these actors play an important role in addressing infrastructural issues. In the cases of automation and LNG, the industry such as terminal operators or refineries also needs to be aligned to provide infrastructural solutions, which is not always the case.

The SIA does not indicate when an innovation will be successful, it shows the potential failure factors that must be removed in order for the innovation to become successful. In a global economy it is not the case that a regulatory bottleneck in one region of the world can preclude an innovation away from being successful. It can easily be developed and implemented in other regions without such kind of bottlenecks. Another limitation of the SIA is the qualitative and explorative nature of the analysis whereby the developed CBA offers a significant quantitative contribution to answer why end-users or, in this research, vessel owners decide to invest in the innovation. The CBA helps to understand if an investment in an innovation is attractive to private investors, in this case the individual vessel owner. By taking into account the effect of the innovation on external costs in comparison with a developed vessel model reference case without the innovation, it is possible to decide if the innovation is also attractive for society.

The outcome of the two conducted CBAs each with a customized case-related vessel model, is the following:

- AV: Traces of advantages of economies of scale are found whereby an investment of multiple AVs (calculated for 5) shows a higher NPV and benefit/cost ratio than the reference scenario. Although the internal rate of return lies higher than the estimated cost of capital, the reference case still shows a higher IRR. The analysis shows that there is a critical level of the number of FTEs that must be taken into account. According to the vessel model it is attractive to invest in an unmanned AV if more than 6 FTEs are replaced when compared with a single conventional vessel or reference case. The external cost analysis shows a decrease of between 3% and 16% compared to the reference case and depends on the potential reduction of emissions by removing the accommodation on-board and the question how much should be invested in infrastructure if it were publicly funded. The external costs related to accidents are already insignificant in the current IWT but are based on unreliable data.

- LNG-D: although the innovation shows a positive NPV, an acceptable IRR and B/C ratio, the reference case scores better for the IRR and B/C ratio in most scenarios. The differences between the project cases and the reference case becomes more attractive for investors if subsidies are taken into account. However, the business case completely depends on the price spread between LNG and diesel and former studies have proven to be too optimistic in forecasting the fuel cost. The presence of subsidies should therefore be considered as a less important argument to invest. An unpredictable evolution of the price spread makes the business case vulnerable. The analysis shows that the TTS bunkering cost as an additional logistics cost does not have a significant impact on the financial results. This aspect will probably improve in the future as on-shore bunkering facilities are implemented. The CBA of the LNG-D calculates the revenue using PJK freight rates which are, together with the fuel costs, partially ex post by starting the analysis in 2012. This includes less forecasting and views in retrospect real price changes of LNG and diesel. The external costs of the LNG-D are related to emissions and greenhouse gases. Although LNG-D is very convincing in reducing emissions, the performance towards climate change mitigation are rather insignificant.

The e-BC case shows a development of a B2B application that has the potential to change the conventional market of chartering a barge. Although, the number of registered users is reported to be increasing, skippers tend to use the application mainly on the dry bulk spot market as an addition to conventional chartering. The main bottleneck for the innovation was the absence of internet coverage and a critical mass of connected users on-board during the initiation period. Another bottleneck but one which is not understood as a failure factor, is the absence of digital or electronic documents that can replace paper chartering documents. Public actors, in particular, still require several paper documents which indicates that improvement is still possible. Finally, the further development of a digital IWT infrastructure such as RIS, can invite future developments to emerge, which is also true for the AV.

The case concerning the small barge convoy suggests that there is still a potential modal shift of volumes from road to these small waterways but that the costs (for instance the crew costs) need to be reduced in order to improve competition. Innovative concepts that try to reduce these costs seem to offer a potentially positive business case, but the IWT market hardly shows any interest and prefers to invest in larger ships. Innovation initiatives such as the small barge convoy try to reactivate these small waterways, but it remains difficult to find market uptake. Despite EU and MS funding in research, development and building since 2006, the innovation is still not operational. More private investors are still to be found.

The case studies revealed that IWT is indeed a niche market in which most potential innovation customers or vessel owners are active on the Rhine. The relatively small size of the market emerged in several cases as one possible reason why investing in IWT innovation is not without risk, but as the sector holds a potential solution for decreasing external costs such as congestion costs in road haulage, innovation in IWT includes a social benefit as it helps the sector to grow. The following part of the conclusion answers what the role of policy is and what public actors can do to support or to resist innovation in IWT.

9.2. The role of policy

The research reveals the complex and fragmented institutional setting of a growing pan-European Inland Navigation Policy which is slowly reforming but still shows elements of improvement in order to create integrated innovation policy. Diverse political and historical reasons explain the existence of several policy levels that need to cooperate, coordinate and steer policy. In an ideal world, policy makers could choose the most efficient and effective policy to address issues while following an

economic rationale or an evidence-based policy, but in reality, they are bound to historical, cultural and political reasoning that is often confounded¹⁹⁴.

The literature review, the analysis of the institutional setting of PEINP and application of the developed PEINPA, offers a definition of the innovation policy of PEIN as follows:

All combined actions undertaken by a multi-layered multi-level policy model with growing actor interdependencies (both public as private) and legal scope that aim at a level playing field for IWT in accordance with safety, environmental, social, legal and technical standards and regulations with the objective to stimulate, facilitate, participate and / or even lead or enforce innovations towards success (or failure in case of an unwanted innovation) and to improve the innovation system in both produced quantity as quality while following a cyclic policy path and using instruments that could target both demand and supply of innovation.

As shown, IWT innovation is just one of the issues on the policy makers' agenda within a multi-level policy structure that has horizontal and vertical dimensions and operates through a continuous policy cycle. After using an economic approach through a lens of transaction costs, it becomes clear that not all policy costs are covered by (multi) annual financial frameworks and that the current institutional setting misses potential synergies. Every public organisation has its own costs referring to translation, communication, information, transportation, housing and other overhead costs. However these costs can be relatively small when compared to internal policy compliance which refers to the process of making regulation that needs to be coherent with co-existing regimes. These costs are generated because of the institutional setting where river commissions often have their own regime in addition to EU regulation. Despite the near equivalence of these regimes and failed harmonisation attempts in the past, the system of mutual recognition has emerged without significantly changing or lowering the compliance costs as co-existence continues. The setting has allowed for the emergence of a collaborative network approach between public actors across the PEINP but without one central actor steering or leading the network.

Although still young and too early to evaluate, the emergence of CESNI can be seen as an important attempt to centralize the IWT standards for technical requirements, crew requirements and recently, IT-related issues. This can lead to a decrease in compliance costs within policy. A reform of the pan-European policy in this regard, without losing the potential benefits (knowledge, constant focus on IWT, network) of specialised organisations in IWT (such as river commissions), may also be positive for private innovators. During the LNG-D case study, the effort or rather the crusade of the first mover, seemed relatively expensive with regular trips to at least three different capitals in Europe to convince fragmented policy makers and experts.

Unfortunately, it was impossible to quantify all transaction costs concerning IWT innovation policy. These costs are usually not collected in sufficient detail and those who are responsible for innovation policy in IWT, also perform other tasks or are involved in other IWT policies. The PEINPA as developed as analytical tool to reveal transaction costs such as compliance and enforcement linked to the policy cycle, faced several limitations in both identification, data accessibility and lack of transparency of the examined public actors. To explain it in SIA terminology, the PEINPA is currently in its initiation phase and needs more testing and theoretical refinement to allow for further development. Nevertheless, testing the tool on the cases, raises awareness, increases insight and explores a relatively unknown field of transport policy within academia. It shows that IWT policy has an impact on the individual business cases examined and causes transaction costs for both the entrepreneur and for the policy actors themselves. Although, this finding is based on a small set of cases and invites further research.

Because of the policy fragmentation, policy tools are situated on different levels of policy. Several tools were identified during the cases and by the literature review. They can be linked to the responsible policy level or public actor such as subsidies for firms, public funding for R&D and pilots, derogations

¹⁹⁴ Confounded refers to hidden effects by unknown independent variables on analyzed dependent variables.

for first movers (e.g. testing zones, no need to comply with standards for a fixed period of time), tax discounts (e.g. port dues, fairway fees), public infrastructure (or allowing private), adjusting regulation and standards, being a public innovator or doing nothing. In all cases the public actor was involved in at least one of the identified periods of innovation development.

It was found that only Member States and lower levels can give subsidies within the limits of European regulation or provide tax incentives. Public actors can also be innovators causing possible disturbance on the market (e.g. SBC of Watertruck+) and are not found above the national level. Subsidies can be co-financed by the EU but this does not necessarily occur.

Infrastructure belongs to the competences of national, regional and local/port level and can also be funded by the EU. According to the SIA, the lack of sufficient infrastructure was considered as a failure factor in every case in at least in one stage of the development. Nevertheless, it is not the intention of this research to declare that this should be public or private infrastructure. It is important to point out the significance of infrastructure for an innovation and its impact on the further development of an innovation.

Based on the case studies, the higher levels of PEINP are found only to be able to provide public funding (R&D, including pilots), invest in knowledge centres, and to adjust regulation and standards. The tool of derogation can also be found at the level of the river commissions and not only at the national or regional level. This tool is important when existing regulations or standards do not allow for the implementation of the innovation. Other policy measures to stimulate innovation in IWT from literature such as public procurement and investments in training and skills were not found in the cases.

The innovation path as applied in the CBAs taking into account the calculation of the external costs, shows important indicators if policy is needed. When private actors find an innovation not attractive enough (too low IRR, B/C or NPV, lower than reference case) but there are social benefits such as a decrease in external costs, policy can play a role. Moreover, when private benefits are sufficiently high, but they come with a high social cost, policy can resist the innovation by taxing to compensate the losers or by regulation to prevent further implementation of the innovation. No cases to analyse the latter are found in IWT though the CBA of the LNG-D shows some concerns in this regard. Indeed, by analysing the LNG-D implementation partially ex-post and adding recent findings of the UNFCCC in regard to the methane CO₂ equivalent factor, the external costs for climate change hardly improved when compared with the reference case of a diesel engine. If policy is aimed at only decreasing emissions to improve public health, support for LNG can contribute to welfare. However if the policy objective to decrease climate change is more relevant, support is less advised from a welfare-economics perspective. Other vessels with larger fuel consumption or vessels with longer trajectories and operational hours could show larger benefits in emissions and in cost reduction which makes the generalisation of this statement rather limited. Nevertheless, the case study shows an important element of concern related to the external costs of the methane slip. Policy can decide to accept LNG as a transitional fuel despite the external costs (or not), while awaiting better developments of other alternatives or solutions for the methane slip. Policy can decide to invest in on-shore bunkering stations or allow private developments and more TTS locations, but this also comes with external costs as not everyone welcomes a bunkering station with LNG installations.

For automation, no need for social compensation was identified in IWT as far it was taken into account, but developments in the labour market are important to follow. It does not mean that ageing of IWT personnel and decreasing labour supply will follow the same trend in the future during the next stages of automated vessels. In future analysis, this must also be taken into account from a welfare-economics perspective. The potential loss of jobs is relative as Schumpeter stated in his theory of creative destruction, but whether skippers will easily find their way to work in a SCC when the AV arrives, is unpredictable.

The entire PEINP, including the UNECE, together with international partners (IALA, IMO) and private actors (verification agencies, innovators, industry and vessel owners) certainly has a role to play in removing regulatory bottlenecks and other failure factors in a coordinated and collaborative way (as long the institutional setting is not reformed). External costs need to be taken into account when judging an innovation and also the benefits of potential market disturbance by policy intervention needs to outweigh the costs. After analysing the institutional framework, despite several seemingly positive evolutions such as CESNI, there is still a valid question as to why a rather small economic sector in Europe, needs so many public actors within complex co-existing regimes that lack potential synergies in reducing their own costs. Hopefully, this study also raises awareness about this issue and can contribute to an institutional reform or innovation of PEINP.

9.3. Research benefits

The dissertation aims to contribute to academia, industry, policy and society at large by exploring this rather uncharted field of transport policy research related to IWT freight transport. This research identifies following groups that can benefit from the insights gained or added value of this research:

- **Academia:** the research shows a multidisciplinary approach whereby elements from welfare-economics, system innovation and a developed policy analysis are combined. The methodological framework is replicable and gives insight into a lesser explored field of research. It is the first known attempt to conceptualise inland navigation innovation from a policy and welfare-economics perspective (according to consulted literature). It contributes to theories of European integration, transaction cost economics and new institutionalism.
- **Industry:** it shows IWT innovators what the challenges can be and gives insight into whether the innovation can become a positive business case if success conditions are met. It also provides an updated institutional map of the European inland navigation policy which can help in looking for public support.
- **Policy:** the research shows how policy makers can judge if an innovation should be supported or opposed. It also recommends from a more economic rationale that cross-border externalities must be taken into account to judge on which policy level the policy cycle could start. It also indicates possible synergies within policy that could lower transaction costs for both public as private actors.
- **Society:** Research into IWT innovation can improve this kind of specific innovation and therefore contribute to this freight transport mode which has the least external costs per ton-kilometre in Europe.

9.4. Generalisation

A final remark in this conclusion relates to generalisation limitations of this research. The following findings need to be taken into account:

The review of the consulted literature already shows that there are few possibilities for triangulation using counterfactual scenarios for the examined cases. Furthermore, evidence is usually limited to a single source. This indicates at least one reason that more research is needed in this still largely unexplored area of transport or policy research.

The Danube region is hardly taken into account. Literature related to innovation on the Danube is even more scarce. The market structure is quite different, and the proportion of the Danube fleet and performance is relatively small in the population of the pan-European IWT fleet. Focusing on the Rhine which is more than 80% of the entire European population, is therefore common practice in most IWT research. The CBA in this research is created for a single vessel owner in the Rhine region, but it can be modified to allow calculations for larger (including Danube) firms with more vessels if necessary cost data can be provided.

I decided to analyse and develop a vessel model that is relevant for the innovation case, to see in greater detail what the innovation impact could be on the enterprise of a vessel owner within the model and what the external costs of that vessel model would be. However every vessel in the fleet is unique. There is hardly any standardization in vessel design and there are diverse types, each having their own sailing profile which limits the generalisation potential of the findings in this small-sample case study. More real-life examples where a vessel owner delivers full transparency of its cost structure and technical parameters, would be needed to improve, test and refine the developed CBA model. If replicated in a larger sample including more sailing profiles, the results can be more generalised. The fuel reduction benefit of the automated vessels as claimed in this research is based on several assumptions. The removal of the accommodation and crew will naturally have an impact on fuel consumption, but the size of this potential benefit differs from vessel to vessel.

The considered theories in this research refer to the application of the methodologies. For example, more testing could further develop the SIA theory (including pattern recognition and typologies) and determine if it fits other IWT innovations. Another limitation which was not always clear during the selection of the cases, is the level of success of the cases. As most analysed cases in this research can be considered to not yet be successful, it is rather problematic to generalize the potential success factors which provide the conditions for an innovation to experience market uptake. It is perhaps easier to examine what causes an innovation to fail than to identify the formula for success and then even to generalize this. Even if all failure factors are removed (if possible), neither the SIA, nor the CBA can guarantee success.

Regarding the findings of the PEINPA and the developed institutional framework, the methodology can be further refined and added to with the role of international organisations such as IALA and IMO which also have an impact on IWT innovation.

Another possible and relevant refinement includes more focus and knowledge on the particularities of the several River Commissions. All the River Commissions are mentioned in this research but the focus lies on the Rhine region and therefore the role of the CCNR was highlighted. There are differences (as examined) because of historical and political reasons that relate to organisational management within the River Commissions, competences, protocols and procedures, and of course member composition. Therefore, generalisation of the findings of the institutional setting and the PEINPA with regard to the Danube or other rivers, need to be understood with caution.

Regarding the SIA and the cross-case analysis, the pattern recognition narrowed down the small-sample case study because the different cases differed in their period of development. Only two cases remained to be examined in the implementation period (e-BC & LNG-D). Both the small-sample case study and also the nature of both cases makes generalisation of findings in this period problematic. The only real similarity between these two innovations is that they are aimed at the inland navigation. Another limitation of the pattern recognition is that it strongly depends on the input of accurate and sufficient information. Variables such as failure factors can still be hidden or not completely revealed.

Another important and more general truth about innovation research, is that a case study shows the current status of an innovation. It cannot predict even if all failure factors are removed, that not another perhaps better innovation will emerge and push the competing innovation away before it is even successful. In the case of alternative fuels, better fuels can be developed which might have fewer failure factors and a more successful path towards diffusion than LNG. Another point to note is that the innovation itself changes during its period of development. It is perfectly possible that even the selected cases in this research, will already be altered or improved while this thesis is in print which demonstrates the fluid nature of the dynamics of innovation.

9.5. Some takeaways for future research

To enhance the methodology, to test the findings or to answer remaining gaps, the following topics may be interesting for future researchers.

9.5.1. From CBA to SCBA

An analysis of the welfare distribution of the benefits and costs can be added to the identification of all losers and beneficiaries of the innovation. Every case tried to identify potential losers and winners of the implementation of the analysed innovation. In case of the LNG an interesting topic could be the calculation of the social costs of an on-shore bunkering station which would have consequences on people living nearby and which could create externalities such as habitat damage.

Replication of the CBAs on more vessels could add to the generalisation of the findings or reject them. An approach to other IWT innovations will produce more results that can support a more generalized theory. A relevant and interesting case could refer to passenger vessels, containers vessels or convoys in different sizes and with different sailing profiles.

Another interesting SCBA relates to the implementation of the SBC. It is stated that there is hardly any privately-driven innovation to target the small waterways which makes public innovation and potential disturbance outweigh additional social costs. This needs further scrutiny or a complete SCBA that calculates the welfare loss for remaining vessels on the small waterways if more cost data can be found.

Most consulted literature used forecasts from the international energy agency of 2015 which predicted an increasing diesel price. They did not predict the decreasing spot price spread between LNG and diesel because of the lower diesel price. This issue requires frequently monitoring and research as it is vital to calculate the reduction of out-of-pocket costs and the return on investment of the LNG vessel.

Future case specific research could improve the LNG-D model by adding the stage V engine. It was not possible yet to compare the LNG-D dual fuel engine with a stage V engine. As more type-approved stage V engines come onto the market, this analysis and existing literature can be updated.

The forecast of the freight rate and the expected earnings do not take into account the possible changes in the market. If the demand for tanker vessels decreases, so will the freight rate (if supply does not change). Demand is significantly more volatile than capacity supply, because of the typical features described, such as lack of bankruptcies, building time, and other aspects (van Hassel, 2017). The forecast of the freight rate in the CBA took changes of water depth in account. This seasonal phenomenon could change in the future if the Rhine were to be canalized or because of a modal shift towards railways and trucks due to higher IWT freight rates and lack of capacity. Although this approach may be debatable, it could improve forecasting because it takes into account periods of high and low freight rates and leaves more conventional linear forecasts behind. Further research could improve or reject this approach.

9.5.2. PEINPA testing and further development

To replicate the PEINPA, the value of the interviews and the observations as participant-observer within PEINP are important to take into account. To describe an institutional setting and regulatory framework, some experience as a participant-observer can contribute significantly in similar research. In-depth interviews and access to data are vital to further improve the PEINPA and to keep a link to real practices in the policy arena. Researchers in various fields such as public management, could further investigate the identified transaction costs and try to quantify them because literature concerning transaction costs in public organisations is very scarce (especially in IWT).

9.5.3.Environmental research and engineering

Although there is unanimity in the academic world that humans have a significant negative impact on climate change, there are still a number of questions that need to be addressed. The effects of methane on climate change is still a topic for further research as new findings, measurements and improved methodologies emerge. Another topic is to find or develop the holy grail of alternative fuels or propulsion for vessels in both maritime and inland navigation without emissions or greenhouse gases (from WTP). Can an alternative fuel or propulsion from WTP be completely CO₂ neutral? How can transport research and development or innovation help to achieve climate change objectives?

These questions do not only refer to alternative fuels but also include issues such as vessel design and further technological development (e.g. automation). All of this implies an economic dimension which also requires research.

External cost calculation can be further improved and needs a frequent update. Measurement of emissions in real-life needs to be taken into account in IWT from different places on-board of a vessel (exhaust, engine room) and during different situations (stationary or operational). Furthermore, the accident costs need sufficient data which are hardly ever collected. The scarce data that is available needs further validation and quality improvement.

9.6.Policy recommendations

Although the answer on the RQ concerning the role of policy already gives several important recommendations, this part offers some more case-related recommendations. However, first an important remark should be made. This part of the RQ could have an underlying normative rationale which is fundamentally political in nature. The economic rationale as developed in this research can only provide insight and advice but does not identify all political reasoning which usually stays undisclosed. It does not answer what policy should do but what it can do.

Throughout the research, it has become clear that policy can have a significant impact on innovation. Policy can support an innovation or even jeopardize further innovation implementation. Regulatory bottlenecks are identified in almost all cases and the lack of infrastructure (which can also be private) is considered to be an important failure factor. Sufficient investments in maintenance and infrastructure to provide a good navigation status is fundamental to allow innovations or the market to grow.

The level of technical complexity of the innovation includes a potential risk for asymmetrical information between different public and private actors. Any lack of alignment and central steering between policy levels could lead to a fragmented approach which increases the transaction costs for the innovators and the involved policy makers (e.g. compliance, coherence). The co-existence of multiple legal regimes in Europe requires additional effort in order to implement some kind of collaborative network approach between policy actors in the PEINP setting. This is found to be true in removing regulatory bottlenecks and it can be recommended to review the institutional setting and implement policy reform to decrease compliance costs and enforcement costs.

The introduction of e-documents and automated processes within policy administrations with well-established legal value at pan-European level, may facilitate the implementation of the automated vessel, and stimulate further diffusion of e-barge chartering. This may, in turn, lower the administration costs for the vessel owner and the monitoring costs (e.g. for the traffic manager).

Innovation policy can also cause market disturbance. In the case of the e-BC, this could result in pushing out private innovators such as 4Shipping instead of encouraging more VOs to join an electronic barge chartering platform (e.g. AGORA). In the case of the SBC (Watertruck+), although aimed at attracting “new” cargo flows that do not yet exist on the current IWT market, there is a risk of market disturbance by pushing out remaining vessels from this segment. Future research and observation of the market

on the small waterway could indicate if there is a need to compensate those who lose out because of this public innovation.

Without public intervention, it seems that the small waterway fleet would further reduce while shifting volumes mainly to road haulage. However public innovation comes at a cost as it disturbs the existing market. The relatively high crew cost is noted to be significant, especially on the small waterways. It is questionable as to whether the current crew requirements are still aligned to technological developments and the relatively low external costs related to accidents.

The social benefit of a strong and growing IWT, is still high enough for policy makers to invest and to conduct an effective innovation policy. Infrastructure maintenance and the removal of regulatory bottlenecks remain the most fundamental elements of any IWT policy.

10. Annexes

10.1. List of interviewees and participants of expert meetings

Without the contribution of following experts, policy makers, innovators and stakeholders, this research was not possible during the past years. The time and willingness to answer all questions added a significant value to the research.

Interview respondents		Case specific contributions and/or participation in expert meeting	
Names	Organisations/firms	Names	Organisations/firms
Ad Hellemons	Aquapol	Alessandro Zanderigo	Trelleborg Marine Systems
Alain De Vos	CITBO	Ann-Sofie Pauwelyn	De Vlaamse Waterweg
Antoon Van Coillie	Blue Line Logistics	Bas Kelderman	EICB
Axel Goetze-Rohen	Bargelink	Daisy Rycquart	CITBO
Bas Joormann	Lloyd's Register	Edward Verbergh	MTTC BVBA
Ben Maelissa	Danser Group	Erik Büthker	PitPoint bv
Benjamin Boyer	CCNR	Ferenc Szilágyi	CFT
Bente Braat	CCNR	Herlinde Liégois	De Vlaamse Waterweg
Cornelis van Dorsser	Mercurius Shipping Group/BLN	Johan Boonen	Watertruck +
Dick Van Doorn	Van Doorn Consultancy	Martin Sandler	innovative-navigation
Didier Bacon	Touax River Barges	Pieter Vandermeeren	Port of Antwerp
Dirk Beernaert	DGT	Véronique Sterkens	De Vlaamse Waterweg
Eloi Flipo	VNF		
Erwin Fessman	CCNR		
Eva Molnar	UNECE		
Filip Verbeke	Watertruck +		
Frédéric Swiderski	ITB		
Gernot Pauli	CCNR		
Guillaume Legeay	CCNR		
Gunther Jaegers	Reederei Jaegers Gruppe		
Hester Duursema	ESO		
Hilde Bollen	Promotie Binnenvaart Vlaanderen		
Inga Lauts	Mariko		
Jan Snoeij	4Shipping		
Jörg Rusche	CCNR		
Kai Kempmann	CCNR		
Katrin Moosbrugger	CCNR		
Khalid Tachi	EICB		
Lars van Meegen	Port-Liner		
Louis-Robert Cool	SeaFar		
Lucy Gilliam	Transport & Environment		
Marleen Coenen	MOW		
Myriam Chaffart	ETF		
Nick Bakker	Netherlands Maritime Technology		
Norbert Kriedel	CCNR		
Paul A. Williams	Caterpillar		
Peter Schotten	BP Shipping		
Remco Pikaart	Shipping Factory		
Richard Payne	Cummins inc.		
Rob van Reem	EDINNA		
Ronald Somers	Somtrans NV		
Theresia Hacksteiner	EBU / IVR		
Ton van Meegen	Port-Liner		
Winfried Kliche	BMVI		
Wirdum Meeuwis	Marin		
Wolfgang Hönemann	Rhenus Logistics		

10.2. Annex of the SBC case

10.2.1. Minimum crew for rigid convoys and other rigid assemblies

Source: CCNR, RPN 2018, p.8, https://www.ccr-zkr.org/files/documents/reglementSTF/stf1_102018_nl.pdf

Group	Crew members	Number of crew members in operating mode A1, A2 or B and for equipment standard S1 or S2					
		A1		A2		B	
		S1	S2	S1	S2	S1	S2
Dimensions of the assembly L ≤ 37 m W ≤ 15 m	boatmaster.....	1		2		2	2
	helmsman	-		-		-	-
	able boatman	-		-		-	-
	boatman.....	1		-		1	-
	apprentice	-		-		1 ¹⁾	2 ¹⁽³⁾
	engineer or engine-minder	-		-		-	-
Dimensions of the assembly 37 m < L ≤ 86m W ≤ 15 m	boatmaster.....	1 or 1	1	2		2	2
	helmsman	-	-	-		-	-
	able boatman	1	-	-		-	-
	boatman.....	-	1	-		2	1
	apprentice	-	1	1 ¹⁾		-	1
	engineer or engine-minder	-	-	-		-	-
Pusher + 1 pushed barge of L > 86 m or Dimensions of the assembly 86 m < L ≤ 116.5 m W ≤ 15 m	boatmaster.....	1 or 1	1	2		2 or 2	2
	helmsman	1 1	1	-		1 1 ²⁾	1
	able boatman	-	-	-		-	-
	boatman.....	1	-	1		2	1
	apprentice	-	1	1 ¹⁾	2 ¹⁾	-	1
	engineer or engine-minder	-	-	-		-	-
Pusher + 2 Pushed barges ^{*)} Motor vessel + 1 Pushed barge ^{*)}	boatmaster.....	1	1	2		2 or 2	2 or 2
	helmsman	1	1	-		1 1 ²⁾	1 1 ²⁾
	able boatman	-	-	-	1	-	1 1
	boatman.....	1	-	2		2 2	-
	apprentice	1 ¹⁾	2 ¹⁾	1 ¹⁾	2 ¹⁾	-	1 1
	engineer or engine-minder	-	-	-		1	1
Pusher + 3 or 4 Pushed barges ^{*)} Motor vessel + 2 or 3 Pushed barges ^{*)}	boatmaster.....	1 or 1	1	2		2 or 2	2 or 2
	helmsman	1 1	1	-		1 1 ²⁾	1 1 ²⁾
	able boatman	-	-	-	1	-	1 1
	boatman.....	2	1	2		2 2	-
	apprentice	-	1	1 ¹⁾	2 ¹⁾	1 ¹⁾	2 1
	engineer or engine-minder	1 1	1	1	1	1 1	1 1
Pusher + more than 4 Pushed barges ^{*)}	boatmaster.....	1 or 1	1	2		2 or 2	2 or 2
	helmsman	1 1	1	-		1 1 ²⁾	1 1 ²⁾
	able boatman	-	1	-	1	-	1 1
	boatman.....	3	1	3	1	3 3	1 1
	apprentice	-	1	1 ¹⁾	2 ¹⁾	1 ¹⁾	2 ¹⁾ 1
	engineer or engine-minder	1 1	1	1	1	1 1	1 1

¹⁾ The apprentice or one of the apprentices may be replaced by a deckhand.

²⁾ The helmsman must hold a boatmaster's certificate specified under these regulations.

³⁾ One of the apprentices must be over the age of 18.

^{*)} Under this article the term "pushed barge" also refers to motor vessels not using their main engines and towed barges. Moreover, the following equivalence applies:

1 pushed barge = several barges of a total length not exceeding 76.50 m and a total width not exceeding 15 m.

10.3. Annexes of the automation case

CBA scenario 1, project case: The discount rate from private equity perspective is set at 10% to incorporate the higher risk of using new technology and the unknown lifespan of the AV. It is assumed that the AV – hardware has a lifespan as long as the vessel. The loan payback period was 15 years and was not replaced by a new loan in this hypothetical example. Fuel is based on a simple forecast based on time series and desk research but considered as relatively high in expected growth. The calculations method is based on van Hassel (2011a) and calculated with Excel. The values correspond with scenario 1 as elaborated in Chapter 5.4. The first 11 years and the last year are shown.

NPV/cap ratio	0.23	IRR (equity)	10.99%	NPV	EUR 410,915								
Kw	5.35%	IRR (ent)	9.94%	NPV	EUR 4,744,270								
	YEAR 0	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10	...	YEAR 40
Balance	4,130,000	3,931,290	3,723,638	3,506,642	3,279,881	3,042,915	2,795,286	2,536,514	2,266,097	1,983,512	1,688,210		
inter		185,850	176,908	167,564	157,799	147,595	136,931	125,788	114,143	101,974	89,258		
Principal		198,710	207,652	216,996	226,761	236,965	247,629	258,772	270,417	282,586	295,302		
pay back loan		384,560	384,560	384,560	384,560	384,560	384,560	384,560	384,560	384,560	384,560		
depreciation	5,900,000	145,500	145,500	145,500	145,500	145,500	145,500	145,500	145,500	145,500	145,500		145,500
Insur	index	67,850	69,071	70,315	71,580	72,869	74,180	75,516	76,875	78,259	79,667		136,055
other(admin)	index	300	305	311	316	322	328	334	340	346	352		602
fixed costs		452,710	453,937	455,186	456,457	457,751	459,068	460,409	461,775	463,165	464,580		136,656
OPEX		388,241	396,091	404,607	413,207	421,892	430,665	439,525	448,476	457,518	466,654		793,645
Fuel	forecast	134,082	137,357	141,216	145,075	148,934	152,793	156,652	160,511	164,370	168,229		283,999
Compliance	index	6,750	6,872	6,995	7,121	7,249	7,380	7,513	7,648	7,785	7,926		13,535
SCC	index	190,960	194,397	197,896	201,459	205,085	208,776	212,534	216,360	220,254	224,219		382,918
Charterers %	index	10,861	11,056	11,255	11,458	11,664	11,874	12,088	12,306	12,527	12,753		21,779
F&P	Index	19,002	19,344	19,692	20,047	20,407	20,775	21,149	21,529	21,917	22,311		38,103
M&R		26,586	27,065	27,552	28,048	28,553	29,067	29,590	30,122	30,665	31,217		53,311
revenue	index	1,086,096	1,105,646	1,125,547	1,145,807	1,166,432	1,187,427	1,208,801	1,230,560	1,252,710	1,275,258		2,177,868
ebitda		629,705	640,178	650,315	660,703	671,348	682,255	693,426	704,869	716,587	728,585		1,247,567
EBIT		484,205	494,678	504,815	515,203	525,848	536,755	547,926	559,369	571,087	583,085		1,102,067
EBT		298,355	317,770	337,251	357,405	378,254	399,823	422,139	445,226	469,112	493,827		1,102,067
TAX		76,080	81,031	85,999	91,138	96,455	101,955	107,645	113,533	119,624	125,926		281,027
EAT		222,274	236,739	251,252	266,266	281,799	297,868	314,493	331,693	349,489	367,901		821,040
cash flow	-5,900,000	367,774	382,239	396,752	411,766	427,299	443,368	459,993	477,193	494,989	513,401		966,540
free cash flow		-16,786	-2,321	12,192	27,206	42,739	58,808	75,433	92,633	110,429	128,841		966,540

10.3.1. Identified actors in the automation of the inland navigation



10.3.2. Air pollutants, climate change costs (CCC) and up- and downstream costs (U&D)

			Low sulphur oil		Diesel particulate filter (DPF)		Selective catalytic reduction (SCR)		DPF+SCR		LNG		Average load factor, tons				
type (tons)			bulk, tanker	heavy bulk	bulk, tanker	heavy bulk	bulk, tanker	heavy bulk	bulk, tanker	heavy bulk	bulk, tanker	heavy bulk	bulk, tanker	heavy bulk			
freight capacity (tons)	Motor vessels and barges	250-400	Air pollutants € per 1000 t	5,7	5,4	5,4	5,2	1,4	1,4	1,1	1,1	1,5	1,4	158	189		
			CCC € per 1000 tkm	3,1	2,9	3,1	2,9	3,1	2,9	3,1	2,9	3,1	2,9			2,8	2,6
			U&D €ct / vkm	1	1,1	1	1	0,9	0,9	0,9	0,9	0,9	0,9			0,8	0,8
		400-650	Air pollutants € per 1000 t	5,7	5,4	5,4	5,2	1,4	1,4	1,1	1,1	1,5	1,4	248	297		
			CCC € per 1000 tkm	3,1	2,9	3,1	2,9	3,1	2,9	3,1	2,9	3,1	2,9			2,8	2,6
			U&D €ct / vkm	1	1	1	1	0,9	0,8	0,9	0,8	0,9	0,8			0,8	0,8
		650-1000	Air pollutants € per 1000 t	5,8	5,5	5,6	5,3	1,5	1,4	1,1	1,1	1,5	1,4	608	729		
			CCC € per 1000 tkm	3,1	3	3,1	3	3,1	3	3,1	3	2,8	2,7			2,8	2,7
			U&D €ct / vkm	1,2	1,1	1,2	1	1	0,9	1	0,9	0,9	0,9			0,9	0,8
	1000-3000	Air pollutants € per 1000 t	4,4	4,2	4,2	4	1,1	1,1	0,9	0,8	1,1	1,1	1356	1627			
		CCC € per 1000 tkm	2,3	2,2	2,3	2,2	2,3	2,2	2,3	2,2	2	1,9			2	1,9	
		U&D €ct / vkm	0,8	0,7	0,8	0,7	0,7	0,7	0,7	0,7	0,7	0,7			0,6	0,6	
	Pushed convoys	3000-6400	Air pollutants € per 1000 t	4,2	4,1	4	3,9	1,1	1	0,8	0,8	1,1	1,1	2475	2970		
			CCC € per 1000 tkm	2,3	2,2	2,3	2,2	2,3	2,2	2,3	2,2	2	1,9			2	1,9
			U&D €ct / vkm	0,7	0,9	0,7	0,9	0,7	0,7	0,7	0,7	0,7	0,7			0,6	0,6
		6400-12000	Air pollutants € per 1000 t	2,8	3	2,7	2,9	0,7	0,8	0,5	0,6	0,7	0,8	6240	7020		
			CCC € per 1000 tkm	1,4	1,5	1,5	1,6	1,4	1,5	1,5	1,6	1,3	1,4			1,4	1,4
			U&D €ct / vkm	0,6	0,6	0,6	0,6	0,5	0,5	0,5	0,5	0,5	0,5			0,4	0,5
9600-18000		Air pollutants € per 1000 t	2,2	1,8	2,1	1,7	0,6	0,5	0,4	0,4	0,6	0,5	9009	10530			
		CCC € per 1000 tkm	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,1			1,1	1,1	
		U&D €ct / vkm	0,4	1	0,4	1	0,3	0,6	0,3	0,5	0,3	0,5			0,3	0,5	
Average	Air pollutants € per 1000 t	4,4	4,2	4,2	4,0	1,1	1,1	0,8	0,8	1,1	1,1	2543	2957				
	CCC € per 1000 tkm	2,4	2,3	2,4	2,3	2,4	2,3	2,4	2,3	2,4	2,3			2,1	2,0		
	U&D €ct / vkm	0,8	0,9	0,8	0,9	0,7	0,7	0,7	0,7	0,7	0,7			0,6	0,7		

Table 95: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs)

Source: CE Delft (2011), Ricardo-AEA (2014); in €ct/vkm, CCC= marginal climate change costs, evaluated at the central value for CO₂: €90/tons. Averages are own calculations, EU average (prices of 2010)

10.3.3.Minimal crew on board of motorized ships and pushers:

Source: CCNR, RPN 2018, p.16, https://www.ccr-zkr.org/files/documents/reglementSTF/stf1_102018_nl.pdf

Group	Crew members	Number of crew members in operating mode					
		A1, A2 or B and for equipment standard S1 or S2					
		A1		A2		B	
		S1	S2	S1	S2	S1	S2
L ≤ 70 m	boatmaster.....	1		2		2	2
	helmsman.....	-		-		-	-
	able boatman.....	-		-		-	-
	boatman.....	1		-		1	-
	apprentice.....	-		-		1 ¹⁾	2 ^{1) 3)}
70 m < L ≤ 86 m	boatmaster.....	1 or 1	1	2		2	2
	helmsman.....	- -	-	-		-	-
	able boatman.....	1 -	-	-		-	-
	boatman.....	- 1	1	-		2	1
	apprentice.....	- 1	1	1 ¹⁾		-	1
L > 86 m	boatmaster.....	1 or 1	1	2	2	2 or 2	2
	helmsman.....	1 1	1	-	-	1 1 ²⁾	1
	able boatman.....	-	-	-	-	- -	-
	boatman.....	1 -	-	1	-	2 1	1
	apprentice.....	- 2	1	1 ¹⁾	2 ¹⁾	- -	1

¹⁾ The apprentice or one of the apprentices may be replaced by a deckhand

²⁾ The helmsman must hold a boatmaster's certificate specified by these regulations.

³⁾ One of the apprentices must be over the age of 18.

With operating mode A1 = navigation for a maximum of 14hrs, A2 = navigation for a maximum of 18 hrs. and B= navigation for a maximum of 24hrs. The functions and training requirements of the crew are under the Rhine regime mentioned in RPN but will be in the future subjected to CESNI/QP standards.

10.4. Annex of the LNG case

10.4.1. IWT Emission limits

Emission limits for IWT according to the Regulation (EU) 2016/1628 (EC, 2016b) of the European Parliament and of the Council of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC. Exhaust emission limits referred to in Article 18(2) for IWP and IWA.

‘category IWP’:

- (a) engines exclusively for use in inland waterway vessels, for their direct or indirect propulsion, or intended for their direct or indirect propulsion, having a reference power that is greater than or equal to 19 kW;
- (b) engines used in place of engines of category IWA provided that they comply with Article 24(8);

‘category IWA’: auxiliary engines exclusively for use in inland waterway vessels and having a reference power that is greater than or equal to 19 kW;

Table II-5: Stage V emission limits for engine category IWP defined in point (5) of Article 4(1)
P = installed net propulsion power of the vessel in kW

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NO _x	PM mass	PN	A
				g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
		kW							
Stage V	IWP-v-1 IWP-c-1	19 ≤ P < 75	all	5	(HC + NO _x ≤ 4,70)		0,3	—	6
Stage V	IWP-v-2 IWP-c-2	75 ≤ P < 130	all	5	(HC + NO _x ≤ 5,40)		0,14	—	6
Stage V	IWP-v-3 IWP-c-3	130 ≤ P < 300	all	3,5	1	2,1	0,1	—	6
Stage V	IWP-v-4 IWP-c-4	P ≥ 300	all	3,5	0,19	1,8	0,015	1 × 10 ¹²	6

Table II-6: Stage V emission limits for engine category IWA defined in point (6) of Article 4(1)

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NO _x	PM mass	PN	A
				g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
		kW							
Stage V	IWA-v-1 IWA-c-1	19 ≤ P < 75	all	5	(HC + NO _x ≤ 4,70)		0,3	—	6
Stage V	IWA-v-2 IWA-c-2	75 ≤ P < 130	all	5	(HC + NO _x ≤ 5,40)		0,14	—	6
Stage V	IWA-v-3 IWA-c-3	130 ≤ P < 300	all	3,5	1	2,1	0,1	—	6
Stage V	IWA-v-4 IWA-c-4	P ≥ 300	all	3,5	0,19	1,8	0,015	1 × 10 ¹²	6

Specific provisions on total hydrocarbon (HC) limits for fully and partially gaseous-fuelled engines

1. For the sub-categories where an A-factor is defined, the HC limit for fully and partially gaseous-fuelled engines indicated in tables II-1 to II-10 is replaced by a limit calculated using the following formula:

$$HC = 0,19 + (1,5 \times A \times GER)$$

where GER is the average gas energy ratio over the appropriate test cycle. Where both a steady-state and transient test cycle apply, the GER shall be determined from the hot-start transient test cycle. Where more than one steady-state test cycle applies, the average GER shall be determined for each cycle individually. If the calculated limit for HC exceeds the value of $0,19 + A$, the limit for HC shall be set to $0,19 + A$.

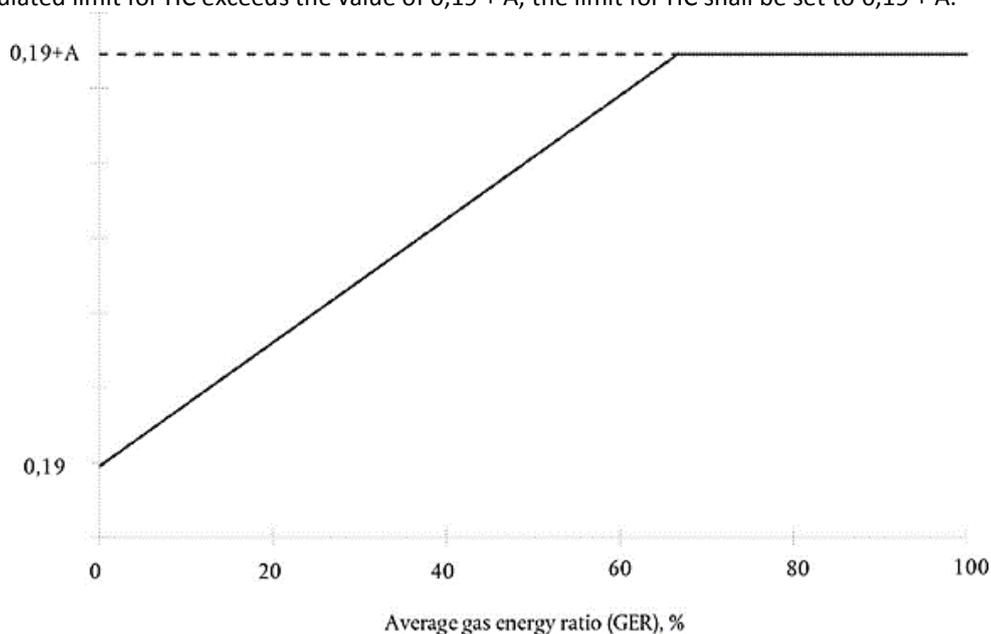


Table III-5: Dates of application of this Regulation for engine category IWP

Category	Ignition type	Power range (kW)	Sub-category	Mandatory date of application of this Regulation for	
				EU type-approval of engines	Placing on the market of engines
IWP	all	$19 \leq P < 300$	IWP-v-1 IWP-c-1 IWP-v-2 IWP-c-2 IWP-v-3 IWP-c-3	1 January 2018	1 January 2019
		$P \geq 300$	IWP-v-4 IWP-c-4	1 January 2019	1 January 2020

Table III-6: Dates of application of this Regulation for engine category IWA

Category	Ignition type	Power range (kW)	Sub-category	Mandatory date of application of this Regulation for	
				EU type-approval of engines	Placing on the market of engines
IWA	all	$19 \leq P < 300$	IWA-v-1 IWA-c-1 IWA-v-2 IWA-c-2 IWA-v-3 IWA-c-3	1 January 2018	1 January 2019
		$P \geq 300$	IWA-v-4 IWA-c-4	1 January 2019	1 January 2020

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