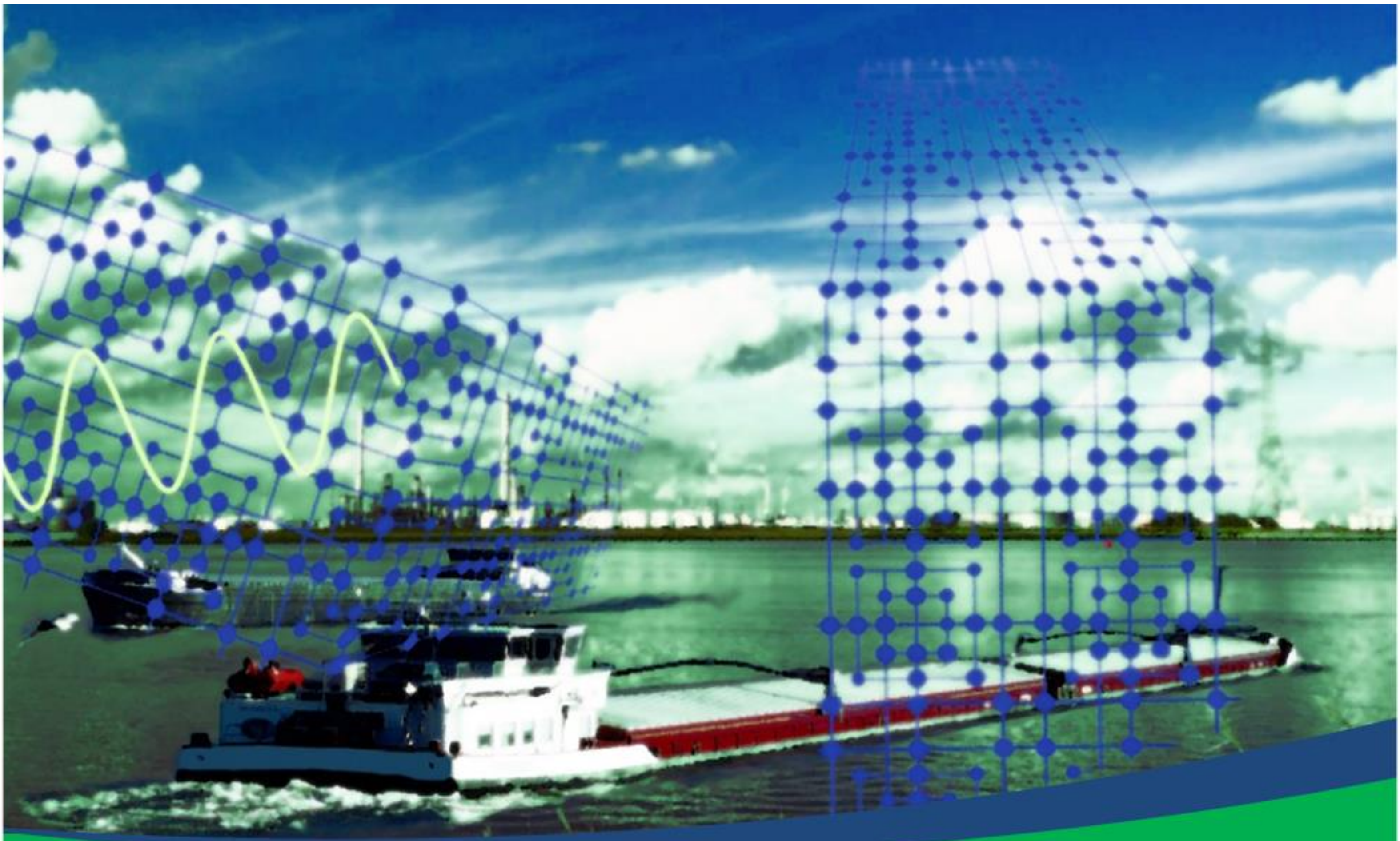

INN-IN

INNOVATIVE INLAND NAVIGATION

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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
AGN	European Agreement on Main inland waterways of international importance
AER	Automated Engine Room
AIS	Automatic Identification System, standard in IWT is called inland AIS.
AWS	Automated Wheelhouse System
CCNR	Central Commission for the navigation of the Rhine
CAPEX	Capital expenditures
CEF	Connecting Europe Facility
CESNI (/QP & /PT)	Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure: European Committee for the development of standards for inland navigation; /QP : Qualifications of personnel; /PT: Technical requirements
CEVNI	Code européen des voies de navigation intérieures
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
DPF	Diesel particulate filters
EBU	European Barge Union
EC	European Commission
ECDIS	Electronic Chart Display and Information System for Inland Navigation
EFIP	European Federation of Inland Ports
ERI	Electronic Ship Reporting in Inland Navigation
ESPO	European Sea Port Organization
EU	European Union
ESO	European Shipper Organization
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation vessels
ETF	European Transport Workers' Federation
IALA	International Association of Lighthouse Authorities
ICPD	International Commission for the Protection of the Danube
ICPR	International Commission for the Protection of the Rhine
IKSE-MKOL	International Commission for the protection of the Elbe
INE	Inland Navigation Europe
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
IWT	Inland Waterway Transportation
LAESSI	Leit- und Assistenzsysteme zur Erhöhung der Sicherheit der Schifffahrt auf Inlandwasserstraßen
LNG	Liquefied Natural Gas
MC	Moselle Commission
MS	Member states
PA	Political analysis
PEINP	Pan-European Inland Navigation Policy
PIANC	Permanent International Association of Navigation Congresses
RC	River Commission
SCBA	Social Cost-Benefit Analysis
SCC	Shore Control Centre
SCR	Selective Catalyst Reduction
SIA	Systems of Innovation Approach
SIGNI	Signs and Signals on Inland Waterways
TEN-T	Trans-European Networks for Transport
UNECE	United Nations Economic Council for Europe
VO/O	Vessel owner / operator

Management Summary

This research looked for positive innovative business cases in inland navigation and asked what policy could do. In building up the research design, it was decided not to list up as much innovations as possible but to go deeper with in-depth case analysis. Five cases were carefully selected.

The innovation cases can be divided in three clusters with specific targets:

- Small waterways:
  - Innovation that is implemented on the small waterways aims at reviving business on these parts of the waterway network which are increasingly abandoned because of several identified reasons.
  - The development of small barge convoy concepts and the pallet shuttle barge are selected to examine closer.
- Automation and digitalization:
  - The case of e-bargebooking targeting organizational improvements in reducing empty trips, facilitating one-to-one communication between operators and customers and providing relatively and possibly cheaper transport because of lower charterers provisions which could invite more users.
  - The case of the automated vessel that could reduce accidents, emissions and allow inland navigation to become more integrated in multimodal logistics.
- Alternative fuels: it is clear that inland navigation is lagging behind the developments in other modes concerning emissions and greenhouse gases, despite the lower external costs of inland navigation. More stringent emission standards (stage V) and the expected increasing fuel cost, are the main incentives to develop innovations in this field. The case of LNG is considered to be the most advanced option and is selected as case.

To answer the research questions, a combination of research methods is chosen. This combination comprises systems of innovation approach where innovation barriers and success factors are identified, social cost-benefit analysis where the business case of the innovation is examined and a policy analysis that takes in account the current institutional setting of the European inland navigation.

Not all information was accessible because of confidentiality and disclosure of each innovation, but the relatively high number of interviews, case related contributions and close cooperation with the experts of the CCNR delegations and the secretary administrators, addressed this challenge effectively.

In this research, small waterways are defined as class II and lower, although often the European definition sticks to a vessel with a length smaller than 86m and a payload of 1,500 tonnes which can sail on class IV waterways. The main benefit of reactivating the small waterways, is the possible shift from road haulage, which lowers the external costs for society such as congestion, emission and accidents. The relatively small size of the inland navigation market and the small waterways in particular, are not always appealing for manufacturers to invest in tailor-fitted R&D. The issue of funding, and the role of policy are considered vital for the market uptake of innovation. Indeed, despite the social benefits of a sustainable inland navigation, it is delicate to improve its market share and to support modal shift from road haulage.

The institutional framework of the European Inland Waterway Transport policy also provides challenges due to its complexity such as the existence of dual regimes in a multilevel governance policy model. The last decade, this policy model has been subject to incremental transformations. Knowledge concerning the policy framework, is crucial for the innovator to succeed while applying for a derogation procedure or for subsidies.

1. Institutional framework

Regulation could be threatening for innovation uptake if it is not adjusted on time and future proof. Policy has to provide a consistent regulatory framework to ensure a sufficient level playing field. Inconsistencies and delays have an impact on the business case. Furthermore, requirements have to be as technology-neutral as possible to allow other innovation to emerge. The same goes for infrastructure. If an innovation needs infrastructure to allow market uptake, delays in implementation also negatively impact on the business case.

In case of alternative fuels, the lack of necessary infrastructure such as on-shore bunker facilities, could lead to failure of the innovation. However, choosing not to have the appropriate legislation or infrastructure could also be a valid policy decision.

The European Inland navigation policy experienced some changes in its development in the last 30 years. Vessel innovation, infrastructure, crew qualifications, environmental requirements and others changed, as well as the market model, which evolved from static and government-organized (Tour-de-rôle system, ship exchange) towards more dynamic and liberalized. Noticeable steps are being undertaken to switch from a fragmented policy spread amongst river commissions, European Union, United Nations Economic Council of Europe, national and regional governments, towards a more coordinated policy, aimed at making European standards applicable to all waterways and reducing the legal uncertainty by ensuring the level playing field (e.g. CESNI, ADN, CMNI).

2. e-Bargebooking

The first case analysis concerns the digitalization of the business organization. The conventional relationship between a human freight broker and a vessel owner gives room for a number of innovations. This can be a virtual market place such as Bargelink, where supply and demand meet each other or even a digital freight broker such as 4shipping. The latter even allows price negotiations without intermediary actors such as a freight broker.

Several projects at the beginning of the liberalization of the IWT market were financed by public funding and even in one case the innovator was public (BIVAS). Most of them failed, but the experience and knowledge gained by these developments were useful as soon as more conditions for market uptake were installed (more than 15 years later). With or without public funding in this phase of development, the market uptake seems likely to continue.

The main barriers that were identified for *e-bargebooking*, are:

- Paper documents are still needed. After studying the CMNI and the national legislation, it is not clear if a completely digital system with e-documents would already have the same legal value in court as original paper ones (because of risk of forgeries next to data security issues).
- Legal status of the digital broker. There is no legal status for the digital freight broker, nor is there a clear legal status for conventional brokers on the market. There is also differentiation between member states.
- Resistance of competing brokers. Conventional freight brokers can feel threatened because of their potential loss of market share.
- Trust-based relations depending on digital security of confidential data. Cyberattacks and misuse of data could jeopardize the innovation.
- Currently limited to be an additional tool for the spot market of mostly dry bulk. Tanker barges are often locked in contracts that comply to safety requirements of the European Barge Inspection Scheme and have therefore less incentives or flexibility to register for digital applications.

- Needed infrastructure; internet coverage is not fully available on all waterways, but internet access has reached a significant penetration on board of vessels within the fleet. Roaming costs disappeared in the European Union but several telecom operators still limit the data use once the border of the Member State is passed. Switzerland, which is not an EU Member State, is not included in this regulation and still demands significantly high international roaming costs for mobile internet.

3. Small barge convoy

The small barge convoy, as the second analysed case, aims at the revival or reactivation of the small waterways as does the pallet shuttle barge. This innovation is still rather conceptual. The main focus lies on the small barge convoy concepts as developed during a number of European and regional projects such as ECSWA, INLANAV, Watertruck and Watertruck+ which are explained in the analysis. From a technological, organizational and managerial point of view, the innovation is feasible, but the main barriers relate to funding and regulation. The innovation targets the building of a small barge convoy with small pushers and small barges that are adjusted to the dimensions of a class I and II waterway.

The most recent variation of this concept is Watertruck+, which recently claimed to have started to build the first barges with European subsidies (Connecting Europe Facility or CEF[1]). The small and big pushers are still being tendered. The concept is very basic, although the business case is relatively complex and still has a number of open questions.

The concept can be operated in several scenarios. First scenario is that the big pushers (also conventional existing ones) bring the small barges (maximum 1,500 payload) in front of a lock towards a small waterway. The convoy splits and the small barges sail one by one into the lock. The small pusher waits at the other side and can push the small barges in a new convoy to the final destination or the small barges can sail independently up to there. Another possible scenario is that the barges are remotely controlled by an operator on one of the pushers when passing the lock. The convoys can differ in payload depending on the maximum power of the pusher. The convoy concept aims at the transport of mainly dry bulk but also could transport palletized cargo and containers.

The market on these small waterways loses share to road haulage which is not beneficial for society because of the higher social (external) costs such as road congestion and accidents. This objective implies attracting new waterbound customers or distribution centers. The concept of the small barge convoy aims at enlarging the transported volume during one trip and reducing cost (fuel and personnel) to compete with road haulage also within an intermodal chain that includes transshipment costs during the pre- and/or post-haulage by road. In order to compete with road haulage, the innovation business case will have to take these elements into account, especially the number of needed transshipments (pre- and post-haulage costs), rather small distances and relatively small volumes. Furthermore, the additional waiting time for convoy formation, splitting and passing a lock one by one, causes additional costs compared to the pallet shuttle barges. The infrastructure on the small waterways includes numerous locks.

The intended scale of the project and the number of barges should offer economies of scale and with sufficient critical mass of volume, the business case could be positive if regulatory barriers are removed such as the limitations of a single headed crew. At the moment, several consulting firms are developing business cases across Europe (including Danube), but no details or data could be given (yet).

The business structure of Watertruck+ is reported to cause problems in attracting private investors and shipyards. The private investor who will be responsible for three years in operating the vessel

[1] https://ec.europa.eu/inea/en/connecting-europe-facility

needs to pay half of the budget upfront, while the Flemish waterway manager remains a shareholder (estimated at EUR 15 million). After three years, the operator can decide to stop activities and return it to the waterway manager or proceed and buy the vessels completely. Not all private investors find this agreement appealing. Furthermore, the subsidies weaken the negotiation position in upwards pressure on prices. Shipyards, for example, tend to bargain maximum prices with the knowledge that the project is 50% subsidized. Finally, 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.

When it was announced that Watertruck+ would receive subsidies to build vessels, the sector organizations' response was rather negative. The resistance of the sector towards this innovation has faded. However, it could rise again when the vessels will become operational and the definition of "new flows" becomes more disturbing than intended. Also, if the innovation would fail, the scenario that the craft will remain on the market is most likely with a possible downwards pressure on freight prices on the conventional market. Although the public innovator claims to only focus on "new flows"[2], it will be a very delicate exercise not to cause any disturbance to the remaining market, which could cause private initiative to be pushed out in a worst case scenario instead of a modal shift.

4. Pallet shuttle barge

One of the attempts to reactivate the small waterways is the innovative ship design of companies such as Blue Line Logistics (BLL). This catamaran-shaped vessel has only one crew member and is equipped with a crane to unload without shore equipment. It is mainly active on the market for transport of building materials and is able to navigate on small waterways because of its limited dimensions (50m). Although the last vessels of BLL left the concept of the catamaran at the end of this research, this analysis focusses on the first two vessels that are implemented (Zulu 1 and Zulu 2).

A potential barrier that could prevent market uptake is the possible behaviour of partially subsidized customers when the regional subsidies end for intermodal pallet transport as well as the limitations imposed by regulation concerning single person crew on vessels beneath 55 meters (not allowed during night, and not at all on Rhine, Western Scheldt and Seine at Paris).

5. Automated vessel

The automated vessel as further explained in this research, is still in the initiation phase where actions are taken such as pilot projects and research. A global network of innovators in this field has emerged and is testing maritime and inland navigation applications all over the world. This innovation comprises a number of sub-innovations in order to reach the final phase of the implementation of an unmanned vessel. Sub-innovations as identified are automated docking stations on shore and on board or automated wheeling houses where navigation can be done unmanned. A number of the needed developments are identified by comparing the required tasks of a human crew as described in the CESNI QP standards. Automated processes and a redundancy of robotics are needed to have unmanned vessels.

The developed model in this research takes in account a shore control center that intervenes whenever needed. Adding an on-shore remote control center (SCC) as fallback system or decisive command center, influences the business case (renting or buying the innovation). When the service of the SCC is rented at a price that is relatively cheaper than the personnel costs, there is a positive business case if all assumptions are met. Despite the relatively high level of these assumptions and the described limits

[2] New flows are challenging to define, but they refer here to shifted cargo flows from road. This definition provokes debate.

of the research, this is the first attempt to identify and quantify cost and benefits for society and for enterprises of a fully automated and unmanned inland navigation vessel.

The main benefits are claimed to be the reduction of crew costs, accident and fuel costs (more efficiency), and an increase of annual trips (no resting time and faster mooring) and payload (no accommodation and conventional sized wheelhouse or machine rooms). The fast data sharing between automated devices and systems on shore and on board, could improve operations, monitoring and traffic management. The labour shortage and ageing crews can also be solved by further automation.
The development of automated inland vessels deals with relatively high development costs, low-scale production and a lack of mass consumer availability. The potential failure factors that are identified are:

- Insufficient funding (private and public).
- Lack of auxiliary innovation (automated docking, solutions for loading and unloading).
- Lack of legal definitions and other regulatory aspects such as liability and responsibility of ship and cargo.
- Risk of different legal regimes.
- Cultural: social resistance and general disbelief.
- An inefficient sector lobby on all policy levels (too fragmented, not professional).
- Lack of mass consumer availability.
- Insufficient machine learning and data-gathering/sharing.
- To strong unimodal focus and not from a multimodal perspective upon developments in other modes.

Social costs concern the relatively high infrastructure costs (digital and physical), administration (e-documents, compatible communication systems with automated vessels and innovation affects relatively high number of regulation) and inspection costs (more expensive profile of inspectors). The latter two costs require the support of highly educated IT profiles to avoid asymmetrical information between policy, market and innovators.

Regarding the safety benefit, it is broadly accepted that inland waterway transport (IWT) has a low number of accidents despite the lack of data to prove this. But if an accident does occur, the impact can be quite disproportional and of such significance that investments in safety of inland navigation such as further automation remain important and legitimate, especially in the case of dangerous goods. Automation is currently experiencing a global window of opportunity with all innovation network actors aligned and with high (possibly inflated) expectations to enroll in the upcoming years the first fully automated ships.

6. Alternative fuels: the LNG case

The analysis first starts with a broad overview of all alternative fuels that were identified through in-depth-interviews, stakeholder meetings, CCNR committees and desk research. Liquefied Natural Gas (LNG) as fuel for the inland navigation was selected as main subject for the applied analyses. A business case was developed based on a 110m long tanker with a dual fuel engine that uses 80% LNG and 20% Diesel.

The following barriers were identified:

- Lack of onshore infrastructure: delays at the port level have slowed down the implementation of the developed LNG masterplan. Bunkering happens with truck-to-ship delivery and also the locations were this is allowed, are limited. There are differences between loading limits of these trucks between MS and they are not allowed to drive in tunnels.

- The business case depends on the volatile price difference between LNG and conventional fuels. The last available forecast of the World Bank predicts a converging of these prices on the long run. The volatility of the price difference makes the business case vulnerable.
- Dependence on one customer. Almost all ships with LNG engines in the inland navigation are operating for Shell.
- Relatively high investment cost of installation compared with stage IIIa engines.
- Remaining uncertainty concerning greenhouse gases. The potential methane slip invites further research and improved real-time measurements. Recent findings in climate change literature, estimate the greenhouse gas methane as 34 times worse than CO_2. The vessel as developed in this research significantly decreases pollutant emissions, but hardly shows any benefit for climate change.
- The installation of the cryogenic tanks reduces payload, which can be solved in the vessel design, but can be problematic for refitting an existing vessel.
- Main focus on the tanker market segment (used to handle dangerous goods) but limited financial means (paying off the last fleet renewal of double-hulls).
- Bunkering and safety procedures require additional training and administration, but which are not considered to be significant costs in this research.
- Small and medium-sized enterprises do not seem to find their way to subsidies.

Although considered to be a transition fuel, LNG is claimed to be a promising fuel that is on the short run feasible and still presents for intensive trajectories, full-operational modes and larger ship sizes a positive business case. Regulation was, sooner than expected by innovators, adopted for LNG as a possible fuel and cargo by the CCNR, EU, CESNI and ADN.

Every LNG ship that was built before the new regulation, had to ask for a derogation of the existing regulation. Not all IWT companies are well connected to this policy. Branch organizations such as EICB and CBRB, and specialized firms such as Lloyd Register and TNO, were important actors in applying for these derogations and to provide expertise to policy makers to prepare more sustainable changes in regulation.

7. General findings

The main general findings of the case analyses are the following:
- Positive business cases in IWT innovation are possible. Investing in LNG and automated vessels can have a positive net present value for the innovator and for the society if failure factors such as the lack of infrastructure and sufficient funding are removed. In most cases the innovation has not experience market uptake (yet, but there is an incremental innovation growth which can suggest a positive business case. Further research (more cases) can consolidate or improve these findings.
- All of the cases show the support of public funding but necessarily towards the actual innovative company. During the initiation and development phases, the innovation could have received public funding. Even if the original publicly-funded innovator fails (e.g. e-bargebooking Just-In-Time Bevrachting), the innovation could find years later market uptake when failure factors are removed. Even if the current private innovator does not have support of public funding, the historical background of the innovation shows in all cases the support of public funding.
- Unadjusted or too defragmented (decreases market) regulation can lead to innovation failure. European regulation needs to level the playing field which influences the potential market size. One legal regime with standards for all of Europe, decreases the compliance costs for the innovator and the innovation customers. The implementation of one regime (CESNI) is expected to have a positive impact on compliance costs for the innovator.
- Infrastructure adjustments are in most cases needed. Not only physical infrastructure (for instance LNG on-shore bunkering facilities, automated mooring devices, maintained waterway

depth and quays) is needed, but also digital infrastructure (for instance secure and reliable internet connections, e-documents).
- The IWT market is a relatively small market and innovation often needs to be tailor-fitted. This pressurizes the innovation prices upwards and could slow down market uptake by consumers in absence of mass production.
- The average freight rate has not shown significant increases to cover increasing costs, which can give the entrepreneur relatively more difficulties to invest in innovation. The lower the freight rates, the less entrepreneurs are eager to take the risks to invest in research and development. The less financial institutions are willing to invest by giving loans. On the other hand, low freight rates, can also give more incentives to invest in cost-reducing innovations. The answer is not clear-cut and depend on the type of innovation.
- Public funding hardly finds its way to SME's in the sector.

If policy would be the sole innovator, there is a risk that private initiatives are pushed away or that the innovation would not be sustainable in market conditions without public funding.

I. Introduction

Innovative initiatives are numerous in the inland navigation, but they seem to experience difficulties to spread and to become successful. 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 raised as main bottlenecks for innovation. But there are more reasons than only age or money that can determine the outcome of the innovation.

1. Research question

This research looks for answers to the following question:

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

This research examines the conditions for technological, organizational, managerial and cultural innovation in inland navigation to materialize effectively and successfully. It looks for reasons why innovations in the inland navigation are experiencing problems, if there are positive business cases and what should policy do.

The innovation process is researched by means of in-depth-case studies by applying methods such as Social Cost-Benefit Analysis (SCBA) and Systems of Innovation Analysis (SIA). SCBA is used to examine how a number of innovation projects (yet to define) react to public push. The Systems of Innovation Analysis (SIA) deals with situations where only a limited number of cases of innovation with each time-limited information are available, for finding common factors contributing to a certain outcome. The SIA and SCBA have been applied previously by the research team to a large set of transport-related innovation cases, and the resulting findings provide a good starting basis for benchmarking and comparison with selected inland navigation cases.

The research focuses on the following sub questions and objectives:

1. **Identifying innovation barriers in inland navigation**

- Understand and describe inland navigation characteristics limiting innovative solutions spread into the market. Is it coming from the sector itself or from innovation solutions that are not bringing enough value ?
- Who are the stakeholders in the innovation?

2. **Identifying a successful innovation policy**

- Identify and describe policy measures best suited to favour innovation in inland navigation.
- Which innovation policies have been applied in the past and in present?
- Which policy measures are applicable?
- By whom should these measures be applied? (private, public, policy level)
- What is the role of government and other stakeholders?
- What are effective / efficient policy measures? What is an optimal innovation policy?
- What are the costs and benefits of each policy scenario?
  - What is the most optimal decision level to invest (in case of government intervention)?
  - What is the role of transaction costs in innovation policy?
  - Which costs and benefits are quantifiable?

2. Research team and steering group

This research was conducted by the Department of Transport and Regional Economics at the University of Antwerp (UA/TPR) in close collaboration with the Central Commission for the Navigation of the Rhine (CCNR). It was partly located in Strasbourg and Antwerp. Main researcher was Edwin Verberght under the project supervision and with the support of Thierry Vanelslander and Edwin Van Hassel. The research was steered by Guillaume Legeay, Laure Roux, Jörg Rusche and Bente Braat of the CCNR.

The research started on 1 October 2017 and the results were presented in October 2018. After drafting the results, further thorough review and editing in transparent and close cooperation with the steering group, this written full report was accepted and published in February 2019. During the research 42 in-depth interviews were conducted. The list of questions and respondents can be found in annex. The content of the interviews is kept confidential. This report was also parallel linked with a PhD research.

3. Research stages

The research was conducted in four stages focusing each on separate issues:

3.1. Stage 1: Start-up

Results at this stage were the identification of possible cases together with first in-depth-interviews.

3.2. Stage 2: Theory building, literature, methodological framework, data-collection

Results at this stage were case selection and preliminary results, introduction and a methodological approach.

3.3. Stage 3: Case analysis

The methodology was applied on three case clusters where possible and provided the first case insights.

3.4. Stage 4: Final results and generalized theory

At this stage, the results of the case studies were further analysed and improved by peer review and discussion with stakeholders and supervisors. The case analyses provided results which could be generalized and which provided the fundaments for policy recommendations.

"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."

Arduino et al (2013), INNOSUTRA project
University of Antwerp

4. Selection process of cases

The selection process was based on a number of elements: interviews, desk research, personal experience, informal and formal meetings with several stakeholders and experts in the European Inland navigation, and several brainstorm sessions. A long list of cases was established and subject to the mentioned brainstorm sessions. The final list was compiled down according to the estimated availability and accessibility of research material for each possible case.

4.1. In-depth-interviews

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

- Exploring interesting cases in different innovation phases: it became clear during the first interviews that several cases were frequently returning.
- Real-time insight in the innovation cycle: where is the innovation located in its innovation path and who are the people behind it?
- Identification of possible barriers: what should be changed in order to make the innovation successful?

It was possible to write relatively early at the beginning of the research a questionnaire for in-depth-interviews aiming at experts, customer/operators, researchers, policy makers and innovation champions. The list of possible respondents grew longer during the research. Actors were identified that play a significant role in IWT innovation. The identification took into account 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.

A. Questionnaire

The used questionnaire 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	Exploration / validation	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?
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 should policy do?
	Policy level	Which policy maker(s) should an innovator address?
Consumers view	Outlook on innovation path	If you would be a skipper with a 40 year old ship, in what kind of innovation would you invest?
		How would IWT look like in 40 years from now?

Table 1: Questionnaire and relevance to research

B. Respondents

The interviewees came from the CCNR Member States and the UK with different profiles from four identified groups:

- Innovators: main driving personalities behind the selected cases, developers or owners;

- Direct stakeholders (incl. vessel owners): organizational representations of branches in IWT such as vessel owners, charterers, unions and customers and other members of industry such as engine builders and fuel producers;
- Experts: people from verification agencies, experts, researchers, inspection and insurance;
- Policy makers from the CCNR, national & regional governments.

The interviews took place at the preferred location of the interviewee. Some interviews were performed through telephone and videoconference. The interview recordings (digital MP3) were treated and processed in a confidential way. Most interviews were recorded and the respondent could decide to refuse recording on every moment during the interview. Some interviews were written down accordingly if preferred not to be recorded. The input was recoded anonymously and interviewees have had the opportunity to validate their input during stage four of the research. In annex 1.3. all the respondents are listed next to case related contributors.

4.2. Case selection

Brainstorm sessions and early interviews allowed listing several possible current innovations while taking in account the time frame of the research and a careful estimation of available material for each potential case. The full list of identified innovations in this phase can be found in annex. *Figure 1* shows the selection process of the cases.

It was originally intended to focus on market-driven business cases, but it appeared during the research that this was not always clear-cut. As the research showed, the later distinction between privately and publicly driven innovation was difficult at the beginning of the project for the long-list of cases and needed more research. For example, in the case of alternative fuels, it can be advocated that the main driver is policy and that the innovation would not have taken place if it would have been left to the market. Nevertheless, the innovators in alternative fuels are private companies that are mainly driven by private revenue with or without the support of subsidies while anticipating more strict regulation (in this case stage V of the non-road machinery directive).

The case of automated or autonomous vessels, which was believed at the beginning of this research to be privately driven, showed already from interviews, participating in the first meeting of the International Forum for Autonomous ships and desk research, that in some experiments and demonstrations, governments and universities are also involved or even leading the development and research. There are possible social benefits (safety) as well as private cost reductions (e.g. personnel cost) to be gained by implementing this innovation. Also the definitions in this innovation case are still subject to debate in inland navigation at this moment. In this research, the innovation was split according to the stages of automation development as stated by the CCNR[3] and based on ITF (2015). The selection process of the innovation cases as described above, ended up in identifying three clusters of cases:

1. Alternative fuels: focus on LNG
2. Internet of ships: focus on automation stages towards developing fully automated barges and online booking platforms.
3. Small waterways: two cases were selected such as a small waterway barge convoy concept and an innovative pallet shuttle barge.

[3] CCNR (2018), Autonoom varen: Voorstel voor een definitie van de automatisatiegraden in de binnenvaart, RP(18)4 as presented for the committee of STF, 21/03/2018 based on Project Adaptive (2015); Shared Automated vehicles and ITF (2015) ; Norwegian forum for autonomous ships (2017), Telematica (2017), Revised update of Cyber-enabled ships ShipRight procedure Lloyd's register (2017). Stage 0: no automation; stage 1: steering assistance; stage 2: partial automation; stage 3: conditional automation; stage 4: high automation; stage 5: full automation. In the latter four stages remote control can be implemented. Stage 0 until 1 are in operation. Stage 2 is expected to be developed. Other modes (road, rail) are already demonstrating a comparable stage 3 and preparing for stage 4. In aviation, remote controlled unmanned planes are already on the market which were driven by military research and operations.

Interviews
- ❑ Stakeholders
- ❑ Policy officers
- ❑ Private operators
- ❑ Sector organizations
- ❑ Innovators

Brainstorms
- ❑ Steering group and research team

Consulted Literature
- ❑ Innovation in general
- ❑ Comparable research
- ❑ Past and current IWT innovations
- ❑ CCNR – archive

Conditions for selection
- ❑ Supported by brainstorms
- ❑ Estimated available material
- ❑ Market driven business case
- ❑ Available network
- ❑ Scope

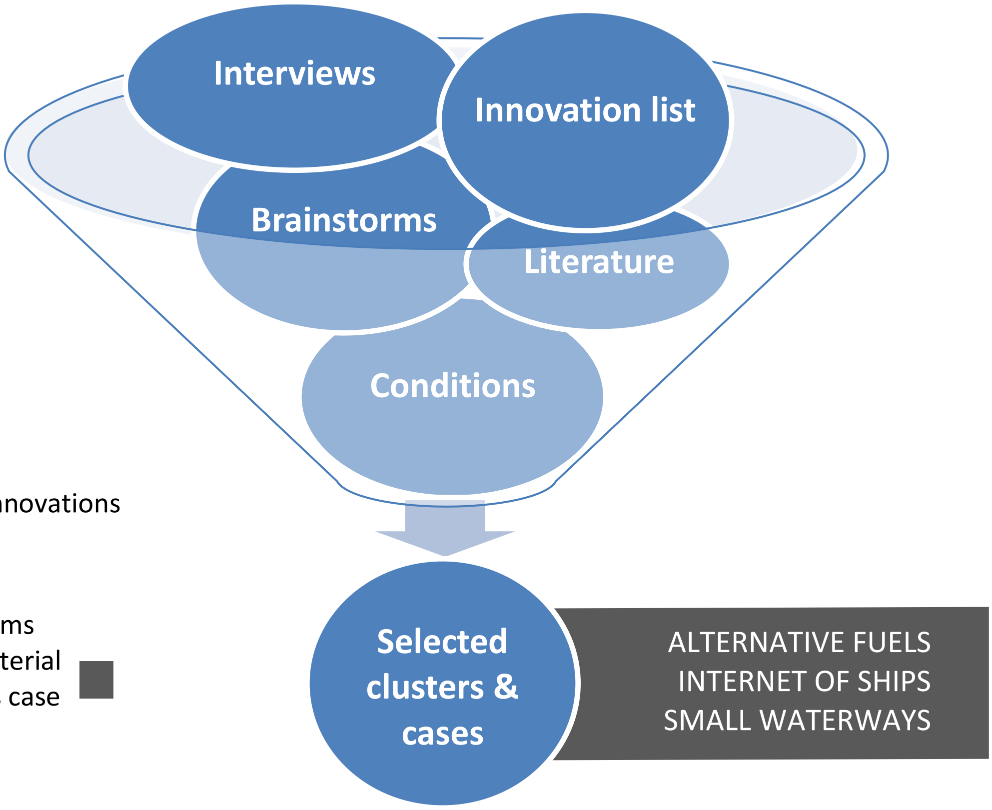

Figure 1: Selection process of innovation cases in IWT

The further case-specific selection was done at the beginning of the research and resulted in the following cases:

1. e-Bargebooking: new ways to charter a vessel such as a virtual market place and a digital freight broker.
2. Small barge convoy: innovation that tries to revive the small waterways with the design of a barge convoy that fits on the small waterways.
3. Pallet Shuttle Barge: new ways to transport pallets with a one single headed crew.
4. Automated vessel: the business case of an automated vessel towards an unmanned inland navigation.
5. LNG: the implementation of liquefied natural gas as fuel in the inland navigation.

5. Outline of the report

Chapter 2 explains the used methodology for all cases. In support of the regulatory aspects in the SIA and the policy analysis, the rather unique institutional setting of the European Inland waterways is addressed in a dedicated chapter 3. The following chapters are the case analyses applying only SIA, which consecutively deal with e-bargebooking, the small barge convoy and the pallet shuttle barge. The two longest chapters are the case analyses of the automated vessel and the LNG implementation where not only SIA is applied but also SCBA and the policy analysis. For each SCBA, a basic null scenario is designed to capture all the costs and benefits of a conventional vessel without the innovation. Upon these conventional vessel models, several scenarios of innovation implementation are applied. Every case analysis ends with a case conclusion. After the case analyses, a general conclusion and policy recommendations are presented. The overall structure is summarized in *Figure 2*.

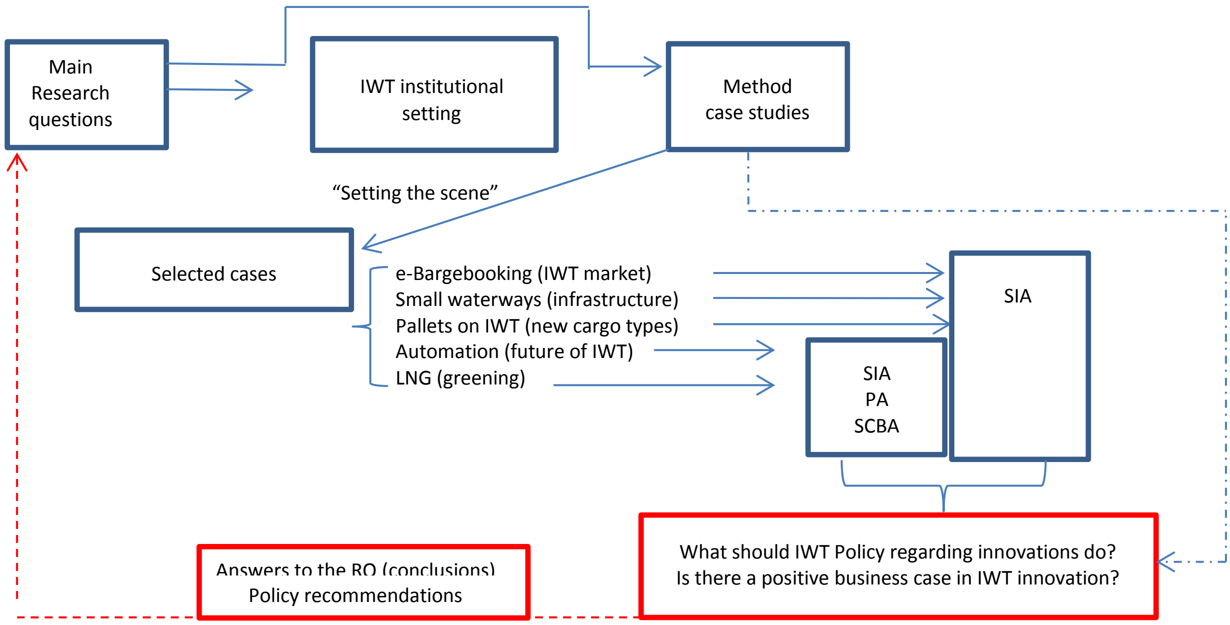

Figure 2: Outline of the research

II. Methodological framework

Before explaining the applied methods in the cases, the general methodological case-study approach is explained.

1. Multiple case analysis

The general approach of this study is a multiple case analysis with five selected cases. The findings of every case analysis provide elements for an inductive theory generation (Eisenhardt, 1989). In other words, through induction, the particularities of a case result in building material for new theories. The answers (general conclusions) to the research questions, follow the exploration (analysis). The similarities and differences between the cases are the main interest of the researcher in order to achieve theoretical generalisations. The latter is less evident, because of the fact that a general theory coming from a limited number of cases has to deal with case-specific elements and context of every case. Therefore, MacIntyre (1985; as cited from Thomas, 2016) refers to probabilistic generalisation. Case studies can address an endless number of topics or as Thomas says:

"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 G., 2016).

All selected cases in this research are innovation initiatives in IWT which have a policy and infrastructure dimension. They are examined on the current role of policy or which policy tools are being used. All selected cases are business cases with a possible influence on the current IWT market in Europe. All these cases are used to build a general conclusion for IWT innovation and result in policy recommendations.

The next part of this chapter gives insight in the applied methods in each case.

2. Methodology of applied case analyses

To answer the research questions, following methods of analysis were chosen for the case analysis:

1. Systems of innovation analysis (SIA)
2. Social Cost-Benefit analysis (SCBA)
3. Policy analysis (PA)

First, SIA is applied to all selected cases. This analysis is rather qualitative and does not need extensive datasets. Most information comes from interviews and desk research.

Second, SCBA is applied on the selected cases where possible. The SCBA needs more data and can determine if an innovation is a positive business case.

Finally, the PA looks at 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 and European multilevel governance and considers the institutional setting AS-IS and its performance. The ongoing institutional process of Europeanisation and in some cases Pan-Europeanisation is taken in account.

The first two analyses are applied to answer the first research question concerning failure and success of innovation in inland navigation and identifying positive business cases. The latter analysis is used for answering the last research question related to the role of policy.

2.1. System of Innovation Analysis

SIA analyses the innovation network after identifying relevant actors, their relations and success or failure factors of innovation. It considers innovation as an interactive process and allows identification of relations between actors. 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* (2011:5-6).

An innovation can be situated in the past (already implemented, off-the-shelf) , in the present (on the market but not yet commercialized) or in the future (in conceptual phase, or not ready for market yet). The degree of the innovation can be systematic, radical, modular or incremental. 'Systematic' refers to multiple independent innovations, whereas 'radical' indicates a breakthrough in the specific field. 'Modular' refers to a significant change in concept within a component. The term 'incremental' corresponds to a small change to existing products/procedures.

'Open' innovation refers to the degree of exchange of knowledge with the external environment; while 'closed' refers to the tendency to keep innovation knowledge within the firm or cluster of firms. An innovation can be partially open and closed. (Vanelslander et.al., 2016). For example, in case of the automation of a vessel, a vast literature can be found on the internet, but often details or even costs of development and research are kept inside the innovating firm.

The SIA literature provides typologies of innovations as presented in Table 2.

Case according to typologies		Alternative fuels	Automated vessel				Small waterway convoy	Pallet shuttle barge
		LNG	partial	conditional	high	full		
Timing	Past							
	Present/future							
	Future							
Degree	Systematic							
	Radical						?	?
	Modular							
	Incremental							
Source	Public-Private							
	Public				?	?		
	Private							
Access	Semi-open							
	Open							
	Close							
Level	Initiation							
	Development							
	Implementation							
Change	Technological unit change							
	Technological - market change							
	Technological, Managerial, Organizational, Cultural - Business Change							
	Technological, Managerial, Organization, Cultural - Market Change							
	Managerial, Organizational, Cultural - Market Change							
	Policy Initiatives (Managerial, Organization, Cultural -Market Change)							

Table 2: SIA typologies and selected cases
Source: own composition based on Vanelslander et.al. (2016)

A. Pattern recognition and failure factors

The SIA indicates which actions, between actors and the institutional environment, are required to establish the success conditions and the area where actions would not achieve the success conditions (Aronietis, 2013:53).

SIA focuses on pattern recognition and the matrix approach links the actors with innovation factors such as market (push), infrastructure, regulation, lock-in effects, culture (values and believes), capabilities (external knowledge and financing) and network aspects (role of innovation champion, influence of actors) which are tested on each case. It provides insight why an innovation is not (yet) pulled by or pushed on the market.

Following elements were identified by desk research, interviews and the validation workshop. These elements could lead to a successful or failed innovation path:

- **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 research subsidies are an expression of a positive soft institution;
- **Networks:** interactions in networks are very important to the promotion and adoption of innovation. These rely on strong and weak networks and both may have positive and negative effects on the innovation:
- **Strong or weak networks:** Linkages are needed between 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 without being locked into existing technologies / patterns;
- **Lock-in effects:** The ability of social systems to adapt to new technological paradigms;
- **Market demand:** the demand among potential users;
- **Competition** (innovation): the extent of competition for the innovation concept.

A pattern recognition exercise is effectuated through a context analysis and the testing of hypotheses. To perform a context analysis, the innovation cases should be grouped on the context (or end scope) of the innovation and then studied with respect to the actors involved and the institutions in place. Hence, the conditions in the innovation system that need to be present in order to successfully implement an innovation are identified and analysed. It also helps in determining which institutions and at which stage of the innovation process were relevant to enhance efficiency and avoid over- or underspending of resources.

If essential actors or institutions were missing, this could lead to systemic failure. Table 3 shows an example of a SIA matrix adapted for inland navigation. It can be used during various discrete phases following the fact that an innovation process is considered as being evolutionary. In general, for technological, managerial/ organizational etc. innovations, three phases may be analysed (initiation, development and implementation), while for "policy innovations", there might be only two, describing ex-ante and ex-post implementation.

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 choses to keep the knowledge inside. The rationale behind the innovation, often technical knowledge, is considered to be of competitive value. A closed innovation is much more difficult to research.

Interactions within the SIA matrix can have a negative or positive effect on the innovation evolution. The problems in the matrix are represented graphically by black and grey areas and are described in every case analysis.

In all the basic elements (such as infrastructure), systemic imperfections (or systemic problems) can occur if the combination of mechanisms is not functioning efficiently[4]. If so, innovation by actors may be blocked. These systemic failures mentioned in the literature as summarized by Norgren & Haucknes, (1999), Smith (2000), Woolthuis et al (2005) and Edquist & Chaminade (2006) to include:

- ***Infrastructural failures***: A lacking of necessary infrastructure to have a successful implementation of the innovation;
- ***Transition failures****:* The inability of firms to adapt to new technological developments;
- ***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;
- ***Hard-institutional failure****:* Failures in the framework of regulation and the general legal system prevents or slows down the innovation;
- ***Soft-institutional failure****:* The failures in the social institutions such as political culture and social values, i.e. informal institutions;
- ***Strong network failures****:* The ‘blindness’ that evolves if actors have too close links and as a result miss out on new outside developments;
- ***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);
- ***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.

B. SIA Matrix

The SIA matrix (Table 3) makes the analysis results presentable to identify the factors of failure or success which are linked with the actors that have an important role during the innovation path. The matrix is scored by findings coming from the interviews and desk research. The matrix 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.

[4] Roumboutsos, A., Kapros, S., Lekakou, M. (2011) Motorways of the Sea in the SE Mediterranean: innovation systems’ analysis of policy instruments, ECONSHIP 2011, Chios, June 22-24, 2011

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

Table 3: Example of Systems Innovation matrix for the inland navigation of the initiation phase of the pallet shuttle barge
Source: based on Vanelslander et al. (2016) and Innosutra D6, p.41-44
VO/O= vessel owner/operator: 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

2.2. Social Cost-Benefit Analysis

SCBA monetarizes the costs and benefits of a project or policy. The social aspect goes further than merely corporate return on investment. It looks at the costs and benefits of society and the environment. SCBA finds its origin in welfare economics and puts all impacts in monetary terms. Despite some critics, this tool is finding 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 in account. First the purpose of the SCBA is briefly explained. Followed by a non-exhaustive overview of costs and benefits that could be identified during a SCBA.

A. Purpose

SCBA is an analytical tool that is used to appraise an investment decision in order to assess the welfare change attributable to it. The purpose of SCBA is to facilitate a more efficient allocation of resources, demonstrating the convenience for society of a particular intervention rather than possible alternatives (EC, 2015).

SCBA includes net returns to the society-at-large while merely financial CBA is preferable used by private firms to calculate the net results for a private group or individual referring to a private industrial component. But this difference does not mean that the usage of an SCBA is only interesting for policy makers. For an innovation that needs a change in regulation in order to become commercialized for private profit, a positive SCBA could convince policy makers to respond and give policy support.

Financial analysis is an important component of SCBA which includes a financial discount rate to calculate future cash flows deriving from the (non)-implementation of the project according several scenarios (e.g. BAU, business as usual, nothing changes).

B. 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 taken in account but also opportunity costs concerning irreplaceable production factors. Means that are used for one project cannot be used for another. 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 vice versa by changing the symbol, but in this research, costs contain all effects of the investment that require welfare resources. These factors have a negative impact on welfare. 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 (*Figure 3*) shows the benefits of the project or the total willingness-to-pay for the demanded products or services in a perfect economy. The supplied quantity is presented by *x* and the price is presented by *p*.

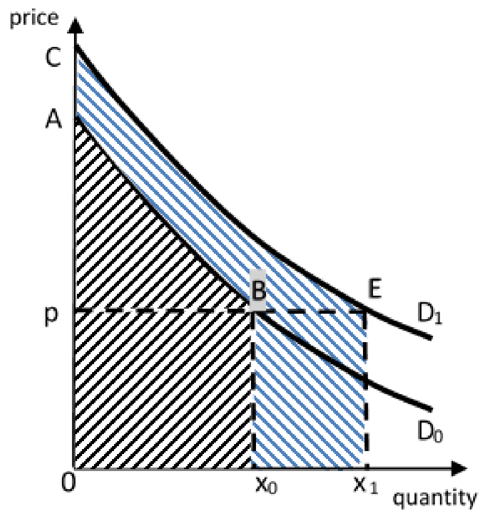

Figure 3: Benefits and demand curve
Source: Blauwens, 1986

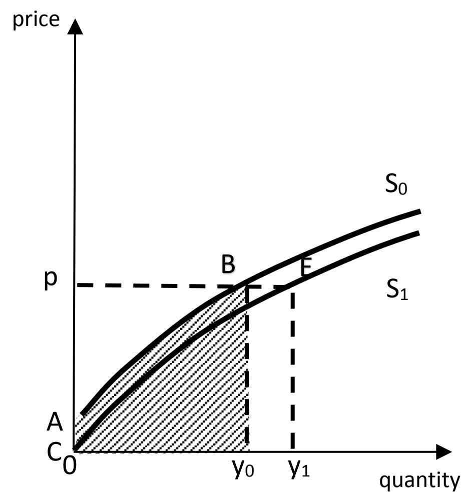

Figure 4: Costs and supply curve
Source: Blauwens, 1986

The benefits are comprised by two parts: total revenue (*pB0*x_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. Assuming that 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 as shown by *Figure 3* (based on Blauwens, 1986). The costs are expressed by the area under the supply curve in a perfect economy.

Figure 4 shows the costs area *0yAB* 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 witch is smaller than the total expenditure *0yBp*. 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 curves in *Figure 3* as the supply curve in *Figure 4*, the function can be assumed to be linear which makes the calculation easier, but more curved lines are closer to reality.

In case of inland navigation, most vessel owners are hardly able to increase the freight rate to pay for their innovation by asking customers for a premium. In this case customers are not willing to pay more for the innovation. With higher costs for suppliers the supply curve would shift in normal circumstances to the left and without change of the demand curve, price would go up. In case of an innovation that reduces costs (e.g. fuel usage reduction), the supply curve would shift to the right, offering more or improved products or services against a price *p*. The latter situation is presented in Figure 4. The triangular area *CpE* represents the producer surplus because of the cost reducing innovation at supply side.

Even if SCBA shows a negative net value and there are no economic reasons to continue, the political reality could decide otherwise. This reality is often undisclosed for the economist (Blauwens, 1986). Decision makers could choose for second or even third best solutions or to proceed even if there are losses identified.

B.1. Costs

Costs can be split in basic categories and in sub-categories:

- Investment cost
    - Technological, managerial and/or research costs
        - Design prototype, planning and development
        - Capital costs: laboratory/equipment costs, plant, machinery, land, building, construction site
        - Business analysis costs: e.g. customer/end user survey cost, publicity
    - Compliance costs
        - Fees for compliance agents, checking formal standards
        - Safety tests (e.g. type-approval), feasibility studies
        - Compliance to complementary products/services
    - Internal resistance costs
        - Cost of appeasing internal stakeholders in business cycle
        - Cost of convincing management (if needed)
- Yearly operation and maintenance cost
    - Quality control: evaluation and problem analysis costs
    - Personnel costs: salaries
    - Energy costs
    - Equipment costs
    - Storage costs
    - Repair costs
    - Management costs
    - Administration costs
    - Insurance costs
    - Waste disposal costs
    - Emission charges (if any) and taxes
    - Information or technology costs: e.g. upgrade of software
    - Compliance costs by changing policy: e.g. technological standards
- Costs for society (external costs)
    - Emissions costs
    - Greenhouses gasses
    - Congestion costs
    - Accidents
    - Infrastructure usage
    - Opportunity costs

B.2. Benefits

Benefits in the simplest approach are the sum of changes in consumer[5] and producer surplus, minus changes in tax revenues (d_{TR}) and in external costs (d_{EC}) (De Borger, 2017) or as following equation expresses:

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

Benefits from innovation could be lower emissions, energy saving, more safety (value of life), more efficiency, etc. Table 4 presents a non-exhaustive list of possible targeted benefits of innovation which can be targeted by the innovative entrepreneur or policy maker.

Profit	Planet	People
Minimizing Costs	Reducing CO_2 emissions	Offering new employment
Optimizing operations	Reducing air pollutants emissions	Retaining human capital
Gaining market share	Minimizing impact of activity on landscape	Improving relations with local communities
Obtaining first mover advantage	Reducing noise	Reducing number of accidents
Avoiding depletion of resources	Reducing water/soil pollution	Reducing fraud
Impacting positively on competiveness	Improving management of waste	Improving efficiency of security requirements
Growing (marketing)	Recycling	Complying with social and labour regulation
Generating employment (substituting labour with capital)	Integrating other developments in the field of sustainability	Complying with safety regulation
Using resources efficiently (equipment, land, etc.)	Complying with environmental regulation	
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		

Table 4: Non-exhaustive list of possible objectives of innovation
Source: based on Vanelslander et al. (2016)

C. Innovation costs and benefits

Introducing an innovation always costs money and its main targets are benefits. Costs are made in every phase of the innovation and it often takes a while before benefits are actually generated. Society will be affected by the innovation and also will have costs and benefits. A possible innovation that could reduce costs such as ecological streaming technology, automation and others, can shift the demand curve, offering a better or more service against price *p*. As a result the supply curve will shift to S_1 as explained in former paragraph. In the short run a shift of the supply or demand curve will influence the price, but in the long run a new market equilibrium will be found between supply and demand in a perfect economy.

[5]**Consumer surplus**, (example of transportation investment) is the excess of users' willingness to pay over the prevailing generalized cost of transport for a specific trip (EC, 2015). The generalized cost of transport expresses the overall inconvenience to the user of travelling between a particular origin (i) and destination (j) 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**, 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 less the change in the producer costs (2015:87)

D. Perspectives

According to Arduino et al. (2010, as cited from Aronietis, 2013), there are two possible views on costs and benefits:

D.1. Industrial-economic view

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 (Figure 4).

D.2. Welfare-economic view

From the point of view of society, 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 (*Figure 3*) 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. But 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 respected[6] in case of subsidy S_p or compensation S_s.

$$\begin{cases} \Delta R_p - \Delta C_p + S_p > \times \\ \Delta B_s - \Delta C_s + S_s > \gamma \end{cases}$$

If an innovation is not interesting (insufficient x) for a private innovator to continue but y 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 y equals to zero or even negative, there is no incentive to continue. The threshold x or y depends on the preferences of the innovator, the investors or the policy makers

[6] Aronietis (2013) focuses on policy driven innovation and mentions some hybrid forms between policy and privately driven innovation. The hybrids are not mentioned here for reasons of presentation.

The innovation path as shown in Figure 5 shows the conditions in which costs and benefits determine the failure or success of the innovation for both private and/or policy driven innovation.

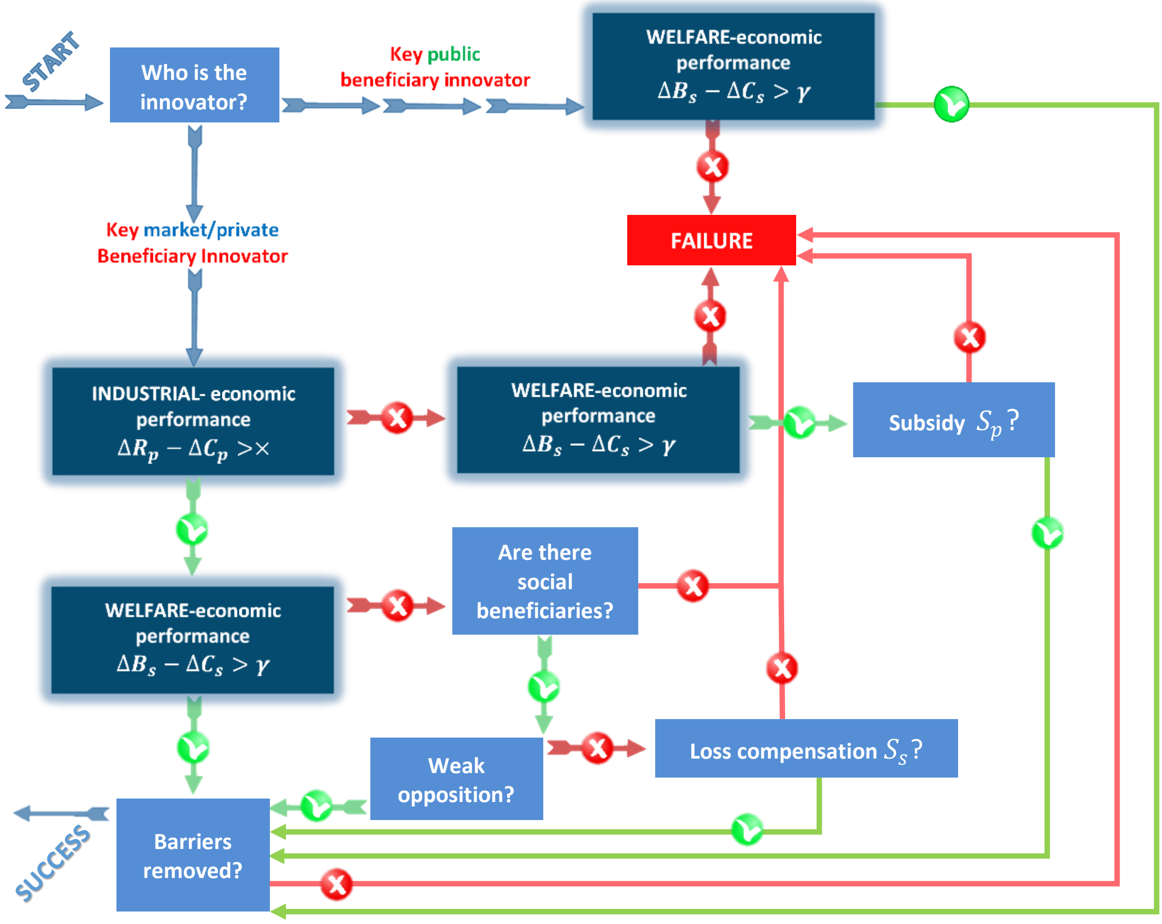

Figure 5: path to innovation success
Source: based on Aronietis (2013:51)

If the key innovator is public, there will be hardly any 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 perceived unfair competition and 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 have to 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).

E. Possible SCBA scenarios

The thresholds as explained, determine the outcome in several scenarios. Table 5 shows a private innovator that has a return on investment that is higher than threshold x, but from a welfare-economic perspective the threshold y 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 chose 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 × as net result[7]	$\Delta B_s - \Delta C_s$ with γ as net result	description
Private innovator	> ×	< γ	Private actor has high enough positive net result but at a too big social cost. Innovator can compensate society or face policy resistance, but will try to continue
	< ×	< γ	Not enough positive net result for innovator and for society. Innovation will probably fail.
	< ×	> γ	Innovator does not receive sufficient profits, but there are enough benefits for society. Policy can decide to support this innovation by a subsidy otherwise the innovation will fail
	> ×	> γ	Private innovator and society benefit. Innovation will likely succeed.
Public innovator		> γ	Social benefits, public innovator will continue. Innovation likely succeeds if no other barriers
		< γ	Welfare benefits are too low or even negative. Innovation will probably fail.

Table 5: Possible situations of benefits and costs between private and public innovators
Source: based on Aronietis (2013)

F. Cost and benefit values

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 are 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.

For an outsider (outside the innovation project), getting reliable data about the basic cost categories is challenging. More detailed information about these costs (such as mentioned in the subcategories) requires full access to a project 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. Furthermore, in case of investment in a new inland vessel, the technical or crew requirements might change over time during the relatively long lifespan of that vessel. The latter is on average longer than 30 years in the Rhine fleet. Compliance costs are in order to have crew and technological standards at check. Usually, vessel owners have no compliance advisors or necessary internal capability and rely on own transaction costs to stay in check with policy developments or on the quality of information dissemination of branch organizations such as ESO or EBU and their national or regional branches.

G. Calculating Net Present Value

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).
The discount rate in the economic analysis of investment projects, the Social Discount Rate (SDR), reflects the social 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 of time (i):

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

[7] The innovator can decide to aim at a higher threshold than 0 for × or γ in order to decide. For society × = 0 as net result can also be defendable 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.

The “t” represents the index of the annual costs and benefits in constant prices. The project or policy adds value if the NPV is positive, while it is negative the project or policy should be rejected (Eijgenraam, et al., 2000). The NPV can be a Pareto correction, whereas losers are compensated for by the winners[8].

2.3. Policy Analysis

In helping to understand inland navigation policy, the experience at the CCNR, the EC, UNECE and other institutions of attending and participating in formal and informal meetings, conversations and interviews with policy makers and other targeted respondents for the interviews, offered a trunk load of information. The political analysis performs an subsidiarity test, examines more closely the compliance and enforcement costs, evaluates the subsidies, but most importantly, the perspective is not from an institution, but from the customer’s perspective of the innovation and goes deeper than the analysis of regulatory or institutional aspects in the SIA.

In this research, it is assumed that not only the type of policy (subsidies, do-nothing, fiscal incentives, taking over innovation, etc.) has an influence on innovation, but also the policy level. The level could determine the scope of the policy and offers a policy arena with multilevel governance networks and possible funding.

The relevance of this question, and especially the inland navigation and transport in general, relates to the institutional competition (as described in Terlouw et al., 2004, EFIN), to determine European and even Pan-European policy. During the last decade, the transition was made for regulating the waterway transport of dangerous goods (ADNR became ADN, or from CCNR towards UNECE) and the sector saw the creation of CESNI, what might be the start of some kind of European inland navigation policy center replacing dual standards for technical and crew requirements for the entire EU.

There are different costs and benefits that can be identified of each policy on an international, Pan-European or European Union level in 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 at the left bank has more water bound industry and thus more benefits to organize maintenance of the river. The riparian state at 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.

The externalities that different levels try to tackle could be different and relate to the competences of each level. Policy success depends in the given institutional setting, on internal transaction costs such as compliance, legal consistency, enforcement, coordination, delegation and others.
By whom and how these externalities should be tackled is included in the European treaty of Maastricht (art.5) and in the Lisbon treaty:

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 at 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.

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[8] 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. The Hicks-Kaldor-compensation principle adds that the project should be adopted only if winners are able to compensate the losers and are still better off (Eijgenraam, et al., 2000:135-144).

Subsidiarity suggests that a policy should be executed at that level that can offer the most effective and efficient way to solve a problem or externality. It refers to the existence of a multileveled governance that often provides an arena for competing institutions in search of powers (Portuese, 2010). It is generally accepted that the lowest policy level is the most efficient because of the better and faster access to voters' preferences and legitimacy reasons and if proven otherwise higher levels of policy gain initiative. Pelkmans (2006) however defines subsidiarity not as a one-way stream but looks for the most efficient level to tackle externalities in centralization or decentralization from a more neutral perspective.

Proportionality means that every policy should check 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. Proportionality can be static or comparable according to a described scenario in a SCBA (Trachtman, 1998:35).

During this part of the analysis the institutional setting is examined more profoundly and includes different institutional realities. This component should help analysing the multilevel governance structure and give more aid in defining the conditions based on economic arguments within the institutional setting to send powers to an "optimal" policy level. Most authors such as Schumpeter stated that an optimal policy is impossible and that policy is about politics and not about economic rationalism. The costs and benefits of each policy level are expressed by

$$B_i - C_i > z$$

With B_i as the societal benefits from an institution 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, but further research can possibly quantify this component. 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 (compliance with Mannheim Convention, MS regulation in case of stepping out of power limits)
  - Information costs (price of asymmetrical information can be higher than paying for the 'right' information, closer to sector more or less information)
  - Enforcement costs (updated service instructions, court law, police enforcement)
  - Monitoring costs (market observation and analyses; time and spatial differences)
  - Subsidies, funding and tax cuts

- Benefits:
  - Scale of economy towards cross-border externalities
  - Single Market scope with freedom of services and persons
  - System of mutual recognition
  - Level playing field for enterprises

For example, one of the possible policy scenario's which is frequently used in contemporary European policy is the method of mutual recognition (MR). This method can be expressed by benefits and costs that are derived from transaction cost theory as shown in Table 6.

Costs	
Information	• MR is often invisible for actors • Grey areas because MR is often based on case law • No real 'legal text book' available
Compliance	• 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 transaction costs	• 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	• National autonomy is protected by objectives concerning safety, health, environment and consumer protection • Emphasis on objectives, not on technical details
Strategic	• 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	• Stimulates competition and growth • Influences quality of different policies (if bench marked)

Table 6: Costs and benefits of mutual recognition
Source: based on Pelkmans (2006)

Mutual recognition is a method to create one single market that is situated at the level of the MS 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 CCNR also uses the system of mutual recognition of equivalence of non-Rhine boat master certificates, service record books and radar certificates with Romania, Hungary, Czech Republic, Slovakian Republic, Austria, Poland (excl. radar) and Bulgaria in the absence of 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.

Another example is centralized regulation at the European and pan-European level. In this policy scenario, the role of the European Commission, CESNI, the river commissions and the UNECE were highlighted in the analysis and each can be used to centralize regulation.

In the case of the alternative fuels such as LNG, the innovator had to address the CCNR, the EC and the UNECE (in case of dangerous goods). For the case concerning automation of the fleet, all described institutions will have a role in adjusting the regulation and were analysed from a SCBA - perspective.

The next chapter goes deeper in the institutional setting and provides insight in the policy transformation within the sector during the past decade and supports understanding of the political analysis. Depending on the case, it is decided which part of policy should be analysed. In the case of the automated vessel, the policy analysis analyses the impact of derogation timing on the business case. In case of the LNG vessel, the given subsidies are evaluated.

III. Institutional Setting

This chapter explains the complex institutional setting of the multilevel governance model of IWT in Europe. It is necessary to understand the current institutional framework that could support or even limit an innovation.

1. Policy actors

As mentioned in Romboutsos (2013), important actors inside the multi-dimensional innovation system can be found at the different levels of policy. This document identifies and analyses the current inland navigation institutional framework in order to tackle regulatory bottlenecks, by addressing the relevant policy actors. Other reasons for this identification is to develop insight on possible public funding sources for innovation in inland navigation.

1.1. Ports

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 also develops a policy towards innovation. For instance, introducing compulsory requirements for the use of Automatic Identification Service (AIS) by barges can have a positive influence on the market penetration of the Automatic Identification Service transponder system. The emission sensitive price setting of the port dues for inland navigation by major ports can also have an influence on the enrolment of greener alternative fuels. For example, most important European ports are investigating or have implemented discounts for lower emission vessels or even forbidden “dirty” vessels (e.g. Port of Rotterdam). In the case of automation, ports present themselves as a partner of the innovator during the different phases of development.

1.2. 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 also conduct research and experiments concerning automated vessels such as the Province of Western Flanders. They are often partner in infrastructural masterplans or sometimes give subsidies for the IWT. Only four regions in Germany have kept this government layer or regional mid-level local government (Baden-Würtemberg, Bavaria, Hesse and North Rhine-Westphalia) but for the ones that remain, no policy concerning inland navigation was identified. In Switzerland, only Basel-Stadt could have an influence on the Rhine as a canton, but no IWT policy or other initiatives were identified on this level. 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.
All these entities on this administrative level could be important as their policy choice can have an impact on the deployment of innovation in the sector., because it has to agree for instance, to allow truck-to-truck bunkering for LNG vessels. The regions are explained in the next paragraph together with the national level.

1.3. Regional and national levels

The third identified level consists of the regional or national waterway managers as well as inland navigation policy officers and ministers:

- In the Netherlands, the waterway manager (Rijkswaterstaat) belongs to the ministerial department of infrastructure and Water Management.

- In Germany, the waterway manager falls under the *Federal Waterways and Shipping Administration (WSV)* which belongs to the *Federal Ministry of Transport and Digital Infrastructure's Public Information Service*.
- In France, the *Waterways of France* (VNF) falls under the French Minister of Environment, Sustainable Development and Energy.
- In Switzerland, The Swiss Federal Office of Transport (FOT) is responsible for all railways, buses, ships and cableways. Despite the refusal to become a member of the European Union and its historical neutrality, Switzerland is active as a CCNR member and also houses the UNECE in Geneva. The national level controls the shipping companies which have a federal concession. Other shipping companies are the responsibility of the cantons.
- In Belgium the waterways are partly a federal matter (pleasure navigation, exploitation permit of freight vessels, Shipping Register, river police) but most powers are at the regional level (Flemish, Walloon and Brussels region). The latter comprises most of the international representation (EU, CCNR, UNECE), and is responsible for matters relating to certificates, training, examination, infrastructure, etc., which is in most countries a national competence. Moreover, most international institutions only accept CCNR delegations and their positions. The Flemish regional waterway manager forms a separate organization next to the department of Mobility and Public Works, which both fall under the Minister of Mobility and Public Works, while in the Walloon region, IWT is managed fully by the Ministry of Public Works (*Service Public de Wallonie*, SPW). In the case of Brussels, the port authority of the port of Brussels is also responsible by delegation from the Brussels Regional government for the waterways in the region (two lift bridges, two locks and 14 km of waterways) with funding of the regional government.

Before going deeper into the European level, it is important to note that a number of multilateral or bilateral cooperation agreements between national institutions 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 or maintenance. Also at port level, cross-border cooperation can emerge, such as the merger between the ports of Flushing, Terneuzen and Ghent into the North Sea Port.

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. In light of the already important number of organizations trying to influence IWT policy making, identifying whether there is a real need for more organizations is a valid question. Replacing the existing fragmentation by one organization is also a valid question. However, creating such an organization, and therefore going in the direction of more centralization, may be unrealistic in the short run and attempts have failed so far.

1.4. 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 (CCNR) and the Danube Commission (DC). Other river commissions are 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 a number of observing members. The members of the DC are Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, Ukraine, Russia and Moldova and also the DC has observer members. Turkey, Macedonia, Greece, Cyprus and Montenegro are also observer states of the DC. 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 is responsible for regulations in areas such as police, inspection, technical vessel requirements, transport of dangerous goods (until ADN on UNECE level) and crew requirements. The CCNR is also responsible for the annual 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 falls under these river commissions.

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

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 are the only public administrations, regulators and even tribunals (in case of CCNR), that have a team of experts, experience, tradition, network and knowhow, with a daily sole focus on inland navigation. During the research, a comparable level of expertise with the sole focus on inland navigation was not found at other policy levels. Port authorities, regional and national agencies and ministries do not have similar departments or even divisions (mostly combined with other modes), nor does the European Union.

1.5. European Union

Inland navigation policy in the European Union has experienced 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 disappeared. The entire 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). 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 policy makers bigger than the former scope with was focused on the Rhine region. New MS were obliged to accept these directives for their inland navigation market. Even if non-MS of the EU share a river such as the Danube with a neighboring EU-member and even if the national fleet is state-owned, free competition becomes through enlargement or Europeanizing of the EU in the longer run, rather unavoidable, especially in international transport, disregarding possible cabotage restrictions.

The European Union and its Commission can be considered as the main power behind the liberalization wave in the inland navigation market, in the development of River Information Services (RIS), in identifying infrastructural bottlenecks (TEN-T), promoting the sector, fleet innovation, education programs and environmental improvements through the NAIADES programs and the Platina platforms. Another initiative of the EU was the Marco Polo funding programs for projects which could shift freight transport from road to sea, rail and inland waterways. From 2008, third countries or EU neighboring countries, were also eligible for funding. Nowadays, the European Commission invests in transport through the Connecting Europe Facility (CEF) and Horizon 2020 funding schemes. Several innovation cases as discussed in this research, receive support by these programs.

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.[9]

The mandate of the coordinators includes drawing up the relevant corridor work plan; supporting and monitoring implementation of the work plan; regularly consulting the Corridor Forum, which is a consultative body bringing together MS and various stakeholders; making recommendations in areas such as transport development along corridors or access to financing / funding sources; annual reporting to the European Parliament, Council, Commission and the MS concerned on the progress achieved (EC, 2016). The governance system around the coordinators includes a support structure such as corridor fora and thematic working groups of experts. Public and private authorities, at the regional, national and local levels, infrastructure managers, investors, social partners and other actors are involved.

[9] According to the Progress Report, Implementation of the Ten-T Priority Projects of the European Commission (2012) the Seine-Nord Canal was for 22% ongoing in 2011 and the Rhine/Meuse – Main – Danube axis was for almost 60% finished (EC, 2012:6). The government Hollande revised the financial budget of the project which caused delays on both the French as the Walloon side. Next to the financial crisis and its effect on governments' budget, and the policy agenda of a new government, the critical problem concerning the delays in project implementation is closely related to the considerable amount of financial resources required (Rothengatter, 2005). A systematic underestimation of the real project costs seems to run out the budgetary constraints before completion of the project. Under the government Macron the CSNE was not abandoned but the further development has paused due to budgetary restraints from the French side. The last three French presidents did practically the same. Former French prime minister Alain Juppé stated in 1995 that he gave instructions to proceed with the CSNE as quickly as possible after the first studies in 1993. The CSNE was estimated at EUR 4.5 billion, but a report of the Conseil général de l'Environnement et du Développement (CGEDD) estimated the real cost at EUR 7 billion. Recently, the government announced that there is a new compromise with local governments to finance the CSNE between Compiègne and Aubencheul-au-Bac. The European Union would pay EUR 1.8 billion, national and regional governments would add 2 billion and the remaining EUR 700 million would be lent. New in this compromise is the changing of responsibilities. Whereas the national state had the lead in the project, the responsibility shifts to the regions. The regions will do the entire investment and bill the national government and the European Union. The national state will guarantee and safe hold the investments risks. The Belgian regional governments of Flanders and Wallonia are finalizing the CSNE recommendations from their side (modernization of fairway and gauge) and are adjusting locks and bridges awaiting the CSNE. The CGEDD report shows that costs change over time. Building material can become more expensive, economic parameters can change and new insights or recalculations can lower the value of benefits outside the scenario testing of former ex ante CBA. Although the details of the CSNE are outside the scope of this research, it is important to grasp the infrastructure reality and the possibility to change infrastructure at European level when dealing with infrastructure issues within the SIA of the selected cases in this research. The case of the CSNE shows the possible budgetary and organizational difficulties that European policy makers have to deal with in removing widely agreed bottlenecks in IWT.

The TEN-T program is managed by the Innovation and Networks Executive Agency (INEA) following up the Trans-European Transport Network Executive Agency (TEN-TEA) of 2006. Officially the INEA started from 2014 onwards to implement the EU programs such as Connecting Europe Facility (CEF), Horizon 2020 (parts of Smart, green and integrated transport; Secure, clean and efficient energy) and legacy programs such as TEN-T and Marco Polo 2007-2013.

Only a relatively small share of the EU transport budget goes to inland navigation (especially when compared with other modes) and when budget is allocated, it still seems difficult to implement a relatively large infrastructure project for the IWT (e.g. CSNE).

1.6. 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 it 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 the most clear Pan-European character. A disadvantage analysing the effects of a certain UNECE policy lays in the soft power of its treaties and resolutions. Unlike the European Union, the UNECE is not able to ask its MS to enforce legislation. Most treaties have to be signed and ratified by all partners and this according to their own speed. 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.

Next to UNECE the UN also created Economic Commissions for Asia and the Far East (ECAFE) on the same date, for Latin America (ECLA) in 1948, for Africa (ECA) in 1958 and for Western Asia (ECWA) in 1973. All these regional commissions report to the Economic and Social Council which is the principal organ to coordinate the economic, social and related work of the UN and the specialized agencies and institutions.

To facilitate Pan-European transportation in general, the UNECE tries to establish one single Pan-European regime or set of rules in a number of 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 down 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 all MS and the two most important river commissions in Budapest on 3 October 2000. In 2001 and 2002, it was signed by all officials. A special article in the 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 depository state not to make any reservations as to ratification, acceptance or approval. The CMNI entered into force on 1 April 2005 and 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.

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. 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 Commission for the Danube was first an observer during the establishment of this treaty and became then full part of the joint revising committee (with the UNECE and the CCNR) that adjusts and updates every two years the ADN. A special article in the ADN treaty, allowed the treaty to come into force as soon as seven MS accepted, accessed or ratified it. On 1 January 2011 the ADN fully replaced the ADNR in the CCNR-MS.

The ADN in IWT is comparable with other modes such as road: ADR (1957), railway: RID (1985), sea: IMDG (1965) and air: IATA DGR (1956). Because of the unification it was made easier to ²anticipate changes in the treaties of the other modes. In intermodal international transportation, harmonization and mutual recognition of certificates can facilitate the transportation process, decrease transaction costs, by mastering the administrative and juridical complexity, and increase the level of safety for crew, vessel, environment and cargo.

For inland navigation following working groups at the UNECE are the most relevant:

- ECE TRANS SC3 WP: Annual Working Party Inland Water Transport (WP IWT):
- ECE TRANS SC.3 WP: Working Party on Standardization of Technical, Safety Requirements in Inland Navigation (WP STSRIN),
- ECE TRANS WP 15 AC 2: ADN SAFETY COMMITTEE (WP ADN), twice a year
- ECE/ADN/ administrative committee, twice a year

The UNECE is able to align 56 MS for a common goal and to reconnect with the UN and its other economic commissions worldwide to create global standards and resolutions. But when zooming into the minutes of the meetings of the past years, one can question the pan-European nature of groups related to Inland navigation within the UNECE. The attendance and participation of MS is relatively low and seems to ignore the economic importance of each river (*Table 7*).

Working Party	Years	Identified MS delegations	Number of meetings	Average participation rate	CCNR MS Avg. Share	DC MS Avg. Share %
IWT	2002-2017	25	16	55.5%	24.4%	49.2%
STSRIN	2007-2017	23	21	48.4%	24.7%	51.7%
ADN SAF	2015-2018	13	7	86.8%	36.9%	55.7%
ADN Admin	2015-2018	14	7	77.1%	38.6%	51.1%

Table 7: The working parties of the UNECE in IWT
Source: Based on own analysis of minutes, online available on the UNECE - website
Germany is member to the DC and the CCNR and is double counted in the average share of attendance in the sample of UNECE meetings

For the past 16 meetings of the Working Party Inland Water Transport at the UNECE (in this sample), 25 MS showed up at least once to attend. The average participation rate of all meetings is 55.5%[10] Four out of five CCNR MS attended on average the meetings of the WP IWT in the examined sample, which represents a share of 24.4% of all MS that were present. On average 49.2% of the participants were Danube countries. The remaining MS were United Kingdom, Turkey, Poland, Norway, Montenegro, Lithuania, Latvia, Kazakhstan, Finland, Czech Republic and Belarus which have all visited a meeting as an official delegation at least once.
For the other meetings taken into this sample, the numeric dominance of the MS of the Danube Commission is even more outspoken in the ADN safety committee with 55.7%, although due to the relatively low number of total MS, the difference with the attending CCNR members is more balanced.

Measuring the attendance of relevant meetings over a sample is a highly debatable indicator. This small analysis does not show any information of contribution of both the attending and the non-attending delegations. During all meetings, the minutes also showed regular attendance by stakeholders from the sector.
As the economic heart of the sector lies in the ARA region, most stakeholders are also active in the ARA and are usually nationals from one of the CCNR MS.
The findings in Table 7, could explain why some IWT countries prefer the level of the UNECE to discuss or to reopen debates from other policy levels concerning IWT regulations and standards. Non-EU members are at the same level as EU members, which is not the case if a non-EU member country has to negotiate with the EU in a bilateral way.

Other institutions such as CESNI and the European Commission have a comparable number of countries involved in the working groups concerning inland navigation during the input phase of policy. The Pan-European character of the UNECE for the IWT is at least at the input side of the policy, hardly more Pan-European than other institutions according to the number of attending MS.

2. 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'Élabouration de Standards dans le Domaine de Navigation Intérieure*) between the CCNR and the EU. Within this framemwork the European Commission works closely together with the CCNR on common standards for crew regulation and technical requirements. This agreement aimed more precisely at: technical requirements and information technology concerning inland waterway vessels; the modernization of the legal framework on boat master certificates governed by Council Directive 96/50/EC of 23 July 1996 on the harmonization of the conditions for obtaining national boatmasters' certificates for the carriage of goods and passengers by inland waterway in the Community and its extension in the area of professional qualifications for workers in the field of inland navigation, in line with the provisions of the Treaty on the Functioning of the European Union; and market observation of the European inland waterway transport market as agreed under the Technical Assistance contract between the European Commission and the CCNR.

3. Overview of members

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 MS (MS's) and in some cases non-MS (NMS's), regional and local governments, and the port authorities. Table 8 gives an overview of membership in the above-mentioned international organizations and bodies:

[10] This is calculated by dividing the average number of participating MS for each meeting by 25. The attendance of the CCNR MS is on average 4 times.

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

Table 8: Full membership in inland navigation policy institutions
Source: updated from UNECE, 2011 pp.40

4. Policy network

It becomes clear already that there is no central 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 as Figure 6 shows, or as Doni described already in 1965:

"Eine der wesentlichsten Aufgaben europäischer Binnenschifffahrtsverkehrspolitik ist deshalb die Zusammenführung dieser noch widerstreitenden Strömungen zu einem gemeinsamen Ergebnis (Doni, W., 1965:91-125). [11]*"*

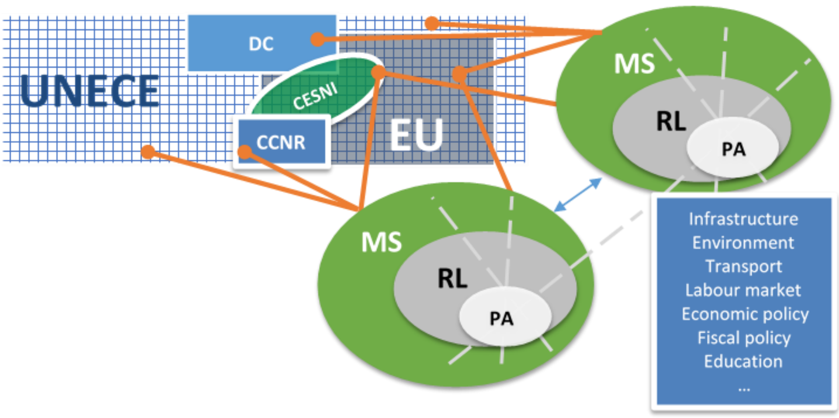

Figure 6: Institutional actors of the Pan-European IWT policy framework
Source: own creation
PA: port authority; RL: Regional and local governments; MS: Member States

[11] 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

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.

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

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.[12]
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, governance institutions and actions of actors in the decision environment. These institutions are further explained in the next paragraphs.

4.1. 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 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)[13], 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. CEVNI[14], ADN).

According to Aquapol (European organization of river police) more than 450 different crew certificates have to be recognized by the river police during their inspections. Other sources confirm that all official documents are still in paper and differences between countries are still noticeable (e.g. Belgian exploitation permit, periods between two mandatory dry dock inspections, fiscal policy, police regulation on Rhine and other waterways,…etc.).

4.2. 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

[12] 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.

[13] 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 at 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).

[14] 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).

and culture. Trying to reform institutions, even informal ones, can result in institutional resistance. In reality, mostly MS with a special interest in inland waterways take actions regarding to IWT policy in the EU.

4.3. Governance institutions

Governance institutions relate to rules of conduct, government operational guidelines and organizational framework. After the EFIN rapport (a new regulatory framework for the inland navigation in Europe, 2004:98) and the NAIADES programs, effort 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 complex PEINP governance structure.

The UNECE has the largest scope but the resolutions are not binding for the MS. The ADN concerning dangerous goods by IWT is the result of a relatively long governance process between the UNECE and the River Commissions. The EU IWT policy consists more of coordinating and steering between river commissions and national/regional policy actors, although IWT directives and regulations from the EU are binding. The CCNR, being the oldest supranational organization, has binding governance institutions regulating the IWT from a consensual model. 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 and the CCNR would exchange information concerning working programs (market analyses and police regulation), 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 lays on the waterway infrastructure rehabilitation and maintenance on the Danube, follow-up of actions within the respective mandates of the Danube Commission and DG MOVE and on participating and coordinating the implementation of a Master Plan for the rehabilitation and maintenance of the Danube River. This Master Plan refers to the Luxembourg Declaration of 7 June 2012 and the Danube Transport Ministers conclusions of 3rd December 2014 on effective waterway infrastructure rehabilitation and maintenance on the Danube and its navigable tributaries and the improvement of comprehensive waterway management. Other elements concern the elaboration of technical standards for navigation, in particular, infrastructure maintenance and navigability status assessment on the Danube River, contribution to the elaboration of technical standards for inland waterway vessels and market observation as regards the Danube Basin. Between the CCNR and the DC cooperative frameworks have also been reached: e.g. the mutual recognition of the boat masters' and radar certificates and service record books.

4.4. Actions of actors

Actions of actors in the decision environment can also be regards as institutions such as voting procedures, lobbying or even social dialogues. During the conducted interviews within this research, most policy actors were perceived by private actors as rather bureaucratic and slow to adapt to sudden changes. The social partners and the industry seem to have this perception in common. But it is also broadly accepted that the behaviour of the policy actors in PEINP is evolving. Over time, there were several moments when institutionalism, lack of trust and fear of uncertainty concerning changes and (inter-)national agenda's, made it very difficult to work on European harmonization. Previously, no official delegation would openly agree with this view, but it partly explains why the European integration inside PEINP has a very slow pace compared with other modes.

Sector organizations such as the European Barge Union[15] (EBU), the European Transport workers Federation[16] (ETF) and the European Skippers Organization[17] (ESO) have an outspoken European dimension, but nevertheless 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. But economic issues still can have different views and beliefs between both organizations[18].

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, labour unions, experts and lobbyists), media, environmentalists and others that influence the policy making system as well. This complex network results in a multidimensional 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 are also interdependent. 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.

Policy actors frequently meet interest groups which are organized at a European level. Most representatives from these European organizations are in favor of European integration but show an ambiguous approach concerning the existing policy fragmentation.

5. Reviewing the EFIN report

The EFIN report (European Framework for Inland Navigation, 2004) evaluated some shortcomings of the (Pan-) European inland navigation policy in order to achieve a more optimal policy efficiency:

- Low political impact (major investments, economic aid, social policy, weaker lobby than in other modes, lack of professionalization of sector representatives,…);
- Incomplete opening up of the markets (EC, Mannheim Convention, Belgrade Convention, third countries): *Deregulation is quite well advanced. But in order to have favorable 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 (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);

[15] 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.

[16] 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. At 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.

[17] 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).

[18] 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. But also inside the European organizations different views are possible. During the skipper strikes in the Flemish Region in 2013, Flemish skipper organizations accused Dutch operators of unfair competition.

- 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.

Although major breakthroughs happened since the EFIN report (such as ADN, CLNI, CMNI, CDNI, CESNI), the PEINP can still become problematic if actors create their own legislation, as a number of reports pointed out, such as the Impact Assessment and Evaluation Study "*Proposal for a Legal Instrument on the harmonisation of boatmasters' certificates in Inland Waterway Transport* (Europe-Economics, 2009).

Studies like EFIN (2004) stated that the complex multi-governance network of the PEINP in 2004 could result in policy inefficiency. The NAIADES communication of the EC identified this as an important regulatory and organizational bottleneck. Recent studies of Steer (2009) assessed the main developments in the common transport policy and also pointed out the administrative and regulatory barriers which would limit the scope for new entry to the market.

Since the EFIN report, there has been some changes but further work still needs to be undertaken. As long all the identified policy actors overlap with other (inter)national and regional actors, inefficiencies can occur. As the world of transportation, where the PEINP comprises just a relatively small part, changes rapidly, governance networks with complex interdependent relations and a significant number of institutionalized actors could find it difficult to respond effectively to challenges.

The policy topics in inland navigation can be understood in three dimensions. First of all, 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...). The regulation can distinguish among rules of public law (technical and safety regulations) and private law (regime of legal obligations and liability). The technical regulations as described in the EFIN report deal with differences between the waterways concerning certificates for vessels and crew:

Regarding the technical specifications for vessels, the level of equipment chosen has important implications for the financial constraints on ship-owners and on competitiveness on one hand, and for safety levels on the other. Adaptation to the physical characteristics and socio-economic conditions of each waterway is logical, but it compromises ease of circulation. In practice, almost all international regimes of technical specifications are inspired by the Rhine regulations. In contrast, Russia and the Ukraine on the one hand and the United Kingdom on the other are more inspired by traditions of maritime safety. To this must be added the question of acquired rights and transitional provisions. Concerning boat-masters' certificates, there is a good degree of similarity between the qualifications required under the Rhine and Danube regimes on the one hand and Community regulations on the other, but in addition, boa-masters are required to have practical knowledge of particularly difficult stretches of the waterways (EFIN, 2004).

The cooperation and combined efforts between the European Commission and the CCNR resulted in CESNI which tries to reinforce governance at EU level. The outcome such as the ES-TRIN (European Standard laying down Technical Requirements for Inland Navigation vessels) and the standards for the crew competence requirements, should be able to remove differences between the MS and improve labour mobility and vessel safety on the European waterways.

These two major changes (crew and technical requirements) created one regime which is relevant for technological, operational and managerial innovation on the European inland waterways. More than ten years after the EFIN report these shortcomings are assumed to be tackled.

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). 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). But according to Kroos (2011)[19], 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 expected. The lack of mandatory nature of the convention does not make uniform the rights and duties of the various parties of an IWT contract, nor does it unify in practice the exoneration possibilities and liabilities.
Another convention is the CLNI (entered into force in 1997, revision in 2012), Convention on the Limitation of Liability in Inland Navigation.

The EFIN critique concerning the poor human resources is almost outdated. 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. But still, it can be perceived that only a relatively small number of salaried employees exist in and outside those organizations such as consultants, researchers, lobbyists and others for IWT inside the PEINP in regard to other modes. A trend which is currently observed in the Rhine countries is the shift in gender balance and generational change.

“Dispersed responsibility and lack of cohesion in the exercise of competence (EFIN, 2004)”, is still a shortcoming in the PEINP. Mostly the same experts and institutions representatives travel from one policy arena to another, answering comparable questions and participating in similar debates. This is not necessarily a negative feature because institutions learn from each other and insights are subject to interactive processes such as debates. The frequency of these meetings in different arenas, even repetitions, could lead to more policy quality but can easily also lead to less policy efficiency.
In the case of alternative fuels, the innovator has to lobby in Brussels for the European Commission, in Strasbourg for the river commission and in Geneva for the UNECE after doing the same traveling inside national, regional and port governance networks.

After the financial crisis in 2008, there was hardly a common European strategy in addressing the problems IWT operators were facing. The need for a more strategic approach still remains today, despite the efforts in suspending some new technical requirements in 2013 by the CCNR and changing the regulation concerning the European reserve fund, opening it up towards support for greening measures by the European Commission. Some national governments introduced crisis initiatives such as the Belgian government in introducing a fair pricing law (2014). This latter law could have invited more differences between IWT-countries but is still not implemented. The Dutch support of possible freezing of loans of vessel owners also differentiates policy between the IWT countries.

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, are not filled by 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.

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

6. Pan-European Inland Navigation Policy

Based on the conducted 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, it is clear that the PEINP can be described as follows:
"a multilayered multileveled governance model with growing actor interdependencies and legal scope aiming at levelling the playing field for the IWT in accordance with high safety, environmental, social, legal and technical standards."

This definition is not always accurate and also 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.

Challenges remain in the DNA of the existing institutions which tend to look for ways to survive or to reinforce their own competences. As one regime for technical and crew requirements is becoming a legal fact, the functioning of CESNI still relies on a multi-annual financing arrangement between the CCNR and the European Commission.

A more thorough, in-depth comparison between different transport policies in Europe could show more evidence of the significance of the complexity of the institutional framework of the PEINP. This requires further research and a more multimodal approach, literature and scope.

7. Costs and benefits of PEINP

The complex institutional setting could add to lobby costs and compliance costs of innovators or manufacturers which have to comply with several regimes to achieve more critical consumer mass (external compliance costs). Derogations and subsidies also can have an impact on the business case. Both are tested during the policy analyses of the automated vessel and LNG. It is not the intention to repeat a SCBA during the policy analysis, but rather to identify the costs of PEINP within the innovation case. When it is possible, the impact can be measured on the business case as developed during the SCBA of the case analysis.

In analysing the different policy levels needed to have a successful innovation policy, the political analysis focuses on enforcement, compliance costs and in case of asymmetrical information also on the information costs. These costs are transaction costs that are considered vital for a successful outcome of policy.

First, all policy costs are identified where possible, before a selection of costs can be made to focus on in the analysis. The mentioned policy costs and benefits can help in identifying the optimal level of policy, which has the best CBA net result. In different policy scenarios, benefits and costs differ from each other, especially when multiple policy levels are involved to address the same topic.

Policy institutions use factors from the economy which implies an opportunity cost on society's welfare. The factors (e.g. money, expertise or time) needed to establish a certain policy are not being used for others. The costs and benefits can be observed and identified at all policy levels but also in accordance with the phases of the policy cycle (Table 9). These costs are called the total internal policy costs in this research and are allocated in the public budgets. The choice to allocate budgets, is a political one and lays outside of the scope of this research.

Most of the mentioned costs in Table 9 are considered as less important in this research for the outcome of a policy or the impact of the PEINP on innovation. Administration, translation, publicity, employment, housing and transport costs are typical overhead costs which can be found in every institution and company. All costs are identified under the assumption that the policy actor conducts all cost related tasks, which is not always the case and is hypothetical.

Evaluation costs are not mentioned separately but can be located in every phase of the policy cycle. Most evaluation costs are included in the information costs.
Enforcement costs depend on monitoring costs of the policy. If monitoring shows that operators refuse to comply with new regulation, enforcement could be needed: by juridical procedures, fines, inspections, costs the policy maker and thus society. During the outcome phase of policy, enforcement costs have to be made. Also during other phases, enforcement costs can be identified.

Institutions without means or legal basis to enforce policy, have a weaker impact in the policy cycle, which also can lead to government failure. Policy makers in such an institutional setting have to comply internally with other legislation from policy levels according to the precedence principle. In a multileveled and multilayered governance model, it is not uncommon that institutions meet each other in courts[20].

The higher the complexity of the institutional setting, the higher the internal compliance costs of policy. These costs are included, normally, in the budget of administrations and other regulation sources.

From a policy management and public budget point of view, the total internal policy costs are relevant and give more insight into the internal efficiency of the organization related to management and accounting literature as lean-management or ABC accounting, but they will not be used in this research for studying the institutional setting of PEINP. Nevertheless, these internal policy costs remain elementary for policy success. Lacking an efficient organizational overhead can weaken every phase in the policy cycle, especially in times of budget restraints and cuts causing external policy costs.

[20] E.g. an EU-Member State does not want to implement a new European directive, and therefore to comply with a contract, the Court of Justice will be the next meeting place.

<table>
<tr><th></th><th>Input: demands and support, defining an issue</th><th>Agenda/selection of issues</th><th>Decision</th><th>Implementation</th><th>Outcome/evaluation/ feedback</th></tr>
<tr><td colspan="6">Costs</td></tr>
<tr><td>Information costs</td><td>Expert meetings, conferences, interest groups activities, research (academic and consultancy)

Higher if asymmetrical information</td><td>Research support for deliberation,

Nautical, technical economic and juridical advice,

Budget information,

Suggested solutions</td><td>Information for meetings of officials

Choosing the "right solution"</td><td>Information about implementation</td><td>Surveys,

Effect analyses,

Monitoring policy,

Information for evaluation purposes</td></tr>
<tr><td>Administrative costs</td><td>Secretary work

Organizing meetings

Reports and preparation of meetings</td><td>Secretary work

Listing the alternatives

Reports and preparation of meetings</td><td>Organizing meetings

Secretary work

Reports and preparation of meetings</td><td>Communication with and retrieving information from stakeholders</td><td>Gathering statistics,

Organizing meetings

Secretary work

Reports and preparation of meetings</td></tr>
<tr><td>Translation costs</td><td>Reports and preparation of meetings, interpreters</td><td>Agenda, interpreters</td><td>Translating policy papers and decisions, Interpreters</td><td>Translating official documents towards MS</td><td>Translating evaluation activities and documents</td></tr>
<tr><td>Communication costs</td><td>Publishing meeting reports</td><td>Publishing agenda</td><td>Communicating decisions</td><td>Publishing guidelines for implementation</td><td>Evaluation results, reviews</td></tr>
<tr><td>Employment costs</td><td colspan="5">Civil servants, representatives, officials, experts</td></tr>
<tr><td>Housing costs</td><td colspan="5">Meetings and conferences at different locations, hotels</td></tr>
<tr><td>Transport costs</td><td colspan="5">Traveling abroad: signing charters, depositing signatures
Moving official documents and working staff
External costs</td></tr>
<tr><td>Enforcement costs</td><td colspan="5">Demanding statistical data input, transparency
Enforce if necessary and possible by police, courts, fines</td></tr>
<tr><td>Compliance costs (internal)</td><td colspan="5">Consistent with equal legislation
Precedence of legislation
Competences check</td></tr>
<tr><td>Project costs</td><td colspan="5">Investment of the chosen policy/project
(subsidies, infrastructure)</td></tr>
<tr><td>Opportunity costs</td><td colspan="5">Use of scarce government means for policy development and implementation and not the alternative</td></tr>
<tr><td colspan="6">Benefits</td></tr>
<tr><td>Quality benefits</td><td colspan="3">Valid information and knowledge, reducing asymmetrical information problem
Learning curve through pool of experts and consultation; private and public stakeholders</td><td colspan="2">Scope of implementation influences the benefit
Evaluation capacity
Learning curve
Output of insight and information to market
Credibility of policy</td></tr>
<tr><td>Synergy benefits</td><td colspan="5">Bringing experts regularly together can cause sustainable synergies in research and other inputs
Exchange of best practices between MS</td></tr>
<tr><td>Social benefits</td><td colspan="3">If changes already occur in expectation of the developed policy, this can already can give social benefits.</td><td colspan="2">Redistribution of welfare, infrastructure, health and environment, Safety,…etc.</td></tr>
</table>

Table 9: Policy costs and benefits in a policy cycle
Source: own creation and policy cycle literature (Crabb et al. 2012; Lasswell, 1956)

7.1. Policy costs

Policy costs are in this research, costs that are created by policy but are not paid by the government or policy makers, nor by taxes. These costs are paid by certain groups, individuals or the society as a whole because of the result of regulation. The economic transaction cost theory literature (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. 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. Adverse selection can be observed when mostly ill people would buy a health insurance, causing the premium to increase, 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. Another example is the scandal of some car manufacturers that succeeded to misguide official inspections and emission tests. In the latter example, it is both an "internal" policy cost (better inspections, other regulations) and an "external" policy cost (when policy gathers wrong or insufficient information to create policy) that increase costs for society beyond the initial intention which was expressed by the contract parties (manufacturers and government).

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.

C. Private compliance costs

Compliance costs, as mentioned before, have a public and private dimension. From an innovator point of view, compliance means that the new 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 expressed by professionalized lobby groups.

An innovator is also 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 the certain point of the innovation development, talking to the government can be unavoidable.

D. Transitional social 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 adapt early on to expected regulation or subsidies, start the change before policy implementation. The market can even be disturbed by policy without policy implementation. In some cases, this is intentional and part of the policy strategy, but often not all possible impacts of policy are taken in account. Sometimes, it is choice of political decision makers to ignore certain possible impacts.

E. Other private policy costs

Other private policy costs concern the indirect effects of a policy on innovation. Policy that provides inadequate outdated standards or other failed policy, causes external costs. Innovators could choose other markets to explore and take their potential benefits with them. Market-disturbing subsidies could disadvantage operators that are already on the market (also transitional social costs). Adverse selection of a certain innovation by enforcing the innovation through regulation, can indirectly eliminate any incentive for other perhaps even better alternatives[21]. These costs are considered to be mostly captured by losses in producer and consumer welfare and are not to be double-counted in the analysis.

7.2. Policy benefits

The identified benefits in Table 9 relate to policy quality and synergy next to the more outspoken social benefits. The main targets of a policy are policy benefits. It is the inherent goal of the policy cycle outcome to change or improve society without revenue driven incentives. The main targets of policy are not benefits such as a high revenue on a project or on other state investment. This distinction between revenue-driven and societal rationales behind a policy is not always clear in practice and could both result from a political choice. Synergy benefits can be identified in the policy cycle, but they can also be caused outside the cycle. These benefits are called policy benefits and do not only include social benefits for the good of the society but also includes benefits for the institution or even the individual actors within the institutions.

Not all benefits can be quantified because of lack of data. Some benefits could be considered negligible and omitted in the analysis. The causality between a given policy and observed social change or other targeted benefits, is not always clear and sometimes difficult to prove.

A. Synergy benefit

Bringing experts, stakeholders and policy makers together in a governance 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 governance model is not only a multidimensional and multilayered meeting room between public and private players focusing on an issue inside the policy cycle but it often gives opportunity to participants to build sustainable relationships and to learn from each other. Next to spin-off ideas for new innovation, collaboration between policy and private actors or between private actors and between policy actors can create new synergies.

B. Quality benefits

Another benefit is policy quality. 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

[21] 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 at 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.

not sufficient to improve quality. The degree of professionalization and specialization, and the accessibility of the arena by others and new voices are vital to improve quality of policy. An institution or organization that does not have a dynamic and transparent network could weaken the policy outcome. Size is not everything and defining or measuring policy quality is very challenging and often dependent on politics rather than science. The accessibility of relevant stakeholders during all phases of the policy cycle can also improve policy.

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. A lack of accessibility is an external cost, but when sufficient accessibility is granted for innovators, users, stakeholders, there is a benefit that can go further than the institutional setting and improve quality of the innovation. Policy can require homologation tests of the innovation (e.g. LNG engines, automated devices) and provide a derogation period where the innovator is allowed to derogate from existing rules under permission while complying to a comparable or improved safety level. Both of these 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 as such in order to improve the innovation.

C. Measuring policy benefits and willingness-to-pay

Policy benefits are heavily discussed in literature and comprise a number of direct and indirect benefits. In this paragraph only some of them are highlighted. Improving the infrastructure can benefit the inland waterways, but also benefits society as a whole. Infrastructure improvement could increase the fleet efficiency to ship more freight and to attract more volumes from heavily congested modes with higher social costs such as road haulage.

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. But 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 arena's to get a topic on the political agenda.

7.3. Policy costs and benefits according to level

Different levels or institutions in the multileveled governance model of pan-European IWT are described and summarized in Table 10 in perspective of their transaction costs and benefits.

Institutions \ C-B	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 centers, infrastructure, knowledge center, 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, weaker for other initiatives.

Table 10: Costs and benefits of multileveled PEINP

Caution is needed in interpreting the theoretical findings of Table 10. 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 these institutions are important as they add up to a real PEINP. But these relations can be ad hoc and more sustainable in other cases. Between the institutions there is also a competition of best practices. Between ports, regional and national governments and even between MS and between European institutions, actors find themselves sometimes in competition to develop the best policy or merely to survive (institutionally) by continuous attempts to prevail their relevance.

7.4. Beneficiaries and losers

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. Policy makers can be innovators by implementing new systems. In both cases, 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.

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 claimed to be introduced by the innovation. Society has social benefits or a reduction in 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, although there are social and private benefits, certain groups or individuals could lose. 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 a successful innovation.

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 a particular industrial equipment or process mandatory. The last two types are technology forcing while the first one is inducing innovation on the market. Technology forcing policy has the potential to constrain the available technological choices and may remove incentives to improve or to develop new technologies. All of these policy instruments will possibly have losers and beneficiaries.

8. Policy tools

Policy makers can use several economic intervention tools to introduce or stimulate an innovation on the IWT market whereby vessel owners are the consumers and the innovator the producer (e.g. engine manufacturer or a service provider). These intervention tools can be subsidies, enforcement by regulation and/or taxes. The introduction of these tools can cause changes at the supply and/or demand side. The size of these changes depends on the market structure and price elasticities[1].

There are two perspectives that should be explained in case of policy support for IWT innovation. The first perspective is from the position of the innovation producer. Subsidies given to the innovation producer can lower the prices of the innovation on the market, which could stimulate market uptake. A second perspective is from the consumer of the innovation. Consumers can receive subsidies or even be forced by regulation to buy the innovation. Both parties can also receive subsidies in order to support market uptake of the innovation.

Subsidies for the innovator lead to an increase of supply of the innovation, which will have an impact on the market price of the policy-supported innovation. The innovation becomes relatively cheaper for the consumer.

Making the innovation compulsory through regulation also has an impact on the market price of the innovation product or on consumers' behaviour. In case of an IWT innovation that has social benefits (not only private ones), but with relatively too many barriers that prevent innovation diffusion, it could be the case that policy decides to enforce the innovation by making it compulsory through standards or regulation. The demand increases from the perspective of the consumer because all vessel owners are forced by regulation to buy the innovation. If the innovation is produced by a single private producer (monopoly), this policy tool will lead to welfare loss and would not be advisory. If prices become too high for vessel owners to comply with the new standards, policy can also choose to stimulate the supply side by opening up the market for new manufacturers or competing innovators.

The technological neutrality concept within standards allows more innovations to compete and reduces the possibility that other innovators lose the incentive to develop improved innovation initiatives. If policy chooses to support one specified alternative fuel or enforce it on the fleet, the incentive to develop other, possibly improved fuels, will also be reduced. Too much neutrality could jeopardize the policy targets.

Another policy instrument is levying a tax on an innovation. If an innovation is considered negative for society but has benefits from an industrial-economic perspective, policy could decide to levy taxes to prevent too much diffusion or to slow down the innovation implementation. If an innovation has social benefits, but has difficulties to compete or to enter the market, policy could decide to tax the competition. In case of the alternative fuels, policy could tax conventional fuels in order to support the diffusion of LNG, electrical, hydrogen or other more socially preferred fuels. This is also the case on a transport mode level. Taxing road haulage could perhaps favor a modal shift. If policy would increase prices of traditional fuels by taxes, this could lead to a shift of consumer demand towards other substitutes.

Not all identified policy actors and levels are able to apply all three of the mentioned policy tools. The European Union is not entitled to levy taxes and can only apply the first two tools. The CCNR can only enforce regulation through standards, as does the UNECE with the ADN. The MS are limited in subsidies according to the European rules of the internal market. In the case of IWT, taxes are also not allowed on the Rhine because of clear violation of the Mannheim Convention, which advocates freedom of navigation and forbids riparian states to ask tolls. In any case, even if a coherent and integrated policy approach would make use of all three tools to stimulate an innovation, policy makers should be aware of the possible changes they could cause on the market and investigate if the benefits are higher than the market disturbance. A fragmented policy setting could take more time to implement an innovation stimulating policy and in case of innovation, this could in a worst case scenario even prevent market uptake and lead to social welfare losses. In a rapidly changing market, a complex fragmented policy could respond later than a simplified, more transparent and less fragmented policy.

9. Multilevel Governance

Identifying the relevant policy levels for PEINP while explaining parts of the transaction cost theory is not sufficient to fully understand the multilevel governance model. The approach is broader than only the IWT competence or its policy costs. Other competences such as environmental policy or other transport policy compete in gaining attention on the political agenda or in other phases of the policy cycle. Implementation of a policy in a different field than IWT can have indirect effects on IWT (e.g. giving subsidies for freight transport by railway and perhaps undeliberate diverting freight from IWT).

The schematic overview of IWT policy as shown by Figure 6 (*Institutional actors of the Pan-European IWT policy framework*) reveals a complex multilevel, multidimensional and multilayered governance model. “Multilevel” refers to all mentioned levels and their interdependent relations. Multilayer 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 arena’s at 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 lays 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 governance

All of these dimensions demonstrate multi-actor interactions between institutions and can be identified in all levels and layers of policy[22].

Another dimension which is not mentioned yet is the role of the media. In popular media there is hardly any IWT coverage, but professional media (e.g. Scheepvaartkrant, Binnenvaartkrant, Schuttevaer, Flows) can have an influence on the IWT policy. Most relevant policy and private actors have access to these media and organize internally daily news overviews. Usage of the professional media can be an important tool to address relevant customers for the innovator and to address the relevant policy actors to gain support.

Legal structures, regulatory processes, and the nature of the IWT sector (including industry) together frame the interconnections in the multilevel governance model. The technical nature of some innovation initiatives in IWT, especially coming from the private sector, add to the complexity of the public-private dynamics in every layer, dimension and level of policy. In most cases, the innovator maintains an important position in the governance model having the most knowledge of the given innovation which can cause the problem of asymmetric information. If the latter mentioned problem is solved in one 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.

[22] an interesting paper highlighting the 5 core dimensions in a clear manor is Osofsky, Hari M. (2011), Multidimensional governance and the bp Deepwater horizon oil spill (February 12, 2011). Florida law review, vol. 63, 2011; Minnesota legal studies research paper 11-17

The quality and sustainability, certainty and transparency of the interdependent relations inside the governance model could be necessary filters to minimize asymmetric information and therefore lowering the related transaction costs. As already mentioned, the problem of asymmetric information is not necessarily to the advantage of a firm or private innovator. Policy actors can also have more information when they bargain deals or other interactions between actors.

Inside the complexity of a multilevel governance model, the innovator tries to seek a window of opportunity to get support. The views of all relevant actors in all facets of the multilevel governance model should support the innovation to avoid innovation failure. Depending on timing, means, framing and agenda-setting and in every phase of the policy process, this window should remain open. This could be a rather delicate process that includes patience, endurance, diplomacy, means and insight of the lobbyist or innovator to influence policy.

It is impossible to measure or analyse all of the mentioned interactions in all areas of the governance model of IWT in this research. The focus of this chapter lies on the most optimal way to conduct an IWT policy. This chapter gave an overview of the existing institutional setting in the Pan-European Inland Navigation Policy with examples where possible.

10. Conclusion

The reality of the existing institutional setting reflects a complicated multilevel governance model where inter-institutional coordination and mutual recognition and other principles are gaining importance.

In innovation, different policy levels or institutions can take the lead, supported by their network, in removing regulatory bottlenecks within their competences. However, there is not one single level or organization that is competent for all bottlenecks. For example, the UNECE can decide to adjust the ADN agreement for dangerous goods and allow innovation but does not have other instruments to support innovation. The river commissions also depend on MS and in some cases ports to adjust or to build new infrastructure. The European Commission and the MS have most of the economic competences to give subsidies and in the case of MS or national governments to tax or to fiscally stimulate innovation. The regional and port authorities are able, not necessarily together with other levels or institutions, to take the lead in innovation projects in IWT. In the development of a masterplan for alternative fuels or as a partner in innovation projects (e.g. autonomous vessels, small waterway barge convoy), port authorities, provincial and regional governments can thus play an important role together or separately. But even if a coherent and integrated policy approach would make usage of all available policy tools to stimulate an innovation, policy makers should be aware of the possible disturbance on the market and investigate if the benefits are higher than the market disturbance. This fragmented policy setting takes more time to implement an innovation policy, which could in a worst case scenario even prevent market uptake of an innovation and social welfare losses. Because of explained historical, structural and institutionalist reasons, this fragmented policy setting, only shows incremental changes towards more institutional efficiency such as the creation of CESNI and other more structural cooperation between policy levels.

Sufficient reliable knowledge from the market could reduce information asymmetry and allow estimating the potential welfare loss. Especially, when policy decides to implement taxes, subsidies or enforcing standards, sufficient knowledge is needed. As shown, these tools are divided amongst the identified policy levels and need sufficient coordination in order to have an integrated policy which could benefit the IWT. The role of private actors such as the branch organizations and verification

agencies, are perhaps crucial to provide sufficient knowledge, but it is up to policy makers to implement a coherent and consistent policy in a realistic and transparent time frame.
This chapter explained the background of the institutional setting of the IWT in Europe and supports the policy analysis as applied on the innovation cases concerning automated vessels and the usage of alternative fuels within this research. It also supports the understanding of the regulatory failure factors as identified by the SIA.

The following chapters go further in each selected cases. In the first three cases concerning the small waterways and e-Bargebooking only the SIA is applied. For the case of the automated vessel and the LNG implementation, more cross-border externalities were identified which could make an European policy analysis more useful. An SCBA delivers more insight in the innovation and is applied in the latter two cases.

IV. e-Bargebooking

The used term *e-bargebooking* covers both chartering of a vessel by an online platform (*4Shipping*) with virtual brokerage and by the online market place without virtual brokerage (e.g. *Bargelink*). The differences between these types are defined together with the conventional broker who is still dominating the market. Depending on the available data and limited literature, it is also described in this analysis how the innovation emerged.

1. Definitions

This part identifies a number of concepts in relation to the case that are vital to explain in order to understand the rest of the analysis.

1.1. Conventional broker

The conventional or traditional way to charter vessels is through a rather relative complex system of intermediaries between the customer (sender of goods) and the vessel owner / operator (VO/O). One of these intermediaries is the broker. This actor usually has several ships under contract. The broker looks for vessels on the market that are able to transport a volume of freight from a customer or a sender from origin to destination. The rationale behind this process is that the broker is more available and accessible towards customers and can offer more flexibility and critical mass of vessel volume than one or two single vessels or VO/O's. From a shore office, the broker allocates the available volumes according to the 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 broker and offered a freight rate. This freight rate is based on the negotiated price between the broker and the customer and includes a brokers' provision that in most cases lays between 5 or 10 percentage of the freight rate (in Belgium maximum 10%). If the VO/O does not agree with the price, the freight will go to the next vessel that is linked to the broker. If no other vessel is available (usually not the case), prices have to be renegotiated or the customer addresses another broker. The system is not always transparent and the VO/O, in some cases, does not know what is the full price of the transport paid by the customer's charterer.

Figure 7 shows the market between charterer (shipper) and broker (agent), and the market between broker and VO/O (ship owner). The primary market is where a price (p) is negotiated between approximately 50 independent brokers and more than 200 charterers or shippers. The secondary market is where the VO/O negotiates a price (p') with the broker that also implies a brokers' provision (van Hassel, 2013).

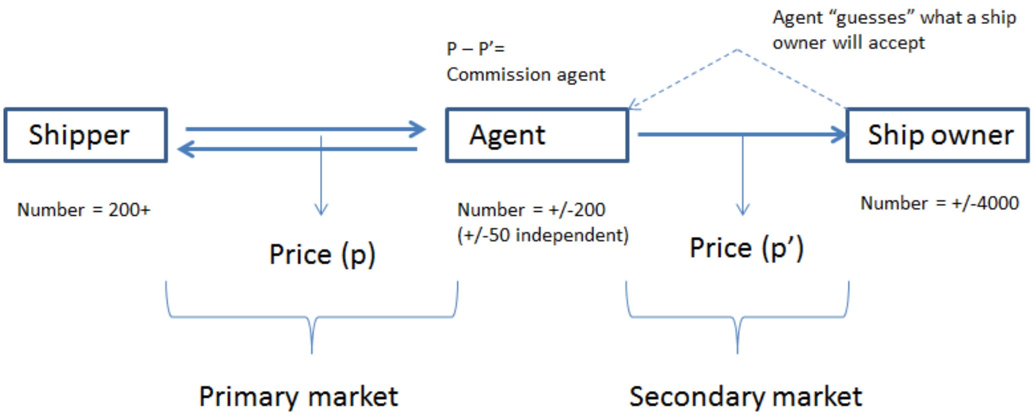

Figure 7: Two separate markets in the dry bulk segment of the inland navigation
Source: Based on van Dijk et al. (2012) and modified by van Hassel (2013:11)

The relation between a contracted VO/O and a broker can be quite ambiguous. There are relatively big brokers with some market power in several segments of the sector which could offer more service to VO/O than small ones. The degree of flexibility (changing from contracts), transparency (provision disclosed or not), the number of offered trips, freight rates and extra services differ between brokers, and influence the choice of the VO/O to prefer a certain charterer. In times of high demand and low supply, the VO/O has more bargaining power than the charterer. In times of low demand and high supply, the broker has more power. A broker can be a business partner of the VO/O or even a co-investor in a new vessel. Sometimes, in times of liquidity problems of the VO/O, the broker can offer relatively cheap credit, which will help the VO/O in the short run but will make the VO/O more dependent of the broker. The personal relationship between the VO/O and the broker 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 broker: frequently too late delivery of freight by the VO/O, 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/O: undisclosed provision of the broker 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.[23]

The ambiguous relationship between brokers and VO/O's is one of the reasons why the *European Barge Union* (representing brokers) and the *European Shippers Organisation* (representing VO/O's) took a very long time to cooperate with each other as representatives of the sector with common goals towards European policy makers and others.

Next to the market of contractual VO/O's lies the spot market. In this market segment, especially when dealing with dry bulk and project cargo, the VO/O tries to work without fixed time contracts with brokers or charterers. In times of relatively high rates, the margins make it interesting 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 of this market are more exposed to volatility than when they are operating under a fixed contract. The possibility to navigate truly independently is for most participating VO/O's the main driver to be active on the spot market despite the risks.

According to a survey in the framework of Platina II[24] in 2014, an average of 60% of VO/O's active in dry bulk was free from broker and active on the spot market. A possible reason for this relatively high share is that there are, because of overcapacity, almost always enough available ships to charter. This makes it less necessary for charterers and brokers to conclude long-term contracts with VO/O's to guarantee sufficient transport capacity.

Figure 8 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 relative high, the spot market becomes more interesting, if prices are relatively low, fixed contracts are more interesting.

[23] Demurrage and detention (D&D) can occur when the loading and unloading times are not respected and the VO/O did not cause this. The damage that the VO/O endures 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 if the charterer has sufficient incentives to pursue proper payments from the customer to cover within an acceptable period of time the D&D of the VO/O.

[24] 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. More information at http://www.inlandnavigation.eu/news/policy/platina-2-has-ended/ and https://ec.europa.eu/transport/modes/inland/promotion/naiades2_en

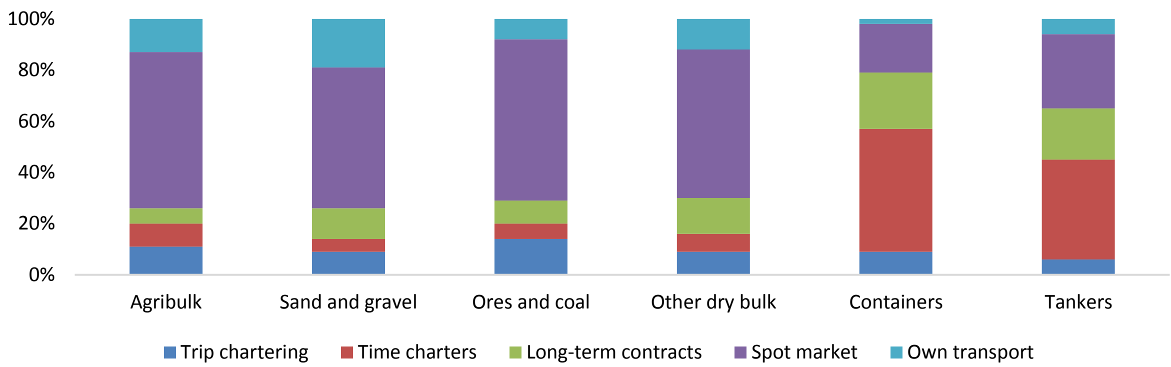

Figure 8: Operating mode for inland shipping dry cargo companies in Rhine countries and Belgium
Source: Platina II (2014) as cited in and based on 391 respondents

1.2. e-Booking

In the past, several attempts were made to digitalize the process of booking or chartering a vessel and to replace or to support the intermediary function of the broker. In other sectors, such as travel agencies, the emergence of platforms such a *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 economy[25] and the innovative tools in IWT is not completely accurate[26].

In the maritime sector, several online platforms emerged the past few years, such as *vesselbot.com* which brings vessel charterers and vessel owners together[27]. 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 also 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, route freight rate indications, negotiation facilitation, charterer party terms. It also posts fixed operations for both charterers and VO's[28]. 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 offer e-booking through their websites (e.g. Evergreen).

In IWT sector, only *4Shipping, Bargelink* and the *Imperial Freight Management System*[29] were identified for the Rhine countries, Belgium and Luxembourg. An attempt of the broker company Transito, with the digital platform *Shipport.eu* in 2012 failed, as did other older attempts. Table 11 gives an overview of identified chartering tools.

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[25] "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 in Zadnik, 2017:7)

[26] Booking.com also rents hotel capacity and resells it. Uber and Airbnb compete with the taxi and hotel industry but operates often without complying to taxi and hotel taxes or other administrative requirements (although, this has changed in a number of countries the recent years). More differences with e-bargebooking lay outside of this research.

[27] Vesselbot (2018), company's website on https://www.vesselbot.com, Athens, Greece, Rotterdam, Netherlands

[28] More information on https://www.vesselbot.com

[29] More information on https://ifms.imperial.systems/#/login/ and on http://www.binnenvaartkrant.nl/wp-content/uploads/2016/01/krant_201615-krant.pdf

Online chartering tool	IWT	Maritime
Market place	*Bargelink*	*BTS Coasting, Vesselbot,*
Digital brokers	*4Shipping*	*ShipmentLink* (Evergreen), *Axsmarine* (BRS Groupe), *Opensea.pro*

Table 11: Overview of identified online chartering tools
Creation: own creation based on companies 'website (non-exhaustive)

Bargelink is a virtual market place for the European IWT where brokers, charterers, VO/O's 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 VO/O's and EUR 55 for brokers. *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 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 are also generated inside the system, after the charterer and the VO/O agree on a price for the transport service.

2. Systems of Innovation Analysis

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 here is a potential market-disrupting innovation that could weaken the dominant position of conventional brokers, especially small ones, at start in the spot market and in the longer run perhaps in the entire market. The innovation in this case is both technological and organizational. This newly developed online application for customers and service suppliers gives an additional marketing instrument next to more conventional ways and has a potential organizational impact on the market by disrupting the conventional brokers.

The results are obtained from interviews with the innovator and an expert panel. The innovation is already implemented and can be considered, with more than 1,400 registered application users, as relatively significant and successful after two years of operation. Knowing from former failed digital booking platforms, trust seems to be an important driver behind the relative success.

2.1. Current situation

The process of chartering a vessel has quite archaic components. Freights and negotiations are mainly through telephone and not that long ago through on-board fax machines. There was hardly any digitalization with the exception of a confirming email from the brokers dispatch without much legal value. Until several attempts were made, mainly from brokers, 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. Most of those initiatives failed. Only two initiatives were identified in this research so far as being relatively successful, *Bargelink* and *4Shipping*.

Bargelink is an online platform that is more some kind of digital market. Customers can meet VO/O's and their available volume, but brokers are also active on the platform. *Bargelink* only brings potential partners together but does not play an active role in negotiations between the market players.

4Shipping is a charterer tool developed by a VO/O and replaces the role of the charterer. Freight rates are negotiated through the platform between VO/O and customer 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.

But despite this, more than 1,400 market players are already registered in the system (since the interview with the innovator in 2018). The main focus lies on the spot market and main competitors are small brokers without additional services. 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[30] and the national regulations on chartering.

2.2. Initiation period

According to a study of the former *Promotiebureau Binnenvaart Vlaanderen* (PBV, 2015) which studied the use of ICT on board between 2005 and 2015, approximately 98% of the responding VO/O's (n=175 VO/O's) 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 vessels responded to have internet on board, the number has risen drastically, although complaints still exist concerning full data coverage.

Dullaert et al. (2005) identified a number of digital innovations with the focus on bringing supply and demand together. In 1998, publisher Wolters Kluwer started with Teleship[31], following the example of Teleroute for road haulage (the latter is still operational for road since 1985). The web-based intranet offered supply and demand system for the inland navigation. The innovation failed within two years. Hardly any VO/O's, 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 VO/O's. Coming from the very popular Dutch IWT internet forum at the end of the nineties and beginning of this century Vaart.nl[32], the VAART-VRACHT was created and also failed.

Another failed attempt was BIVAS (Binnenvaart Intelligent Vraag en Aanbod Systeem) which was an INDRIS project[33] from the Flemish government. The latter public-driven innovation failed despite special training courses for VO/O's for working with these telematics. All of these developments came at the eve of the upcoming liberalization of the 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 were the lack of intelligent components and 'real-time' decision support; a lack of actors that are willing to share confidential business data; no standardization and harmonization of systems and data exchange, the lack of trust at the side of the VO/O's and the need for 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:

- Some required subscription fee while internet cost were already considered high, especially when passing the border on the internal market;
- Not even half of the VO/O's had internet on board during this period;
- Coverage of the network was low and GPRS was not everywhere available;
- Communication costs were relatively high;

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[30] *Convention de Budapest relative au contrat de transport de marchandises en navigation intérieure* of 22th June 2001. The CMNI entered into force on 1 April 2005 and is applied on all inland navigation contracts whereby unloading and loading takes place in two different treaty states where at least one treaty state is a party to this convention.

[31] More information can be found on https://www.nieuwsbladtransport.nl/archief/1997/11/22/teleship-volgend-jaar-van-start/, https://www.agconnect.nl/artikel/binnenvaart-mist-kansen-zonder-it

[32] 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.

[33] INDRAS, Inland Navigation Demonstrator for River Information Services. European 4th RTD Framework Program, between 1998 and 2000, final report (ten Broeke, A., 2001)

- Incompatibility with other existing systems;
- Cultural: privacy-aspects in the exchange of confidential data with government.

Despite these failures, Bargelink succeeded to survive since its beginning in 2001. 4Shipping, which goes a step further and provides online broker services, came later in 2016 and seems to be relatively successful so far.

In the initiation phase the needed infrastructure was not sufficiently available on the side of VO/O's, of which only half was reported to have a personal computer and internet connection on board (Table 12). 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 favor 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 do not find sufficient loading capacity on these platforms.

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

Table 12: System of innovation matrix in the initiation phase of e-bargebooking
Source: own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

2.3. Development period

During the development of *4Shipping* and *Bargelink*, the digital infrastructure improved drastically since the initiation of the *e-bargebooking* systems. With the further enrolment of the 3G network and the upcoming of the 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 European roaming policy gave incentives to the entire economy and certainly inland navigation. Better systems, more compatibility, faster and bigger data sharing, attractive interfaces and easy to use applications, give more fertile ground for market uptake of the innovations such as transport booking platforms.

After the failed attempts at the end of nineties, a new attempt was made by *4Shipping*.com, who went a step further than *Bargelink,* and tried to digitize the core business of the intermediary broker. Since 2016, two sons of VO/O's developed the software (SWIS) and the company. The mentioning of the family linkage on the website and frequent reference in their sales pitch (e.g. during their presentation in the CCNR Economic Committee, 2017), is not irrelevant. 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 automatically generate the needed documents.

Earlier attempts, better 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 new attempts to digitalize the business.

The infrastructure with more VO/O's that are equipped with at least basic ICT, the further uptake and improvement of several river information systems which can be considered as an incentive for VO/O's to buy ICT equipment, the RIS guidelines, directives and standards, are identified as success factors during the development period (Table 13). During this development period, the economic crisis of 2008 had a negative effect on the IWT market and also reduced the number of cargo for the spot market and thus freight customers for conventional and developing online tools. Capability is therefore considered as a failure factor. Sector organizations and others organize training sessions for the use of computers. The funding for RIS research and projects continues during this period (especially European funding) with some important events such as the PIANC guidelines and the update with the river commissions, the RIS Framework Directive of the European Union (2005/44/EC). Roaming costs are still relatively high.

Network effects are monitored because of the low interest of container and tanker fleet. Mostly the dry bulk spot market which has a weaker network with existing conventional brokers is the main target. The tanker fleet seems too strongly linked with conventional brokers.

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

Table 13: System of innovation matrix in the development phase of e-bargebooking
Source: own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

2.4. Implementation period

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 company *4Shipping* reported more than 1400 vessels registered. The strategy to demand 1% provision seems to be fruitful. The company reported some resistance from especially small brokers who feel threatened. The main target for *4Shipping* is the spot market of dry bulk. Operators who use this system, usually do this as additional service above conventional ways of business. This shows that the digital broker has not reached enough critical mass of sufficient supply and demand yet to become the sole broker for a vessel. But as *4Shipping* experiences market uptake, the conventional broker systems could be significantly disrupted. The applications and databases are kept confidential and are only visible for registered users, which corresponds with the vital target of building trustful relationships with a closed market structure which is unlikely to give confidential business data that easy.

Most failure factors are considered to be removed (Table 14), 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.

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

Table 14: System of innovation matrix in the implementation phase of e-bargebooking
Source: : own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

2.5. Initial conclusions

Afterseveral failed attempts around the beginning of this century, *Bargelink* emerged as a digital platform where supply and demand meet each other together with brokers. The *4Shipping* platform goes a step further and offers a basic broker service.

Of course, not all tasks of brokers can be replaced by an internet service (yet). As mentioned, mostly relatively big brokers have more added value on their basic service of chartering a vessel. Often they provide loans, co-investments, administration and compliance support to VO/O's. Trust, genuine link and accessible and affordable sufficient infrastructure on board and on shore, low admission costs, 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 success elements. The factors as mentioned in the SIA matrices are more detailed analysed in the following paragraphs.

2.6. Detailed analysis

Bargelink and *4Shipping* have comparable objectives and already brought online business on board of a growing number of inland navigation vessels. However, these innovations still face potential failure factors that could possibly prevent further market uptake.

A. Infrastructural conditions

A main concern is the safety and quality of the digital infrastructure and of the confidential data inside the system. Data breaches can scare new and old users to work with such applications. The lack of safety and privacy is a factor that damages trust and could even lead the innovation towards failure.

One of the elements that led to failure of comparable e-bargebooking systems at the beginning of the century, was the lack of sufficient digital infrastructures. At the end of 1998, less than half of the VO/O's had internet on board and telemetric advancements were too limited. Connections were slow and network coverage was weak. Prices for wireless data (second generation GSM/GPRS/EDGE and

WAP technology[34]) 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, VO/O's carried and used several SIM cards of German, Dutch, French and Belgian operators to lower these costs.

B. Institutional conditions

There is no supranational framework for this type of business in the European inland navigation. The relationship between brokers and VO/O's is still mostly regulated at national level and is based on a conventional freight broker with paper documents.[35] The differences between national regulations concerning chartering are solved by the binding nature of the State flag where the contract is made. However, an international digital application such as *e-bargebooking,* can pose practical concerns to identify the genuine link of the contract to the State. Furthermore, policy makers should work along digital experts to guarantee the safety and reliability of the information exchange.

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/O 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 also to sign the transport document. The CMNI does not rule out electronic signatures as long as the procedure is not in conflict with the national regulation of the State where the transport document is published. A bill of lading[36] 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 (2000/31/EC)[37] that required MS to consider electronic documents or contracts as equal with paper ones. But according to Gobel (2015:27), not all courts seem to accept an electronic bill of lading for maritime transport. Also 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.

As the CMNI is still rather easily avoided if agreed on by contract parties (Kroos, 2011), national regulation still 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 could facilitate the further development of *e-bargebooking* 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. More forgeries are possible next to data security issues that could allow hackers to change digital documents. This uncertainty makes VO/O's and customers still to prefer paper documents, which makes a full digital application without paper prints not yet possible, but which is considered in the interviews

[34] 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.

[35] For Belgium, this is the law of the inland navigation chartering (Wet op de binnenbevrachting/Loi sur l'affrètement fluvial) from 1936.

[36] 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.

[37] 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

merely as a small discomfort in the use of the application. Despite the fact that 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.
Policy should review this at an international level and make it possible, in a digitally safe way, to leave out printing on paper and to facilitate the further digitalization. This is not only to the benefit of the innovator and its customers but also for society.

Resistance of existing brokers was reported by some respondents during the interviews. It can be assumed that brokers could convince VO/O's not to use these platforms. It could be the case that this conservative resistance influences the further implementation of *e-bargebooking*. 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-bargebooking* implementation, is that conventional brokers embrace this technology and develop their own systems (e.g. *Imperial Shipping*) or adapt to the existing ones.

In the case of *e-bargebooking*, it is not always clear if the legal basis is at hand for this kind of collabourative 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.

Booking or chartering a vessel becomes more transparent for customers with *e-bargebooking* and could become efficient (e.g. less provision). Furthermore, in general, the social benefit of a competitive, modern and sustainable inland navigation, lies in the modal shift from less sustainable modes of transport with higher external costs such as congestion, emissions, energy, infrastructure and accidents.

A last identified possible barrier is the possibility of a mandatory and public online auction platform. 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. The Dutch parliament accepted a motion[38] to support the launch of a two-year pilot project for a public auction system for the spot market (AGORA). The Dutch government 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 regulation[39] that does not allow a regulated IWT market.

C. Interaction conditions

Network effects as Shapiro (1999)[40] 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 VO/O's as forwarders) is at a point that the obtained value of the service becomes higher than the actually 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 of the spot market. According to several VO/O's, it is not always easy to switch from a broker to another one. Particularly in the tanker fleet, the system of the European Barge Inspection Scheme requires that the vessel and the conventional broker are regarded as one unit towards charterers. Switching to another broker often means that the vessel needs to be

[38] Motion for parliament, Smaling & Jacobi, 22 Februari 2017, Tweede Kamer, nr. 140
[39] Schultz M.H.(2017), Letter of the Minister of Infrastructure and Environment, Den Haag, 6 June 2017, nr. 158
[40] Carl Shapiro and Hal R. Varian (1999). Information Rules. Harvard Business School Press.

inspected for a new EBIS report, which can take several weeks (FBB, 2013)[41] 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 VO/O's 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 VO/O's in the tanker fleet depend on specialized brokers that divide the compliance and overhead costs on several ships and have more experience with dealing with such big customers. The services or added value of these brokers is not to be underestimated in this segment.

Despite being originally intended for the tanker fleet, *Bargelink* quickly shifted its activities and started focusing on the dry bulk spot market as does *4Shipping*.

D. 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), but also sufficient time and valid incentives to learn to use these kind 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.

E. Market

The in-depth-interviews revealed that most registered VO/O's on the *e-bargebooking* 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 has to deal with the limitations of the spot market and with existing (sometimes long-term) ties between conventional brokers and VO/O's. The ambiguous relationship between VO/O's and brokers is still dominant and as existing brokers also 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 brokers can evolve comparably with the emergence of online booking platforms such as *booking.com* and the travel agencies, whereas most of them did not succeed 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 brokers that offer additional services (such as credit lines, co-investor in VO/O's 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.

[41] 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.

Only in the Western-European fleet a high number of VO/O's are active. In the Danube basin, most vessels are owned by former state companies and these companies are still relatively big in size. The charter system differs between the Danube and the Rhine: whereas brokers 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 bigger companies could be able to build them in the first phase of the development. Smaller companies such as the described VO/O's will find it more difficult to compete. In this scenario, customers could be the ones that build and own these vessels, leaving any *e-bargebooking* application for VO/O's obsolete.

As the supply chain becomes more digitalized (e.g. by block chain technology), applications such as *4Shipping* and *Bargelink* can offer the necessary data to help inland navigation become an optimal component in the future transport block chain, which invites further research 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 broker of the IWT market with even a higher market power over the fleet.

2.7. Conclusion

It is considered to be unavoidable that *e-bargebooking* 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 brokers, 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 first attempts to offer online broker systems came at the eve of the liberalization of the sector, but failed for a number of explained reasons. The failed attempts, private and public driven, offered a knowledge base for later developments. Major events for the IWT such as the liberalization of the sector stimulated the kick-off development of virtual market places and *e-bargebooking*. The enrolment of river information services stimulated VO/O's further to get connected on board and invest in basic ICT. 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 market uptake as shown in *Figure 9*.

Chartering a vessel can become cheaper with the one percent of brokers provision compared with the offered freight rate of conventional brokers. The price difference can attract new customers on the IWT market and can push disruptively conventional dominant market players aside. Another possible scenario is that a race to the bottom of the negotiated freight rate could be stimulated. An additional service of brokers is that they have more experience in negotiating with customers and often have more bargaining power than most VO/O's. A direct contact between VO/O's through an *e-bargebooking* system does not mean that the VO/O 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.

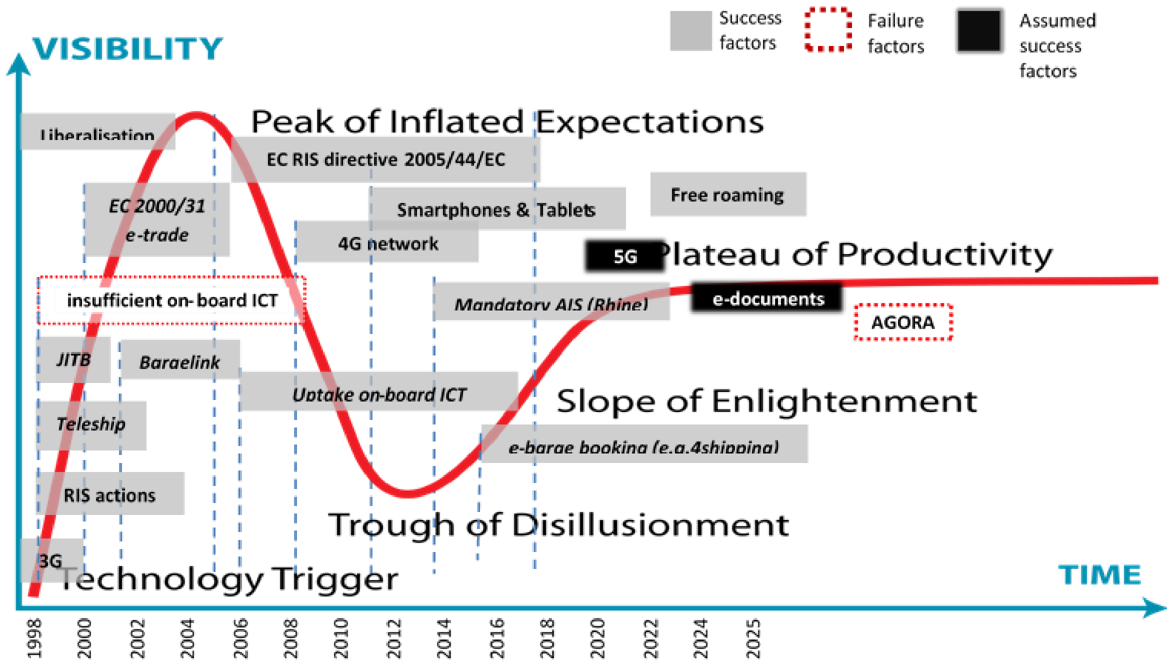


Figure 9: The innovation hype cycle of e-bargebooking
Source: own creation, inspired on methodology of Gartner[42], interviews, expert meetings, *INDRAS* report, history of *RIS*[43]

First, as in the hotel sector with the growing dominance of room booking systems, hotel managers could be dominated by the rate setting of the leading digital platform. The market dominance of conventional brokers can be replaced by the market dominance of a more impersonal system such as a digital platform. And secondly, where travel agencies offer more added value to their original core business, by offering customers solutions for emerging problems during their travelling and other services, the service of brokers can go further than only the core business of chartering a vessel. More complex trips such as project cargo or dangerous goods, could perhaps need a specialized broker while more straightforward cargo (e.g. sand) goes easier with digital solutions. A digital chartering platform will not offer any added services in the short run. The further diversification of the services of brokers will give added value on merely chartering which can easily be replaced by a digital application.

In the short run, conventional brokers could have difficulties in competing with the application and especially with the one percent provision. In the longer run and as the digital application becomes more disruptive and market dominant, with all the gained market knowledge and price evolutions, even bigger brokers that did not adapt on time, could lose market share. Conventional brokers that refuse to adapt to these changes could lose customers because of the cheaper rates and could also lose VO/O's that see more freight and trips coming through these online platforms. Conservative VO/O's that are not interested or not able to pick up this kind of digital innovation can end up without freight and still calling each day their disappearing charterer.

After diving in the online booking of a vessel, the innovative concepts on the small waterways are presented in the next two chapters.

[42] Based on the example of innovation hype cycle of Artificial Intelligence by Gartner inc. https://www.datanami.com/2017/08/29/ai-fares-gartners-latest-hype-cycle/
[43] An historical overview of river information systems is found on http://www.ris.eu/general/what_is_ris_/history

V. The small barge convoy

The small barge convoy concept does not only represent a technological innovation but also brings a business and organizational innovation. Indeed, beyond a small-sized barge convoy including an adjusted pusher, it also brings cost reduction (less required crew in day shift combined with shared overhead benefits thanks to a larger fleet), higher volumes and less fuel use, compared with a single vessel or conventional transport on the small waterway. It is an innovative way to compete against road haulage.

1. Definitions and scope delineation

A small barge convoy consists in the coupling of barges in one convoy which is designed for service on small waterways. A distinction can be made between a pushed convoy and a convoy (Figure 10). 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 I. et al., 2015).

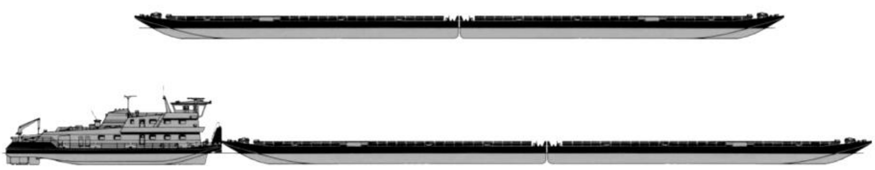


Figure 10: Difference between convoy and pushed convoy
Source: Škiljaica et al., 2015

According to article 1.01 (2.1) ES-TRIN[44], 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 convoy composed of a pusher and a pushed craft coupled so as to permit guided articulation is also considered rigid. 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).

1.1. Push Convoy

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. Figure 11 shows an image of the MS Sprague in operation.

Figure 11: MS Sprague pushing dumb barges
Source: Point Pleasant River Museum, 1930

[44] 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)

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 pusher[45]. Before the introduction of these pushers in Europe, small *opduwers* or *opdrukkers* were used to push or two barges (Martens R. et al., 1977).

One of the unique selling positions of a push convoy service is the feature of decoupling the actual sailing from loading and unloading. The pusher pushes a convoy to a usually fixed destination and decouples. 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.

1.2. Push barges

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.

Figure 12: The first container push convoy in barge-barge configuration
Source: Danser Group

1.3. Small Waterways

The CEMT [46] classification is used to classify 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 in account depth, width, lock size and bridge gauge. 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 (2011). Table 15 shows a basic overview of the classes of vessels according to their dimensions. This classification corresponds with the classification of waterways. A vessel of class III cannot navigate on class I and II but can navigate an all other classes.

[45] More information can be found on https://www.binnenvaart.eu/motorsleepboot/13090-president-herrenschmidt.html and on https://nl.wikipedia.org/wiki/Duwboot
[46] Conférence Européenne des Ministres de Transport

Ship type	Tonnage	Length (m)	Width (m)	Depth (m)	Waterway Class (CEMT)	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 15: Classification of vessels in IWT
Source: Promotie Binnenvaart Vlaanderen, (cited from van Hassel, 2011)

The CEMT classification is needed for designing appropriate equipment for the small waterways. The vessel needs to be able to pass bridges, locks and the fairway in all circumstances (loaded and unloaded). To reach destinations at small waterways of CEMT I and II, the small barge convoy needs to be designed accordingly. Annex 4.2 at the end of this document shows a map of all European navigable waterways according to their dimension.

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 16 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 43,686km).

COUNTRY	I	II	III	IV	V	VI	VII	TOTAL
BELGIUM	533	484	127	6936	792	591		**9463**
FRANCE	6692	580	149	194	2891	200	196	**10902**
GERMANY	1012	395	388	2989	4396	3292		**12472**
THE NETHERLANDS	240	1567	306	1197	1581	1337		**6228**
LUXEMBOURG					37			**37**
AUSTRIA						360		**360**
SWITZERLAND					17	5		**22**
POLAND	110	1761	1905	275		151		**4202**

Table 16: CEMT classification of waterways in km
Source: NEA (2011) as referred to in BVB (2018)

It is considered by a number of respondents that the small waterways could use an infrastructural improvement and that they are underinvested. Although several programs have shown beneficial such as the Flemish quay wall program that supported waterbound enterprises or distribution centres in investing quays. But more investments are needed to improve the navigation status (such as depth and locks) and to enlarge the potential modal shift from road haulage to inland waterways. Infrastructure is not considered a barrier for the implementation of the innovation but needs further investments to stimulate market uptake.

1.4. Small waterway business of push barges

When zooming on the small waterway business in Europe, the top 25 companies according to available and owned small push barge capacity (expressed in DWT), it can be observed that the main sector where these small vessels are being used are dredging and building materials (including cement, stones, sand and gravel), dredging and agri-bulk (Table 17 and Table 18).

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 17: Top 25 of business according to DWT capacity with push barges with a length between 10 and 50m in Europe
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

The companies that are described as “divers” offer capacity to several customers such as containers, dry bulk, tanker push barges and project cargo. The main geographical areas also show interesting differences (Table 18). 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 a number of small push barges in diverse segments are mostly located in the East of Germany, Czech Republic, Poland and France. Most companies in Eastern Europe are historically state-owned companies.

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 18: Main segments of activities on the small waterways
Source: own calculations based on IVR, 2018 and company websites

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.

Finally, the small waterway business shows as biggest costs the personnel costs with more than 50% of the total costs (NEA, 2003 in van Hassel 2011: 23) whereas bigger ships, these costs are around 30%. Small vessels have relatively lower payloads and have therefore less economies of scale even if they have less crew members on board than a bigger ship.

1.5. 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 by following graph.

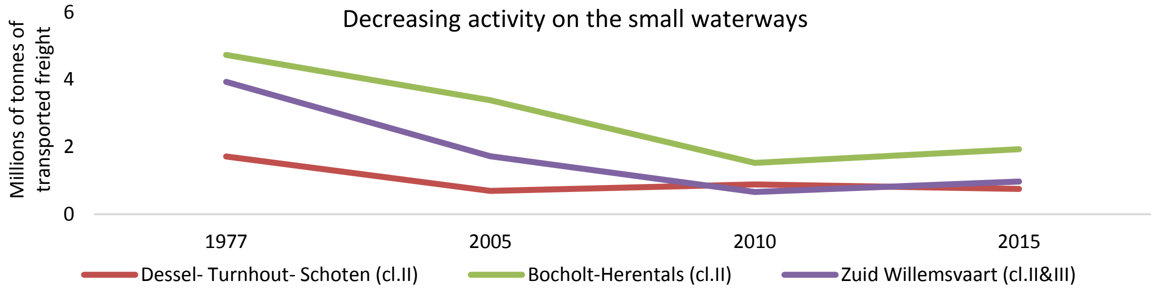


Figure 13: Overview of the transported tonnages on the Flemish small waterways
Source: van Hassel, 2011; Flemish Waterway Managers 2016 (nv DS and W&Z NV), according to available data and compilation from different sources. 'cl' refers to CEMT class. Zuid-Willemsvaart includes a Dutch part

The volumes on these waterways show since 1977 an overall decrease. Several reasons for such a decrease have been identified (based on van Hassel, 2011:101-132):

- modal shift towards road haulage,
- decrease of the SWW fleet where investors are more interested in higher revenue vessels for the bigger waterways which are not able to access small waterways,
- lack of interest of youngsters
- lack of banks/investors (which prefer to invest in bigger vessels with higher expected return),
- relatively high entrance and exit barriers on the market.

The following entry barriers are identified:

- a new vessel (including a loan if one is found) has to 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. The barriers will be further explained in the SIA part.

1.6. Small waterway fleet data

The IVR Ships Information System for the year 2017 was used next to several sources at 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 the following figure. The average dead weight of this segment is estimated at 545 tons[47] 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 in account in the analysis, but a number of 16 vessels are accounted in the database whereas only two have a length beneath 50m. The SPDB's are all registered in the Netherlands.

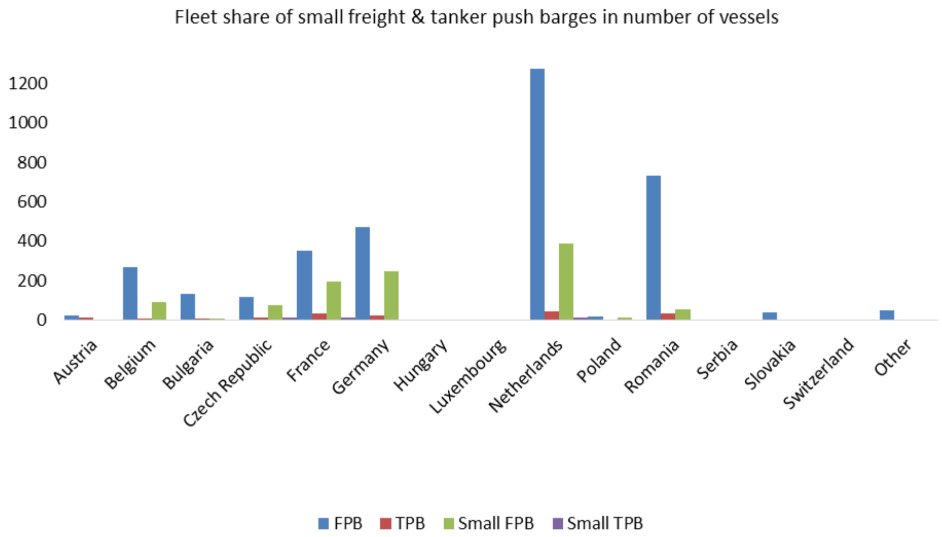


Figure 14: Fleet share of small freight (FPB) & tanker push barges (TPB) across Europe
Source: own calculations based on IVR (2017), small PB's are filtered by length (between 10-50m).

The number of pushers (including tugs with push bow, push tugs and push boats) in Europe are estimated at 1,309 (IVR, 2017) whereas 209 vessels have a length beneath 12m and a draught[48] beneath 1.6m. Figure 15 shows that the Netherlands have the highest share on pushers for all waterways, followed by Germany, Romania, Belgium and France.

[47] Inland navigation can be measured in different ways expressed by tonkilometers (tkm), tonnages (t) and vesselkilometers (vkm). Tonkilometers measure the performance of the mode by calculation the every transported tonnes tonnes tonnes for every kilometer of distance. Tonnages give an idea of transported volumes but do not provide insight in distances of the trip. Vkm is a measure that calculates each kilometer a vessels sails. The latter is useful to calculate emissions and energy use. The tonnages give insight in demand for capacity on the market and tonkilometers can tell more about modal efficiency. For distances in the calculation of vkm and tkm, an average distance is often used.

[48] 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

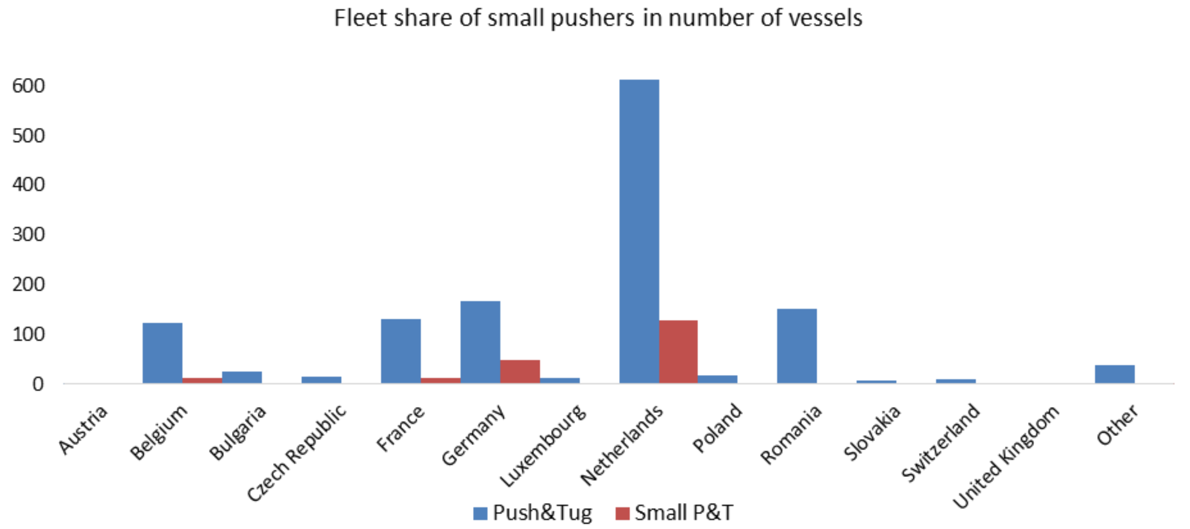


Figure 15: Fleet share of small pushers in Europe
Source: Own calculations based on IVR (2017), pushers include push boat, push tug and tug with push bow. Small pushers are pushers with a draught beneath 1.6m and a length beneath 12m for CEMT I&II waterways

The *Spits* (maximal length of 38.5m, width of 5.05m and payload between 250 and 400 tons) and the *Kempenaar*[49] (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 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 bigger in loading capacity and dimensions while the number of smaller vessels are decreasing. The average loading capacity of the fleet increases, which is shown for France (Figure 16) and Belgium (Figure 18).
The evolution of the fleet in the segment of the small waterways is shown by Figure 17 (France) and Figure 19 (Belgium).

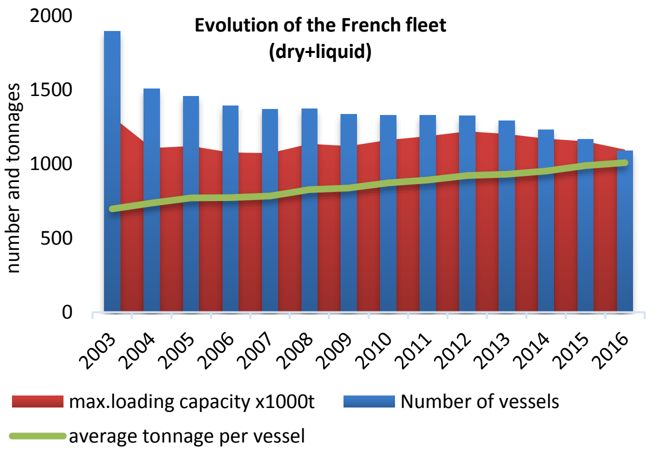


Figure 16: Evolution of the French fleet

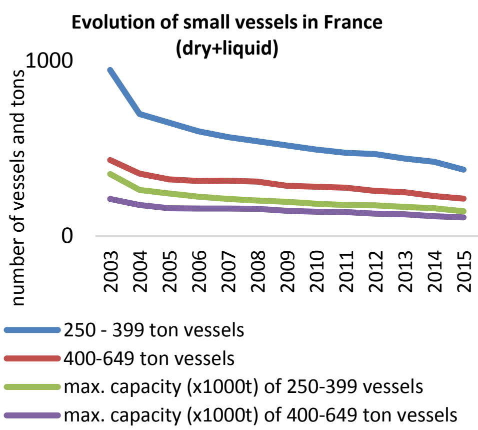
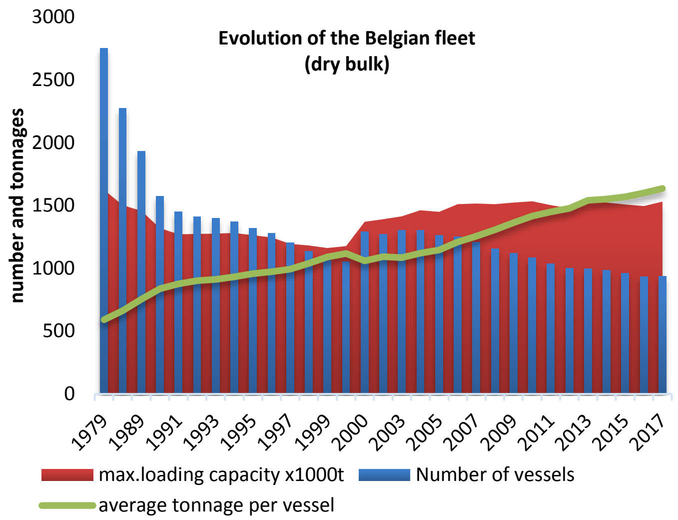


Figure 17: Evolution of small vessels in France

Source: Own calculations based on VNF and market observation (CCNR, 2018) for motorized small vessels

[49] van Hassel (2011) refers to the Neo-kemps as a possible concept as an example for the first mentioned concept but this lays outside the scope of this research.



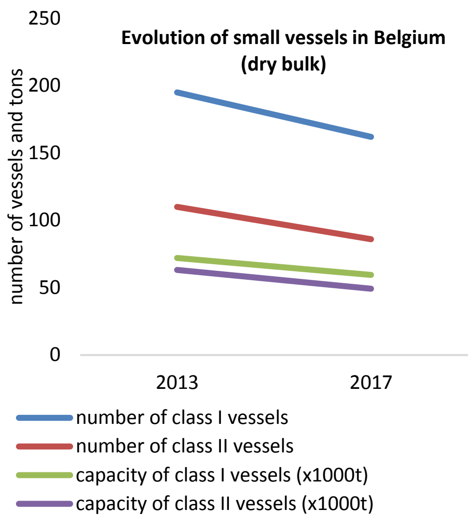


Figure 18: Evolution of the Belgian fleet

Figure 19: Evolution of small vessels in Belgium

Source: Own calculations based on ITB and market observation (CCNR, 2018) for motorized small vessels

The entire fleet (dry bulk) of the CCNR countries as mentioned in the market observation of the CCNR and the EU (2018), shows a comparable evolution where the size of the fleet decreases with less available vessels, especially on the SWW, but where the average capacity per ship increases (Figure 20).

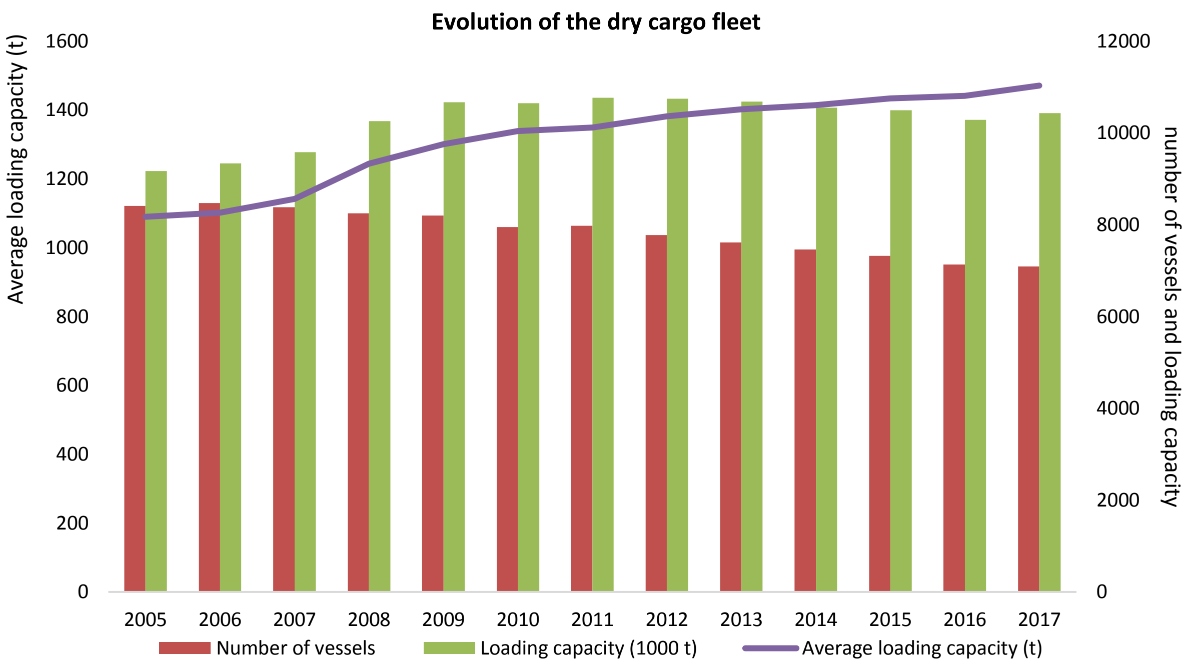


Figure 20: Evolution of the dry cargo fleet in the CCNR countries

Source: CCNR analysis based on data from national administrations. Data Germany, 2017 equals 2016

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, 2017).

1.7. 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 concept[50] 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 have to be sailed on the small waterways, from the drop point to a terminal or another final 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 is able to 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 have to be relocated and are waiting for a pusher, preferably in the proximity of the earlier destination.

To achieve sufficient round trips, sailing between waterbound industrial clusters or distribution centers 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 21 shows the cost reduction of the ratio of transported volumes as payload and the costs of the ship.

[50] This concept finds its origin in Waterslag (2006-2008) as explained during the SIA.

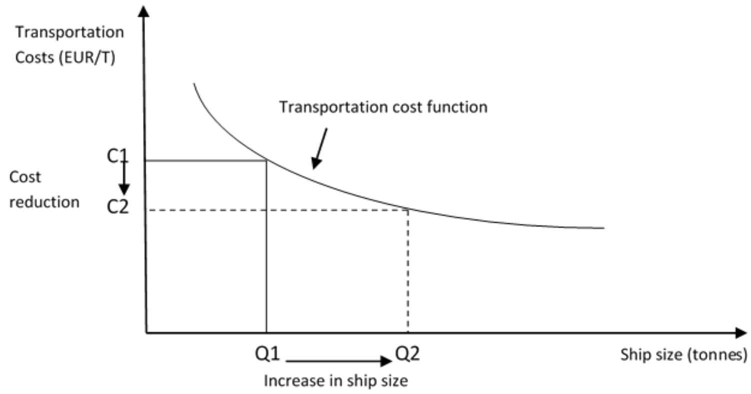


Figure 21: Concept of economies of scale
Source: van Hassel 2011

As of today, the different concepts and the challenges on the SWW are known. The following SIA goes deeper into the combination of concepts two and three as developed by van Hassel (2011), which is also the basic concept (although with a slight variation) of the European project Watertruck+.

2. Systems of Innovation Analysis

The Systems of Innovation Analysis focuses on the possible barriers and success factors of the innovation in order to reach market uptake and is explained in the methodology chapter. First of all, the different innovation phases of the small barge convoy are described, which leads to initial conclusions and a more detailed analysis of the identified factors.

2.1. Current situation

As explained before, the innovative concept of the small barge convoy, has a number of 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 (see 1.2.) 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 despite the fact that no private partner is found yet to operate the vessels. This project was preceded by more than a decade of initiatives to revive the small waterways.

2.2. 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 (Table 19).

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 2011).

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: Young barge-skippers aspire to larger ships with more revenue and low intake of labour where supply does not meet labour demand. The latter is met by a proposed eight-hour shift system in which people go home after a day's work. This also allows reducing the accommodation area and to increase loading capacity.

During these projects, as mentioned in Table 19, research and test cases were done in partnership with universities, stakeholders, sector organizations and government officials. This explains the marking in Table 20 for the available success factor linking knowledge institutions with capabilities and strong networks. 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 all of the preceding projects to develop a small barge convoy, before the last project *Watertruck*+ that aims at really building and implementing the concept.

	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 substantially 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 Small 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.	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, 2011)	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	France, Netherlands, Flemish Region	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, Belgium and Netherlands	INTERREG IVB NWE and EFRO funded 50% of EUR 1.78 million Main actor: Flemish Institute for Mobility (VIM°

Table 19: Overview of Small Barge Convoy concepts
Source: Platina (2011), HBCB (2013), EVO (2010), Vanelslander (2010), van Hassel (2011), Macharis et al. (2011)

The push barges are not only used for transport, they can also be used for floating storage. Unloading and loading happens under less time pressure because of the decoupling of the sailing function and (un)loading procedures. The decoupling raises challenges in safety. The captain is responsible for the cargo during sailing and he or she is not included in the monitoring of loading procedures. The captain should have the necessary knowledge of the ship and its stability in all scenarios as those who load the vessel from shore do not always have this knowledge, even if a software program is accurately followed.

Some first challenges were identified during the initiation period but besides pilots, no real ships were built. To receive a higher return on investment or to improve economic feasibility, a derogation from the RPN is required. The regulation for crew requirements (as the ES-TRIN) demands for convoys with a pusher first of all 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 (boatmaster 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 (art.3.15).

During the initiation period it was found that the infrastructure of the SWW needed more maintenance to reach more 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 and the higher the chance the innovation becomes successful. The infrastructure is nevertheless considered as 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.

The small existing possible 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. 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 considered to be an essential requirement.

Both in hard and soft institutions, several factors are identified, such as insufficient labour force and too strict manning regulation. The innovation network shows strong interactions between project members. As mentioned, private investors are yet to be found. A lock-in effect is noticeable to the extent that the focus lays 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).

Actors / Institutions	Demand: VO/O's, vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies,
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 20: System of innovation matrix in the initiation phase of the small barge convoy
Source: own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

2.3. 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 a number of pushers and push barges. The overall budget for the development of the small barge convoy is estimated at EUR 23 million, of which the European Commission pays EUR 11.5 million and EUR 9 million should come from private partners. 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. In a letter of the European Commission to the branch organizations of September 5th 2016, it is 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 building of this public driven innovation was not welcomed by the sector organizations. But high resistance is unlikely. Most stakeholders agree with the need for innovative concepts to reactivate the SWW. The fear of competition from remaining small vessels (which shows a decrease of an annual 10% for Spits type and 6% for Kempenaar type in Flemish region) does exist,. Indeed, most of these vessels have low equity (payed off loans, depreciated vessels) which makes them more competitive towards new entrance of small vessels that have to pay off loans. Most of these vessels 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 RPN still forbids the *Watertruck*+ concept to sail with two persons as shown in annex 2.1 and 3.7. If *Watertruck*+ initiates the derogation procedure, the minimal safety requirements should be proven by an annual report before any change of regulation on the supranational level can be supported. If no derogation is granted, the *Watertruck*+ concept will have to develop a business case with the mandatory crewing regulation or should focus on the waterways that are not internationally linked.

Infrastructure, as well as potential and existing charterers still needs improvement. 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. 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. A weak network effect is identified as potential investors have not yet been found.

Vessel owners and industry with vessels do not show interest yet to invest in the innovation. This is due to the lack of funding capabilities but also to the fact that higher scale of economy with larger vessels show other opportunities. Although effort is done in upgrading the SWW in most Rhine countries and Belgium (Danube was not included in the scope of this case research), operators still report challenges with the infrastructure.

Actors / Institutions	Demand: VO/O's, vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties lobbyists; manufacturers, consultants, sector organizations	Knowledge institutes, funding, standardization bodies,
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 21: System of innovation matrix in the development phase of the small barge convoy
Source: own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

2.4. Initial conclusions

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 absence of new builds, the reduced labour force, the absence of young successors or inflow and the insufficient maintenance of these waterways (van Hassel et al., 2011:131). Moreover, waterbound companies turn to road haulage to guarantee their supply chain causing higher external costs.

In the worst case scenario, a public driven innovation risks to 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. This could be different if the small barge convoy was built by a private company, but private innovators have not been found yet. Financial capabilities are considered to be low and opportunity costs relate to more interesting investments in bigger ships with more and proven economies of scale.

The SWW network is a relatively important part of the European waterway with 31% identified as class I and II. However, it needs sufficient investments to improve maintenance.

The identified regulatory bottleneck relates to the manning of at least three persons which is required and could jeopardize the initial business case by preventing larger economies of scale and reduction of crew costs. Therefore, the innovator should start a derogation procedure to prove that the concept confirms to the safety standards.

A number of challenges still have to be met during the implementation phase to prevent failure. The innovation is currently at the end of the development phase.

2.5. Detailed analysis

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.

The Waterway policy of the CCNR MS looks for a balance between environmental water policy and the economic function of the waterway. The environmental functions are consolidated in the EU water

Framework Directive (Directive 2006/60/EC) and the Directive on the assessment and management of flood risks. Like the institutional dimension of the economic waterway function in Europe, the environmental policy is also supported by River Basin Commissions for the Odra, Elbe, Meuse, Danube, Rhine, Sava and Scheldt. In some cases, these functions can cause tensions. Indeed, whereas IWT infrastructure policy needs quays and soil replacement, environmental policy focuses on water quantity and flood risks. Keeping an acceptable balance between all of the functions of the waterway is an important challenge for policy makers. The possible tensions between upgrading SWW and environmental policy need further research.

Maintenance of mostly relatively old locks and of the small waterways was reported insufficient by some respondents during the interviews and surveys that were done during the *Watertruc*k project. The question of the infrastructural conditions does not only concern navigable waterways. Sufficient load- and unload facilities need also to be taken in 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 regulatory framework of the CCNR does not allow the manning as suggested in the *Watertruck*+ project. To be allowed on the Rhine, a barge convoy needs to have at least three crew members on board as mentioned in annex.

The following cases are exempted from the CCNR and EU regulation:

1. The Directive EU/2017/2397 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 adress 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 RPN and in national regulation when traffic is conducted only in the national state and possibly exempted (e.g. Dutch *Binnenvaartwet*).
2. According to the Directive EU/2016/1629 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 have to comply with the RPN regulation. The regulation for push barges without steering systems or engines have less requirements to comply with (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). 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 hard 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. The European Shipping Organization (ESO) provided constructive criticism towards reactivation attempts on the SWW but expressed concerns related to possible market disruption. 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* vs *Watertruck+).* Social resistance is considered to be nevertheless too low to prevent market uptake.

The private investor who will be responsible for three years in operating the vessel 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 it to the waterway manager or proceed to buy the vessels completely. Not all private investors find this agreement appealing. Furthermore, the subsidies weaken the negotiation position in upwards pressure on prices. Finally, 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.

In light of the above, it can be assumed that the continuity of the small vessel fleet will be jeopardized without change. Generally speaking, to guarantee continuity of family-owned firms, the children of the family-owned business are mostly asked to take over the firm, which is still a typical phenomenon in IWT. However, on one hand, with the democratization of education, young people in the sector have more choices for their career path and are often overqualified to navigate a vessel.

Most concepts that are discussed in this research show vessels with a reduction of comfort by removing or reducing the accommodation area together with continuous sailing where regulation allows it.

During the interviews with sectorial stakeholders, it was mentioned that a certain level of conservatism could be identified on the side of most VO/O's. It was described that first mover advantage is often too expensive and less interesting than to wait and see. If the innovation becomes technologically feasible, together with a clearly possible market share, after implementation, but fails nevertheless, it becomes more interesting to buy second-handed ships. The Neokemps, the GreenRhine and Greenstream (referring to the LNG case analysis of this research), the river hopper from Distrivaart (as described in the pallet shuttle barge analysis), show a comparable evolution. This behaviour could also explain partially the lack of interest in investing in innovative concepts as the small barge convoy.

C. Interaction conditions

The network of the innovator is identified as strong within a framework of stakeholders, research institutions, policy makers, waterway manager and other relevant institutions.

The small barge convoy concept should 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 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 centers. Logistics service is still often unimodally offered and a lot of efficiency gains seem still to be uncovered. Also the *Watertruck+* concept shows too much focus on the waterway and perhaps not sufficiently on the entire supply chain which 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. Funding for VO/O's is one of the challenges. 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 (2011), EVO 2010).

Also, financial support from the private market is a problem. Private equity demand has gone up due to the financial economic crisis. Furthermore, big companies that could provide the necessary investment from own equity are rather scarce on the market of SWW.

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 relatively high investment (to achieve economies of scale several ships are needed). The typical structure of small businesses, especially on the small waterways, makes the business structure vulnerable to shocks in demand. Also, 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 revenue from transporting freight only and is highly dependent on a relatively small number of charterers and brokers. The overhead costs can be reduced by deeper cooperation with other market players, but independent VO/O's show reluctance to do so. Only when a crisis arises, these companies are more open for cooperation. Cooperation between vessel owners easily evolves to turn into a kind of broker company. This situation could cause an ambiguous relationship which is described in the case analysis of the e-bargebooking. Nevertheless, the vulnerability of the fragmented market structure where small family businesses do not succeed in convincing financial institutions to invest in equipment, hardly showed any evolution in the past decade.

To lower the entrance barrier for private operators to join the project, *Watertruck+* plans to have life-trials until 2019 with a total of 28 push barges. After 2019, operators will be able to subscribe to as lease usage of five years. The real implementation of this small barge concept is thus scheduled for 2025.

Investing in the small waterways also hides an opportunity cost when return on investment is perceived higher with larger vessels.

E. Market

According to van Hassel (2011:244) the concept can present a positive business case[51] when enterprise equity is not too high (below 15%), with 'acceptable' fuel prices (or more fuel efficiency), under a single crew regime and in fifth and sixth scenario by internalizing external costs in road haulage. An upgrade of the infrastructure to a higher classification does not have a big effect on the business case. In all studied scenarios, it is of course vital to maintain the SWW and to provide a good navigation status. Also, the scale of the investment is determinant for a successful market uptake. 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 initial investment presents a high risk to provide sufficient components within a network of small barge convoys.

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

[51] based on research for the Flemish waterways

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.

Although for this case no SCBA is applied, it can be said that the social benefit of reactivating the small waterways is higher than the potential loss of few small vessels or road trucks. It is recommended to the public innovator to compensate the losers in order to at least maintain the market share of IWT if necessary and to monitor carefully the rather delicate implementation of this innovation.

The economies of scale are an important determinant for the business case of the small barge convoy. According to the EVO- feasibility study of the Barge Truck concept (2010), the fixed costs of the Barge Truck were annually estimated as the double of a Kempenaar and almost six times the annual fixed costs of road haulage. The costs for transporting 800 containers from Alkmaar to Rotterdam and Antwerp with only two destinations (dedicated transport for one firm) were estimated at EUR 631 against EUR 400 for a Kempenaar and EUR 425 for road haulage for each container. The concept would have a more positive business case if 2,350 containers were transported each year. The average cost for each container would then be EUR 263 for one Barge Truck and EUR 389 for 2.8 Kempenaar and EUR 395 for each 7.9 truck.

2.6. Conclusion

Research and findings of ECSWA, INLANAV, WATERTRUCK were important to highlight the problems of the small waterways and addressed policy makers across Europe. These research projects offered insights and even new innovative concepts. One of these concepts is the small barge convoy that aims at reducing personnel cost, enlarge economies of scale, and shift volumes from road to SWW.

The social benefit to save small waterways is expressed by the potential modal shift from road haulage towards smaller canals but as shown in the PBS chapter, the ship needs to compete with road including costs concerning the additional transshipment and the last mile delivery (if sender and final receiver are not water bound). In cases of no convincing business cases or lack of private interest, policy could make the social choice to invest.

In case of ship technological innovation, it is clear, also from other case analysis and interviews within the research, that the focus of both private and public innovators lays on environmental benefits (LNG, electrical, hydrogen) and digitalisation (e-bargebooking, automation). Both objectives are also targeted in the development of innovative concepts for the SWW. The return on investment because of cost reductions and the initial investment costs determine the business case. The same is true for the SWW barge convoy.

Concerning infrastructure, the small waterways are reported by operators in the framework of *Watertruck* and *Watertruck*+ as not sufficient. 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.

The crew requirements limit the business case of the small barge convoy, but it is up to the innovator to prove that less crew can equally perform on the same safety level as required by regulation. At this moment, it cannot be proven from a development phase that less crew members provide sufficient safety to sail on a small barge convoy.

Next to the small barge convoy, another innovative vessel concept has emerged to revive the small waterways. The Pallet Shuttle Barge with an on-board crane and the ability to sail with only one single headed crew, is analysed in the next chapter.

VI. The Pallet Shuttle Barge

This chapter describes the Pallet Shuttle Barge (PSB) project, concerning an innovative type of vessel that is intended to reactivate small waterways and reintroduce pallet transport in inland navigation.

1. Definitions

The pallet shuttle barge (PSB) is defined in all aspects that are considered relevant for the innovation analysis. Depending on the available data and limited literature, it is also described in this analysis how the concept emerged.

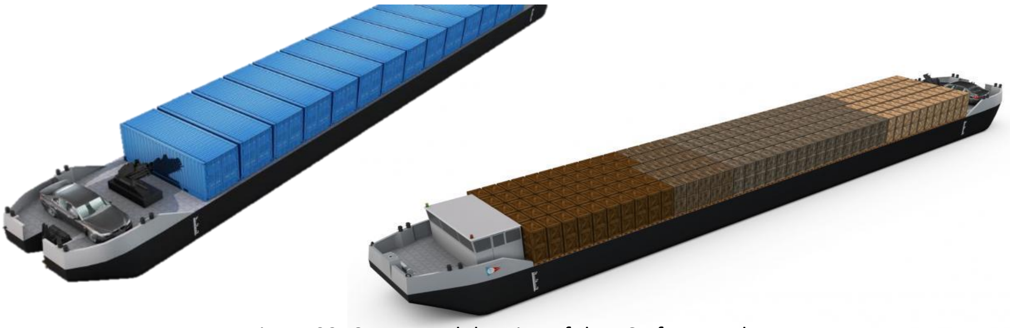


Figure 22: Conceptual drawing of the PSB front and rear
Source: Multi Engineering Services, 2017

The PSB's that are central for this analysis, refer to the Zulu 1 and Zulu 2: two catamaran freight vessels that are mostly active in Belgium and the Netherlands between Antwerp, Brussels, Amsterdam and Liege. The Zulu's are vessels of 50m long, 2.2m deep and 6.6m wide and are designed to carry 300 tonnes or 198 europallets. The PSB has a dwt of 323.1 tonnes (IVR, 2017). The catamarans are designed without any accommodation except for a basic wheelhouse in front of the vessel. The on-board crane-rail system is able to lift two tonnes and 9m far. The catamaran design is claimed to give more stability during the crane operations. The operations are manned with a one-person crew.

The Zulu 1 was put in service in June 2014, Zulu 2 in February 2015 and two more will be let in the water in 2018. The vessels are very basic and explain the relatively low repair and maintenance costs. The average building period for one vessel is very short and varies between two and three months.

The engine on both ships is a 300 HP diesel with hydraulic propulsion and two bow propellers. The Azimuth thruster propulsion and bow-thrusters claim to use less power than trucks to transport the same quantities. This vessel type has the capacity of ten cargo trucks. Goods are directly placed on deck and the pallets could be stacked up to at least 4m.

The PSB is inspired by trucks and catamaran yachts. The lack of accommodation (bathroom, sleeping area, etc.) is comparable with working conditions on trucks (except for the sleeping area). Although the vessel is equipped with AIS, a road haulage track and trace system is more often used by the owner who claims it has more possibilities in real-time to track vessel and cargo.

The first customers were Wienerberger and Beton Coeck. Gyproc joined in 2015 with on average five annual transports to Amsterdam from Kallo. The usage of other types of inland navigation vessels was considered by Gyproc but the volumes (>700 pallets) were too big to deliver in one time for the logistics system for Kallo-Amsterdam to process. Gyproc demanded a smaller vessel for relatively short distances with less critical mass, which is what the PSB offered (Rommens T., 2016).

The manning, operational and technical support are done by the firm Shipit. Shipit has a terminal in the Port of Antwerp and together with Delcatrans, they own the River Terminal Wielsbeke.

The concept claims to be as lean as possible and cuts down operational costs when compared with a conventional type of vessel with the same dimensions. Also, the costs for the customer are cut because of the ships' ability to load and unload without shore equipment. The absence of accommodation further reduces the costs of the vessels.

The PBS targets the small waterways. The small waterways are defined in this research as class II and below which builds further on the findings of van Hassel (2011). *Table 22* shows a basic overview of the classes of vessels according to their dimensions. The typology that is used refers to the Flemish and Dutch names of vessels. The CEMT classification was established in 1992 by the predecessor of the International Transport Forum (Conférence Européenne des Ministres de Transport) and divided the European waterways into six categories taking in account depth, width, lock size and bridge gauge of every waterway.

Ship type	Tonnage	Length (m)	Width (m)	Depth (m)	Waterway Class (CEMT)	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	95-110	11.4	2.7-3.5	V	Large
Large container vessel	470 TEU	135	17.0	3.0	VI	Large

Table 22: Classification of vessels in IWT
Source: Promotie Binnenvaart Vlaanderen, (cited from van Hassel, 2011)

The PBS competes with the *Spits* and the *Kempenaar* in the segment of big bags[52] and pallets and sails with only a captain according to the respective national legislation and within the regulatory limitations (e.g. no night sailing and not allowed on Western Scheldt[53], Rhine and Seine in Paris[54]) as further explained in the detailed analysis.

"Europallet" refers to a standard for pallets that is specified by the European Pallet Association (EPAL). The europallet or EPAL pallet is divided in 15 types with dimensions varying from 600x400 mm to 1200x1000 mm (EPAL, 2018). Most pallets are made of wood. The europallet may weigh up to 1.5 tonnes when equally loaded, otherwise the limit is 1,000 kg.[55] A pallet of 800x1,200 has, according to Beyer (2016), a carbon footprint of around 5kg CO_2 related to the transport, pallet manufacturing, the lifecycle of the used steel, timber harvesting and the carbon stored in timber.

2. Fleet segment of the PSB

According to the IVR database (2017) [56] which is used as one of the sources of the market observation report of the CCNR for new vessel construction, there are approximately 1,334 dry bulk vessels with a dwt under 350 which are registered in the CCNR MS and Luxembourg. The average building year of this group of vessels is 1938 with an average age of 80 years. When calculating the age of a vessel, it is the oldest part of the vessel which is taken into account even if all the other parts of the vessel have

[52] "Big Bags are sack-shaped transport containers of tear-resistant reinforced synthetic web material which have a volume of for example, one cubic meter and which are used for transporting pourable goods." (CIBA SPECIALTY CHEMICALS CORP., 2007, IFI Claims Patent Services, New York)
[53] Binnenvaartregeling Artikel 5.15
[54] Order of 2 July 2008 relating to the crew and conduct of certain inland navigation vessels, https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000019209512&dateTexte=
[55] More elaborated information concerning the types of pallets can be found on https://www.revolvy.com/page/EUR%252Dpallet?uid=0
[56] The database was filtered on general cargo ships, bulk transport barges, freight barges and multipurpose barges of maximum 350 dwt and 50m length. Zulu 2 was not registered in the database and is added manually to the total. It was not possible to filter out the precise number of pallet dedicated vessels.

been renovated.. Although mostly renovated to comply with the requirements, this segment loses market share with road haulage and is decreasing in fleet size.

Only 400 vessels in the database have reported a dwt between 200 and 350, which is the segment of the PSB. The data does not provide a full analysis of the age of the fleet. Only 1,292 vessels registered their age.

For pallet transport in the inland navigation, not much data is found. According to data from the *Vlaamse Waterweg*, 565,518 tonnes were transported by barges in the Flemish region in 2017, which is a relatively small increase by 62,503 tonnes compared to 2016. Market research in other CCNR countries and the Danube could be interesting as part of a feasibility study, but this is outside the scope of this research. According to several sources (Macharis, et al., 2015 and Pekin, 2012) pallet transport by IWT is increasing and holds still a large potential.

3. Systems of Innovation Analysis

The System of Innovation Analysis focuses on the possible barriers and success factors in order to reach market uptake and is explained in the methodology chapter. First, the innovation phases of the PSB are described, then followed by a more detailed analysis of the identified factors.

3.1. Current situation

The firm behind the Zulu's is *Blue Line Logistics nv (BLL),* located in Belgium. The ships sail for customers such as Gyproc, Wienerberger, Beton Coeck, ABInbev and quite recently even for rock festival Pukkelpop (stage material to Limburg in 2018). Two more vessels are being built.

Recently, the French firm CFT became shareholder in the company, which indicates that the vessels will increase their focus on the French market (Flows, 2016). *Taste Westerlund* sold their share, but the reasons are not identified. BLL also has shares, next to the original CEO Van Coillie & Co, owned by the Dutch Almarach Shipping and the Antwerp operator Shipit.

The firm was originally established in 2011 as a firm with limited liability (BVBA). In 2014, BLL changed according to Belgian law into a joint-stock company (*Naamloze Vennootschap*). According to the public online financial statements of the company[57], it did not make any annual profit (yet) since its first operation. The losses seem to have an increasing evolution but are according to the business plan as mentioned in the statements. The losses are considered as start-up losses.

The liquidity ratio has a positive evolution but with a ratio under 0,5 the firm seems vulnerable for liquidity problems. Based on the statements, the first two Zulu's costed together approximately EUR 1,741,011. Currently, the company claims that it is researching the possibilities of automation and hydrogen propulsion to add on the next generation of the vessels.

3.2. Initiation period

Vermunt was according to Groothedde et al. (2005) the first one to propose to consolidate palletized flows between manufacturers and retailers, using inland barges within a collaborative hub network (Vermunt, 1999 as quoted in B. Groothedde et al., 2005). These multimodal hubs combine *expensive but fast and inexpensive but slow* means of transport through collaboration between customers in a synchronized way (2005). This concept was launched in the Netherlands by Vos Logistics and Riverhopper in 2004 (Groothedde et al.).

[57] Belgisch Staatsblad (2018), financial statements of Blue Line Logistics, https://www.staatsbladmonitor.be/jaarrekeninganalyse.html?ondernemingsnummer=0837466425

At the beginning of this century, the Netherlands started with *Distrivaart*, a project where the vessel River Hopper delivered beer and soft drinks (Fast Moving Consumer Goods) with an on board full automatic pallet installation that was able to tranship pallets directly on trucks without external load or unload installations. The project was preceded by several failed attempts[58] to revive pallet transport[59], mainly because of the lack of necessary scale to operate cost-efficiently[60]. In the first phase of the project, a concept of distribution of palletized consumer goods was set up by TNO (2003). In the next phase, a pallet barge was built and launched. The pilot failed because of too high costs and a lack of critical mass of consumer goods at the demand side. Although the River Hopper failed, it managed to attract the attention of the Flemish region, what resulted in a feasibility analysis (VUB, COMiSOL, 2006) that estimated a potential of 6 to 7 million tonnes of palletized building materials to shift from Belgian road haulage to inland navigation, according to the market circumstances and expectations in 2005. Intermodal concepts were tried out and tested. In 2007, the Flemish government initiated several projects concerning pallet transportation in the inland navigation sector and several rounds of digressive subsidy[61] schemes according to the de minimis regulation of the European Commission (EU/1407/2013) were organized[62]. Also, the Brussels Regional government granted a pallet subsidy to cover the difference in cost for customers between road and inland navigation (Du Parc N., 2011:17).

In the initiation phase, the innovator behind the PSB found that the necessary infrastructure and regulation (although limited for single crew) were appropriate for the launching of the innovation. Shipyards, research, market and funding were present and accessible. There was sufficient institutional support for the pallet transport. Both private and public funding were available for both ship development and customer support. The latter did not only offer an indirect effect on the PSB but also included other conventional pallet barges. The company behind the PSB claims that it does not receive any operational subsidies. At the first round of the subsidies, they received support for building the first two vessels. A number of customers also received subsidies to compensate for the cost difference between road and inland navigation (if pre- or post-haulage was included). Some of the customers also received support from the quay wall program.

During the initiation phase of the PSB, the following capability and network effects can be observed (summarized in Table 23):

- Knowledge is available through mentioned programmes, research projects and companies' initiatives in developing the business case (capabilities).
- Sufficient shipyards and expertise are available (infrastructure, third parties).
- Private financial capacity and ship building subsidies are available (capabilities: funding; soft institutions: subsidies).
- Stakeholders are aligned (soft institutions) and sector organizations show no resistance.
- First customers or charterers are found (positive impact of pallet subsidies and quay program for charterers), although the concept is rather unknown during this phase and the customer base has yet to grow (weak network effect).
- Not all potential customers (shippers/forwarders) are waterbound or have quay infrastructure.

[58] Initiatives such as the development of Automatic Seabome Pallet Handling system in Germany (KWS Systems) ended in 1999 when pusher companies Lehnkering and EWT pulled out from the project Pallet-Shuttle which focused on the potential of pallets with automotive parts, beverages and chemical products from Duisburg to Mainz/Mannheim. (http://markt.vaart.nl/archief/1999/arch9901.htm#pal and in TNO, 2004:18). Palletized dairy products of Unilever in 1993, soft drinks for Coca Cola in 1995 and beer products for Bavaria in 1999 (Groothedde et al., 2005).

[59] Although several authors (Macharis et al. 2013, 2015) claim that pallet transport needed to be revived in IWT, no data was found to prove if barges hardly or not at all transported pallets.

[60] A higher number of vessels could have prevented failure because of adding flexibility as advantage of scale. Next to scale advantages, critical mass is used to indicate the minimal required number of customers to make the business case feasible.

[61] Subsidies for IWT customers relate to the decrease of operational cost difference with road haulage. The support is digressive and limited to three years. In the first year 80% of the proven operational cost difference is compensated for. In the second year, this is 60% and the latter year this is 40%.

[62] http://ec.europa.eu/competition/state_aid/legislation/de_minimis_regulation_en.pdf

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

Table 23: System of innovation matrix in the initiation phase of the PSB
Source: own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

3.3. Development period

The development of the PSB followed several other attempts since the Dutch project Distrivaart. The idea for reviving the pallet transport on small waterways grew further during FISN (Flanders Inland Shipping Network) which offered a platform in Flanders for stakeholders, policy and knowledge institutions. In order to strengthen the competitive position of inland navigation on small waterways and for relatively low cargo volumes, the PSB reduces the crew cost to the minimum requirements and adjusts the dimensions of the vessel accordingly.

The vessels are developed according to contracts with customers. Building a *Kempenaar* takes usually longer than a PSB and is less standardized. The PSB's are exact copies of each other what generates overhead efficiencies and economies of scale that grow with every new PSB. After the pilot PSB was in the initiation phase, the second vessel was ordered. During the development of the second vessel, the shipyard went bankrupt what threatened to endanger the building of the vessel. A solution had to be found to finish the second vessel. Because of the very basic concept of the vessel design, it was relatively easy to find a new shipyard to proceed to the implementation phase.

The potential loss of knowledge, as in other cases (e.g. Greenstream), was not considered to be a potential bottleneck. Despite the latter, the bankruptcy slowed down the development (failure factor at the infrastructure side of the manufacturer). Indirect subsidies are still given to the customers to switch to inland navigation. The latter is still a success factor during this phase, which relates to public funding (soft institution).

During the development phase, the success and failure factors were identified as summarized in Table 24, following the applied SIA methodology. More than two vessels were announced during the development period, but they did not succeed in being built because of problems with the shipyard, funding challenges and lack of possible charterers.

Furthermore, the IWT market experienced turmoil in the aftermath of the global economic crisis of 2008, which led, together with relatively high fuel prices, to a period of social unrest in the sector with blockages and VO/O's that refused to sail under the conditions [63] of that time. This turmoil was primarily expressed by Belgian VO/O's with blockages at the Albert Canal in 2013. These events and the later recovery of the market could have had an impact on the already vulnerable small waterways,

[63] Conditions were described by the sectoral organisations and referred to low freight rates, enforced unfair pricing, difficulties to receive financial loans and upcoming technical requirements. The freight rate was claimed not to cover the fuel costs. The outcome of the blockage was the postponement of a number of technical requirements (moratorium) and a federal legislation concerning fair pricing in 2014 but which has not yet been implemented.

but this invites further research and needs more data. Nevertheless, it is assumed in this research that this had an impact and slowed down further investment. The building of new PSB’s was delayed.

Table 24 shows a capability failure factor at the side of shippers/forwarders. BLL shows a strong connection with knowledge institutes and regulatory actors at the national level (strong network effect) and is considered as a success factor.

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

Table 24: System of innovation matrix in the development phase of the PSB
Source: own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

3.4. Implementation period

The ambition of the company is to attract new markets abroad with focus on France and the Netherlands. As before- and after-transport is needed to be performed by trucks, there are additional transhipment costs. These costs are included in the price of the intermodal transport when unimodal transport is not possible.

The Flemish government decreased the pallet subsidies (compared with previous calls) and launched a last call for proposals in 2016. It is not certain yet if a new call will come. The European *de minimis* regulation limits one-time subsidies to EUR 200,000 for one firm over a period of three years. To make it clear, BLL did not receive subsidies during the implementation of the innovation on the market and does not receive directly public support for their operations. Furthermore, it is not found how many customers still receive subsidies and how they would change their strategy and modal choice if public funding would stop. The subsidized customers are required to be committed to continue with IWT for at least five years after the subsidies as the subsidy policy foresees.

According to informal conversations, some of the customers indicated that the quay program and the digressive pallet subsidy were convincing enough to choose the intermodal solution. However, how this would influence their future preferences is not known. The possible effect on the market of the given subsidies needs further research.

During the implementation period, more investors bought shares in BLL, which can indicate a growing belief in the business case. Sufficient capability (funding success factor) and demand were found to order two more vessels (Zulu 3 and 4), but with a changed concept, leaving the catamaran design behind and going for a conventional flat bottom (Schuttevaer, 2018). The catamaran design was in practice less suitable because of the larger needed depth. The new PSB’s will also have a sleeping area.

The influence from road haulage concepts such as the single crew and the track & trace system, and the expertise from the building sector within the company, does not show a negative lock-in effect and is considered to be beneficial for the innovation. After the implementation of the PSB, with two catamarans in operation, no other companies are likely to build a comparable concept yet. The innovation is during this phase better linked within the existing network of charterers, other VO/O's, shippers and forwarders and is now a known vessel design option (strong network effect).

Despite the attraction of additional investors, the regulation for single crew sailing limits the potential for further market uptake. With updated navigation equipment complying to current requirements, it could be the question if limitations for sailing during night or the prohibition on busy parts of the Seine and the Western Scheldt, correspond still with the reality. During the implementation period, interviewees reported that the existing regulation limits further market uptake. However, it was not a barrier for the innovation to initiate and develop operations. For further growth of the concept and of the business case of BLL, the market limitations are as a potential failure factor. The RPN, as mentioned, does not allow the business structure of a single crew member and therefore the largest inland navigation market cannot be entered by these vessels without additional crew.

Table 25 shows the described factors within the SIA matrix while linking them with the relevant actors within the innovation network.

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

Table 25: System of innovation matrix in the implementation phase of the PSB
Source: own creation, based on Aronietis (2013)
Legend: black shaded areas represent identified failure factors. Grey shaded areas show identified success factors

3.5. Initial conclusions

The market for the PSB is focused on trip volumes of maximum 300 tonnes in the Amsterdam Rotterdam Antwerp (ARA) region and in the following phase in Northern France. The vessels transport mostly palletized building material but also fast moving consumer goods such as beer bottles for ABInbev. The competition in this segment is first of all road haulage but also remaining small vessels, such as the "Kempenaar", which are active in palletized goods.

According to literature, the segment of small vessels witnessed a fleet reduction and a noticeable ageing of the fleet. The small waterways are being abandoned and demand, even from waterbound companies, has shifted in the past decades towards road haulage. Still a high potential of volumes can be shifted to inland navigation on these waterways.

Public and private funding made a number of initiatives possible to address the problem of the small waterways such as the development of the PSB.

Investment in infrastructure and revisiting the regulation for single crew transport for vessels below 55 meters can improve the business case. It could be the case that the required and mandatory level of safety also can be maintained during the night or in busy places. The latter lies outside the scope of this research and invites further research with the necessary measurements and third party monitoring during a possible derogation period.

As more infrastructure is being upgraded and more waterbound companies or distribution centres are convinced about organizing their transport through intermodal solutions, or unimodal if possible, with inland navigation, and with the assumption of available and sufficient funding, the more likely innovations such as the PSB will be able to truly reactivate small waterways.

3.6. Detailed analysis

The PSB is one of the attempts to revive small waterways but the innovation has not experienced market uptake (yet).

A. Infrastructural conditions

Thanks to the fact that the PBS is equipped with an on-board crane, only an appropriate quay is required at the location of the customer. As long the waterway manager invests in the small waterways in order to maintain a good navigation status, infrastructure does not present a barrier.

The idea of a crane on-board of a vessel originates from the Dutch AMS Barge that started operation in 2006. The main issue of an on-board crane is the stability. The catamaran design of the PSB claims to compensate for this[64]. Furthermore, there is no cargo hold beneath deck, as all cargo is put on deck, which makes it easier to load and unload. The basic and cost-efficient design makes it feasible to build the vessel in a relatively short period of time without specialized ship yard and with the possibility to standardize every PSB.

As mentioned, government can support the building of quays to convince more waterbound companies or hubs to use inland navigation. As example, the Flemish quay wall program stimulates public-private cooperation to build load and unload installations such as quay walls. This program started in 1998 under the approval of the European Commission (under conditions as set by regulation 1107/70/EC)[65] and is still running.

B. Institutional conditions

Both hard and soft rules are identified. The hard rules concerning fixed crew requirements can be a restraint for further market uptake of the innovation. In the case of soft rules, subsidies are granted to potential customers to transport pallets by IWT, which goes broader than only the PSB.

B.1. Hard rules

As mentioned, most of the Rhine, Western Scheldt and Seine (in Paris), do not allow single crew operations and an additional crew member is required (RPN, 2018, chapter 3, French and Dutch law). Under Belgian law, single crew operation is allowed according to the Royal Decree of 9 March 2007 concerning crew requirements on the waterways of the Kingdom, which makes an exemption for small vessels. These vessels are defined as vessels under 55m of length. Chapter 6 (article 20) of the decree requires vessels between 35 and 55m with only one person on board, to sail for a maximum time of 12 hours a day and 50 hours a week. The minimum resting time is 12 hours for each 24 hours. Between 10 pm and 6 am, the vessel has to stop sailing operations. The ship has to have a functioning tachograph, together with a spare top light and a bow rudder. Goods as mentioned in the ADN are not allowed.

[64] Researching innovation in a rapid changing world is challenging. As the research comes to an end, the innovator could have decided to change the vessel. In case of the PSB, the Zulu 3 and 4 were recently constructed and were surprisingly built with an conventional ship bottom and left the catamaran design behind. The flat bottom is now claimed to make the vessel less deep.

[65] https://www.binnenvaart.be/images/publicaties/files/11-evaluatierapport1998-2010_DEF.pdf

In the Netherlands and France, "*Alleenvaart*" is legally allowed since 2008 but not on all waterways. The Western Scheldt requires at least two people on board of the vessel (art.5.15). Branch organizations such as the ASV (Algemeene Schippers Vereniging) in the Netherlands claim that the legislation is outdated for the Western Scheldt and that modern equipment makes it feasible for vessels below 55m long to safely navigate[66] with only one person on board.

The number of accidents or the safety argument is difficult to prove without any accident casuistry system, like in other modes, and lays outside the scope of this research. Although, it could be pointed out that the choice of 55m length as a determinant in separate legislation seems an arbitrary rule. More research is needed to examine if "*Alleenvaart*" could be possible on the Western Scheldt or even on the Rhine. In France, it is legally allowed and conditions were modified in 2008 for certain waterways but not on the Seine as mentioned in article one of the concerning regulation:

« Les conducteurs de bateaux de navigation intérieure titulaires du certificat de capacité du groupe B, du groupe A ou d'un titre équivalent depuis au moins deux ans sont autorisés, dans les conditions définies par le présent arrêté, à conduire seuls, en rivière et sur les lacs définis au I de l'article 4, les bateaux de type automoteur de transport de marchandises d'une longueur de 55 mètres au plus ne réalisant pas de transport de marchandises dangereuses au sens de l'arrêté du 5 décembre 2002 susvisé et munis des équipements détaillés à l'article 2. »[67]

According to the regulations for Rhine navigation personnel (RPN) of the CCNR[68], canal barges are exempted as described in chapter 3 of the regulation (art. 3.21) but need to have at least a boatmaster in possession of a Rhine certificate or a Community certificate and an extra person of not less than 16 years old to help in manoeuvring the vessel. In reference with ES-TRIN a canal barge is defined as *an inland waterway vessel that does not exceed 38.5m in length and 5.05m in breadth* (art. 1.01, 1.8). The PSB with 50m of length falls outside this regulation and is not allowed within the scope of the RPN (most of the Rhine[69]) and for waterways where national law does not provide exemptions (e.g. Western Scheldt). The ES-TRIN standards also describe sanitary installations where, according to article 15.3, the floor space has to be at least 1m^2, 0,75 m wide and 1,10 m long. On board of the PSB this is not the case.

B.2. Soft rules

Inland navigation is considered as a sustainable transport mode with social benefits and with the lowest external costs of all freight transport modes (infrastructure, congestion, accidents, emissions, energy, climate change, indirect external costs, as described in RICARDO-AEA, 2014) by many policy makers of countries with an active inland navigation. Modal choice is mainly driven by private and not by external costs and in order to compete with road haulage and to reach a modal shift, inland navigation needs to be competitive even when including before-(pre-) and after- (post-) haulage. The extra transhipment cost in case of the latter, especially when the last mile of the transport is done by a truck, needs to be taken in account. *Figure 23* shows the price difference between an intermodal solution with pre- and post-haulage and the unimodal road haulage.

[66] ASV (2015), Voortgang alleenvaart Westerschelde, Letter to the Ministry https://www.algemeeneschippersvereeniging.nl/nieuwsbrief/nieuwsbrief-april-2015/alleenvaart-westerschelde.html
[67] Article 1 of the Arrêté du 2 juillet 2008 relatif à l'équipage et à la conduite de certains bateaux de navigation intérieure
[68] The latest edition of the RPN can be found on https://www.ccr-zkr.org
[69] When navigating downstream of the Spijk ferry (kilometre pole 857.40) and provided that the German-Dutch border is not crossed in either direction, it is sufficient if the requirements of the Dutch law "Binnenvaart wet" (Staatsblad 2007 issue 498) are applied. (art.3.23 RPN, CCNR 2018). This means that only this part of the Rhine allows 'alleenvaart) "Binnenvaart wet" (Staatsblad 2007 issue 498) are applied).

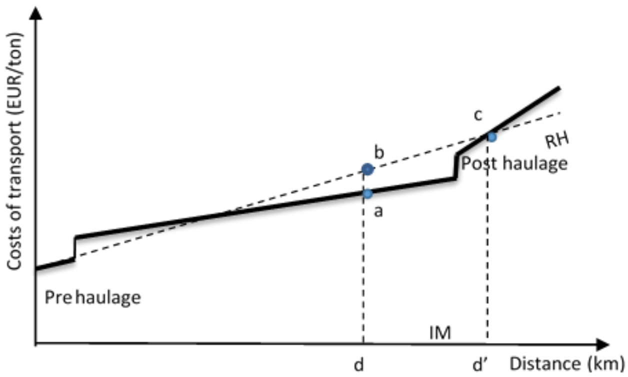


Figure 23: Cost difference between unimodal road haulage and intermodal transport
Source: Own composition based on Mommens K., Macharis C. and Verbeke F. (2013)

In case of shorter distances than *d*, the additional transhipment costs will be in favour of unimodal road haulage (RH) as modal choice if only the internal costs are taken into account[70]. In this case, subsidies can help to achieve a more preferable (for the society) intermodal solution (*IM)*, which could be the reasoning behind the pallet subsidies for IWT. Subsidies should then address the difference in price before distance *d*. If the *IM* has a longer distance than *d*, it becomes cheaper than unimodal road haulage (RH) until *c* with distance *d*', even without subsidies. The suggested pre- and post-haulage costs (*a* until *b*) are the same in theory, but are in reality different. Prices can also differ between road haulage during pre- and post-haulage which explains the different slope at the beginning of *IM* and at the end. The break-even distance is the distance at which the costs of intermodal transport equals the costs of unimodal road haulage (Mommens et al., 2015; Pekin et al., 2012; Rutten, 1998).

The PSB can also transport containers. In case of containers, no subsidies were identified, but the following example explains further. The PSB was used to transport a maximum of 13 containers for an intermodal pilot of the Flemish Institute for Logistics (2018)[71]. The pilot project included a roundtrip shuttle service between multiple locations between Izegem, Antwerp, Geel, Lovendegem and Olen across the Flemish region during four days. The containers were filled with garbage. Breakeven point was reached at minimum 24 containers for every stimulated trajectory according to the study. The following costs were taken in account:

- Pre-haulage: delivering and unloading the containers by truck at the quay with costs related to the mandatory weighing of the containers; cost of truck transport (cost per hour multiplied by the needed time). Costs related to the temporarily stacking of the containers depends on the location which was in case of the pilot the city Izegem at a daily cost of EUR 10 per container and an additional cost for the signalization for road traffic passing by.
- Loading the containers: costs relate to labour and equipment cost per hour
- Haulage by the PSB: costs relate to the daily price within limited 16 hrs a day in operation; the number of sailing hours depending on the waterway (locks, tides, up- or downstream); possible additional costs concerning repositioning, overtime,…etc.)
- Unloading the containers: costs relate to labour and equipment cost per hour
- Post-haulage: temporarily stacking of the containers under conditions as described during pre-haulage which is not an out-of-pocket cost. Loading the trucks with the containers and delivering them to the customer.

Subsidies are granted in the Flemish region to convince potential customers to transport pallets by IWT. In a first call for proposals, six companies were selected to receive a total amount of EUR

[70] For distance d it is assumed that the post haulage by truck follows the slope of RH after transshipment. If this is not the case, as in de post haulage part of IM, the area abcd' offers the price difference which makes IM more preferable than RH.
[71] https://vil.be/wp-content/uploads/2018/01/20180123-Slotevent-FRH-VIL-Flanders-Recycling-Hub-in-de-praktijk.pdf

1,525,000 from the Flemish government. The companies were Isolava, Blue Line Logistics, André Celis, Betonfabriek Coek, M/S Celandro[72] and Wienerberger.[73] These companies received the subsidy spread over three years and were allowed to use it for building a vessel, adjusting an existing vessel or upgrading the needed infrastructure of the company. The objective was that the companies keep on transporting pallets with inland navigation after the subsidy period, otherwise they would have to pay the maximum individual subsidy of EUR 200,000 back. The subsidies are given to support investments with 80% public and 20% private funding. The support to compensate for the difference between road haulage and additional transshipment costs with inland navigation in the first years of initiation lowers every year for every pallet. These costs relate to additional logistics costs, door-to-door logistics and pre-and post-haulage.[74] A second call was organized in 2013. The last call was in 2015 for EUR 1,000,000.

C. Interaction conditions

BLL and its shareholders are companies that have built up experience in innovation projects in inland navigation. They are strongly linked within a network of institutions. Their network is rather nationally and regionally focused than European, although recent participation in a European research program (INTERREG) and interest from the French company CFT, together with announcements in the sectorial press, indicate that the scope and focus of the PSB is being enlarged. The PSB has been participating in an ongoing INTERREG project North-West Europe since 2017,called *ST4W* and runs until 2020. It looks *for a management solution for shipment by inland waterway transport, providing to small stakeholders a simpler and cheaper access to secure data, and enabling them to share a hierarchical track & trace service of shipment, complementing the River Information Services, which localizes vessels.*

Other initiatives such as participation within the mobility lab initiative in Rotterdam for innovative starters and several innovation events, also contribute to the publicity of the innovation which could potentially invite innovation followers and show a growing linkage with existing networks (charterers, industry, other VO/O's).

Not all captains are attracted to this exploitation type. According to the interviews, there is a growing labour shortage of experienced captains and the freight market is currently competing with strong growing passenger cabin ships which offer higher salaries. The inland navigation is typically a family business sector with most of the times a family on board. The lack of accommodation could be less appealing if there is a choice to work on a vessel within a more comfortable working environment or a "truck on the water".

The organization in shifts on the other hand, could attract more people that prefer to work in daily shifts with the opportunity to return home at the end of each shift, which is on other ships and types of operations not always possible. This could perhaps be more attractive for sideways instream of labour forces (on-shore people that are willing to sail). Further research, including an interview sample of operators, can shed more light on the individual preferences of potential and existing crews.

The single crew member does not only have to sail, he or she also has to (un)moor and be trained in manning the crane during (un)loading operations. The impact of these tasks combined, could make the job more demanding than for an operator of a *Kempenaar* where on-shore equipment is needed to unload the vessel and where the operator is only needed to be on board of the vessel but does not have specific tasks during unloading. The impact of additional tasks for the operator, could be examined by further research.

[72] The motorship Celandro (50m, built in 1960) sunk on 15 March 2013 during unloading operations at Beton Coeck and was total loss and was scrapped later that year.

[73] https://binnenvaartlog.nl/zes-bedrijven-krijgen-vlaamse-steun-voor-palletvervoer-met-binnenvaart/

[74] Crevits, H. (2009), 1,5 miljoen euro ter ondersteuning van palletvervoer over het water, press release, Flemish government, https://www.mobielvlaanderen.be/persberichten/artikel.php?id=355

D. Capabilities

Because of the fact that the vessels are claimed to be clones from each other and the concept is very basic, no specialized knowledge is needed to build the vessels, which makes them more independent of shipyards and increases certainty of operation for charterers and shippers when repair or maintenance is needed. As mentioned, the next two PSB's that are being built are leaving the catamaran concept. Financial capability is considered to be relatively available for the further development of the PSB.

E. Market

The implemented innovation has the potential to be successful but it is too early to observe any market uptake (yet). It is not clear yet if pallet transport is sustainable without building subsidies and digressive subsidies for customers. The *de minimis* regulation of the European Commission seems not to allow significant support for an individual firm (maximal EUR 200,000 in three years) in risk of disturbing the market. The policy support is therefore limited in means and in time. Programs such as the quay wall program and modal shift policy can stimulate concepts such as the PSB. In reviewing the financial statements of BLL, the publicly subsidized Watertruck+ is considered direct competition. It could be the question if it is the role of the government to organize competition in the inland waterways and disturb the market with a completely public innovation. Although Watertruck+ looks for private investors and operators, and focuses on new flows, the development of the concept and the building of the small dumb barges is for 50% being done with public funding.

Pallet transport is mostly done for building material. Approximately 25% of freight transported by Belgian road haulage are building materials (VIM, 2012). The feasibility study showed that the highest potential modal shift could be reached if both producer and customer were located near an inland waterway. In other cases, the creation of a distribution center (Regional Water-Bound Distribution Centres, RWDC, Macharis C., et al., 2013) with pre- and post-haulage is needed. The calculations for the optimal location for these types of distribution centers were performed within the 'Build-over-Water' project[75]. The latter project claimed to shift 500 trips from road haulage with a reduction of congestion (lost hours) by 22,000 hours per year and of CO_2 emissions of 9,500 tonnes-equivalent per year[76].

Modal shift of palletized goods to the inland waterways are according to Macharis et al proven to be feasible for Belgium but with a break-even distance (2013). In a later study, Mommens et al. (2015), were the LAMBTOP model was enlarged to the European scale, show that the potential gains were lower than expected, mainly because previous research included only direct transport costs. Adding a total logistics cost model, did not show large enhancement if pallet transport would geographically up-scale.

3.7. Conclusion

The revival of pallet transport which is called by some (e.g. Macharis C., et al, 2013) the third wave (after containers and dry bulk) for the inland navigation, has created an opportunity for innovation initiatives such as the pallet shuttle barge. The analysed PSB type did not find its way (yet) to market uptake but as the number of shareholders is growing, and more vessels are being built following growing demand, the PSB still shows potential. At the end of 2018, four PSB's will be active and additional services will be offered. The pallet market is estimated between 6 and 7 million tonnes of pallets that can be shifted towards inland navigation but shows limited potential at European scale. With only 565,518 tonnes of palletized goods transported by the inland navigation in Flanders in 2017, there is still a significant road ahead to shift the remaining of the mentioned potential.

[75] http://www.wctrs-society.com/wp-content/uploads/abstracts/rio/selected/2807.pdf
[76] http://www.verenigingwenz.be/Repository/Documenten/02_Wenz_Presentatie_KoenValgaeren.pdf

The policy dimension of the case does not fall within the scope of the (Pan-)European policy, which made the developed policy analysis tool in this research (as described in the methodology chapter) not applicable. Nevertheless, some important insights need international answers. The limits on single crew navigation for vessels under 55m, reduces the potential market for the business case. In times of further automation and the implementation of advanced river information systems, the regulatory distinction between 55m vessels seems to be an arbitrary rule and invites further research. In order to enlarge the market for the PSB, stimulating potential market uptake and encouraging other small vessels in direct competition with road haulage, it is recommended to review the legislation concerning single crews with sufficient knowledge of existing technological support on board of the vessel.

Although the influence of the pallet subsidies to stimulate customers and to support shipbuilding can be considered rather limited in individual support and in a period of three years, it is possible that the removal of the subsidies could be a threat for the further market uptake of the PSB and of pallet transport in general. The latter invites further research and more available data.

The societal benefits of reactivating the small waterways which are usually in direct competition with road haulage, were not the main focus of this case analysis, but are considered sufficiently high to legitimize public support for this kind of innovation. The SIA showed concerns about the regulatory restrictions for single crew operation that limits the market for the PSB and other small vessels.

After the small waterways, the next chapter goes deeper in the development of the first automated vessel in IWT. What is needed to develop an automated vessel and what is already possible? Could there be a positive business case already and what should policy do. It is the first attempt according to the consulted literature that an SCBA and SIA are used on a fully automated vessel in IWT.

VII. The Automated Vessel

This chapter presents the research findings of the current status of automated vessels in the inland navigation. Three analyses were applied in this case focusing on barriers that could prevent market uptake (SIA), the social costs and benefits of automation (SCBA), and on the institutional framework of automation in the inland navigation (PA). In contrast with former analyses in this research, an introduction and a brief literature review are added because of the larger length of this analyses.

1. Introduction

Automation is an ongoing and unavoidable development that has already changed the inland navigation sector fundamentally. The auto-pilot is already installed in most wheelhouses and the machine room runs more and more automated. One of the next possible steps is the technology for fully automated operation systems (AOS) under conditions and with the possibility for human intervention on-board and on-shore which is being currently developed. Numerous companies are involved in developing the first automated freight transporting vessel, foreseen to be available within a few years both in maritime and inland navigation (Seafar, Rolls-Royce, Wilhelmsen, KONIGSBERG, …etc.).

The question whether a completely automated vessel will be a disruptive game changer as some believe, or rather just an incremental innovation that gradually replaces all crew members, is still a difficult one at this stage. It has the potential to be disruptive in the entire supply chain as all transport modes are discovering their automation potential. The technology is assumed to have a possible 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).

Fully automated, possibly unmanned vessels are coming, but it is difficult to predict when they will be ready to buy from the shelf. First of all, 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 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.

A brief literature review offers insights in the development of this innovation, which is covered by the first section of the case analysis. A second section investigates the barriers of fully automated vessels adoption and implementation from a consumer and regulatory perspective (SIA). Thirdly, a cost-benefit analysis is conducted. Equally, an indication is given of what inland waterway policy can do or not do.

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. The recent CESNI/QP competence table that developed the upcoming standard for the European inland navigation boatmasters and boatmen, is compared in the final part of this chapter with a possible automation counterpart. But first of all, automation in inland navigation needs a definition. When is a vessel automated and what is the difference with autonomous. This is analysed in the next section.

2. Literature review

Not much literature is found for inland navigation specifically, but automation in other modes has become in recent years a global emerging industry led by companies such as Google for road haulage of freight and passengers, or Rolls-Royce for maritime ocean liners, and several others. 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 (MUNIN project[77], AAWA and Yara Birkeland), focusing on maritime transport though.

2.1. Definitions

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

Autonomous vessels	**Rephrased or quoted from**
The vessel "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. (1998:316) Alami R, Chatila R, Fleury S, Ghallab M, Ingrand F. An architecture for autonomy. International Journal of Robotics Research. 1998;17(4):315–337
"**Autonomy** refers to systems capable of operating in the real-world environment without any form of external control for extended periods of time."	Bekey (2005:1) Bekey GA. Autonomous Robots: From Biological Inspiration to Implementation and Control. Cambridge, MA: The MIT Press; 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 *Human vessel interaction*;" "The condition or quality of being self-governing."	Huang H-M. Autonomy levels for unmanned systems (ALFUS) framework volume I: Terminology version 1.1. Proceedings of the National Institute of Standards and Technology (NISTSP); Gaithersburg, MD. 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, Jennings NR. Intelligent agents: Theory and practice. Knowledge Engineering Review. 1995;10:115–152
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), A model for types and levels of human interaction with automation, IEEE Trans Syst Man Cybern A Syst Hum. 2000 May; 30(3):286-297.
Automation	**Quoted from**
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 offers assistance 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, Verplank WL. (1978), Human and computer control of undersea teleoperators (Man-Machine Systems Laboratory Report) Cambridge: MIT, p.168-170 http://www.dtic.mil/dtic/tr/fulltext/u2/a057655.pdf

Table 26: 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 (Table 27).

[77] 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

Level of autonomy	Description
AL 0) Manual – no automation function.	All action and decision making is performed manually – i.e. a human controls all actions at the ship level.
AL 1) On-ship decision support	All actions at the 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 at 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 at 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 27: 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

The following schematic (Table 28) 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.

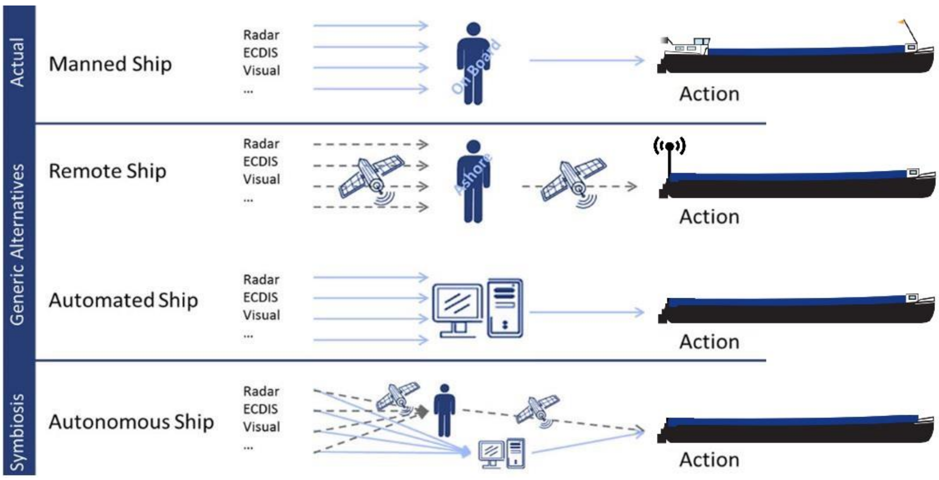


Table 28: Autonomy stages adjusted from MUNIN[78]
Source: own adaptation of the schematic of MUNIN: http://www.unmanned-ship.org/munin/about/the-autonomus-ship/

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. Also, 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,

[78] 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.

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). The CCNR draft resolution RP document 18-32 (2018)[79] recently described a proposal to define automated navigation.

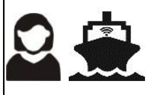
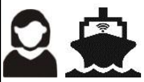
	Level	Description	Navigation (manoeuvres, propulsion, bridge,...)	Sailing area monitoring & interaction	Fall-back measures for dynamic navigation tasks	Remote controlled
Human operator performs most dynamic navigation tasks	0	**No automation** the full-time performance by the human boatmaster of all 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)*				No
	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 when activated	3	**Conditional automation** the **continuous** application of an **AOS** for all dynamic navigation tasks within a specific context, including collision avoidance, assuming that 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 *F.ex. the AOS is not able to pass a lock without human intervention*				
	5	**Full automation** 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 29: Levels of automation as proposed juridical definition for the IWT
Source: based on CCNR, 2018 (some parts are rephrased)

Table 29 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'. With autonomous, the vessel decides by itself, performs fully independent even without remote control, adjusts to all given situations and external variables, meanwhile maintaining the safety standards. Autonomous also includes a highly-developed form of artificial intelligence.

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

A completely automated operating system (AOS) has to 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. It 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 has to retrieve vital information and adjust its course to maintain the safety level. The AV also has to be able to communicate with other vessels and their operators as with shore infrastructure (bridge and lock masters, terminal dispatches,…).

In reality, the Rhine fleet can be situated at the end of level 1 (Table 29). The mandatory use of AIS (automatic identification system) since 2014 and other implemented river information services, and devices (auto-pilot), together with 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 innovation initiatives, the development of a first generation AV's seems feasible from a technological perspective.

The more data is being gathered about 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. Furthermore, 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.

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&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 Center* (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 boatmasters 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.

As ‘autonomous’ requires a certain degree of artificial intelligence, the term ‘automation’ is preferred in this research, with the following definition:

Automation: *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.*

2.2. Costs & benefits from literature

The MUNIN project from the European Commission performed 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) would be 7 million USD more (over 25 years) than a conventional dry bulk vessel (CV), providing 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), a reduction in fuel consumption and emissions and of course in crew costs.[80]

Although the MUNIN project is only conceptual for now, the findings could also 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 (big) data networks;
- Bridge functionalities, manoeuver 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-governance to replace paper documents and international data-sharing.

[80] 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

A. Costs

The voyage costs (related to fuel and port calls) are considered to be variable. 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 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 in 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 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 SCC has an estimated annual cost of USD 873,957 and a one-time cost of USD 2,131,800 for the situation room, software, hardware and other office equipment (MUNIN, 2016: p21-55). The SCC costs could be considered similar with an inland navigation concept.

The development of the Yara Birkeland by Kongsberg is a Norwegian project which is supposed to have 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, is also planned to sail fully electric and will cost approximately USD 49 million (vessel and on-shore equipment). 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 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).

B. Benefits

The main social benefit of automation of vessels is assumed to be an increased safety by removing the human error. However, as Wróbel et al. (2018) claim, more data (accident data) has to 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. 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 has to be extensively rethought with numerous scanners and devices, possible auxiliary supportive innovation in the field of robotics is not taken in account in the analysis. Knowing that most accidents occur because of human error and some confidential sources explain that the rudder phenomena can be used as general excuse to hide human error and responsibility by claiming that a rudder malfunctioning caused the accident, it can be assumed that further automation could make 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. from own experience, 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 come back 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 completely 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.

The effectiveness of hazard mitigation approaches is based on Leveson (2011) who created an extended model of causation (Systems-Theoretic Accident Model and Processes or STAMP). She makes an important distinction between reliability and safety. Two or more system components could be perfectly reliable, but because of dysfunctional interaction between them (mechanical, digital or human component), accidents still can occur. High-tech products do what they are designed to do (by humans). Without proper testing and intellectual management, design errors or insufficient process recognition can lead to reliable but unsafe systems. Leveson defines reliability as: *“the probability that something satisfies its specified behavioural requirements over time and under given conditions it does not fail.”* While safety is defined as *the absence of accidents, where an accident is an event involving an unplanned and unacceptable loss*. Using the information of AIS or radar by a human or robotic operator can be proved reliable, but a dysfunctional reading of the information or receiving insufficient information because of a sudden unique event, can still lead to accidents. Vice versa, unreliable actions can lead to safety if the unreliable and unexpected behaviour of one of the components (doing something that is not in the procedures, against the law or against the design) leads to a successful and safer outcome. In some circumstances, rules have to be broken to avoid accidents or to reduce damage if performed successfully. But when the attempt to avoid an accident fails, this could be much more severe, especially in a legal sense, if procedures were not followed.

Figure 24 shows the tensions between three important drivers of an AOS. In order for the innovation to be successful, a balanced approach should be defined. Investing in a system with too much focus on safety could lead to uninteresting performance or productivity. Reliable systems also need minimum requirements. A regulatory standardization body could be useful in aiding the innovator in search of the optimal balance for the society and for the innovator.

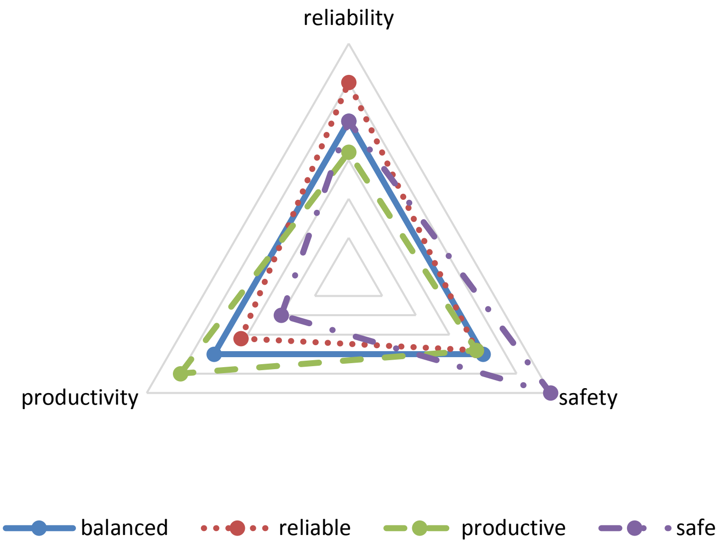


Figure 24: Triangle of safety, reliability and productivity in engineering and possible scenarios
Source: own creation, based on Leveson (2011)

2.3. Automated industrial plants

An automated vessel has a number of processes that are comparable with an automated plant. Cainarca et al. (1989) examined empirically a number of factors that could be relevant for the innovation study of an automated vessel. Their definition of what they call *flexible automation systems* “refers to a set of integrated systems which, owing to advanced hardware and software, allow a predefined variety of products to be designed and / or manufactured automatically.” The last part can be replaced by “a predefined variety of processes and services to be performed automatically,” as it is more the case for inland navigation. Cainarca et al. also summarize a series of factors that influence innovation adopters. They identify high barriers concerning “lack of information and specialized know-how; lack of technological complementarities between integrated automation systems; limited financial status, highly uncertain successful adoption increases capital costs; substitution and sunk costs concerning preexisting equipment and organizational routines; expectation of rapid technological improvements resulting in slower adoption and innovation diffusion; introduction of complementary innovations for the profitability of the adoption of such a flexible automation system.” The latter expresses the need for changes in processes, organizational procedures, market strategies and in firm culture. These factors are also relevant for an automated vessel.

2.4. Obsolescence economics

In case of automation which deals with the market of mainly electronics and software development, *the Economic theory of planned Obsolescence* (Bulow, 1986) could be quite relevant. This theory refers to the production of goods with uneconomically short useful lives, stimulating customers to repeat purchases. In electronics, it is a common practice that the life span of most of the offered products is relatively short (e.g. software, computers, printers…). Perhaps industry does not always necessarily intend to design products with a short life span (Bulow relates intended and planned obsolescence especially by monopolist players without fear of other entrances of new players). But due to a relatively fast changing market, the dominant rationale can be to shorten the life span of different products or systems.

When programs/systems/devices (PSD) need auxiliary PSD to work, there reliable functioning is jeopardized if one or more of the needed PSD stops. Also an update of one of the PSD can cause compatibility issues. If memory capacity is not enough, or processor performance is too low to manage the updated programs or to stock the growing amounts of data, problems could occur in the digital processes related to automation. These are hidden costs and are not always taken in account. Also the value of second hand automated vessel technology could be considered lower because of the quickly outdated technology. The theory of Bulow could therefore be relevant for the inland navigation market. The relatively small size of the market could give headways to specialized monopolistic firms offering a part of the automation PSD on board of an automated vessel.

It could be possible that without proper regulation and efficient inspection, low quality products with a relatively low life-span will make automation less reliable in the short run, but as other firms find their way in to the market, more durable solutions could be offered.

When PSD get outdated, communication with other vessels or infrastructure can be affected, or can lead to even worse situations. Furthermore, maintenance will probably have to be conducted by more specialized ship yards or outsourced firms (in the short run possible monopolists) until all maintenance can be automated. Next to the complicated and specialized systems check, the ships deck, the engine room and the hull, all need maintenance. The level of digitalization will probably change the ship repair business as maintenance of rather complex systems becomes more specialized and could even lead to higher maintenance costs in the short run than more conventional ways of sailing with a crew on board.

2.5. Auxiliary innovation

During the next level of automation of the current Rhine fleet (level 2 as described in Table 29), the helmsman will receive suggestions from the ships’ computer and then decides. The auxiliary innovations are advanced scanners for depth, width and bridge height (e.g. Bridge scout, CoVadem), trip plotting software including actual weather, wind and current information, calculation tools for optimized speed according to fuel-efficiency next to gyroscopes, radars, electronic chart display systems (ECDIS) and loading-unloading monitoring systems. Most of these systems are already available on a modern vessel but a full integration or sharing between the systems, still has to be improved in order to have an integrated interface for the helmsman and an AV that could make suggestions based on the interaction between all available systems. To improve safety, the integrated vessel system should be able to communicate and share information with others vessels that are in the same sailing area.

The innovation hype cycle as presented in Figure 25 describes several factors that are needed, including auxiliary innovation, to reach level 5 of automated navigation in IWT. The current enthusiasm which is quite noticeable amongst several actors, helps to situate this level of automation innovation before the ‘peak of inflated expectations’. In order to reach the plateau of productivity where the innovation is implemented and reaches market uptake, a phase of maturation is essential. After the technology trigger and the high expectations, the reality hits, which is called the ‘*trough of disillusionment’ (*Gartner, 2017*)*. In this phase, the AV builders and investors are vulnerable. When all essential success factors are in place, the plateau of productivity can be reached and the real first-mover advantage becomes accredited by the market uptake.

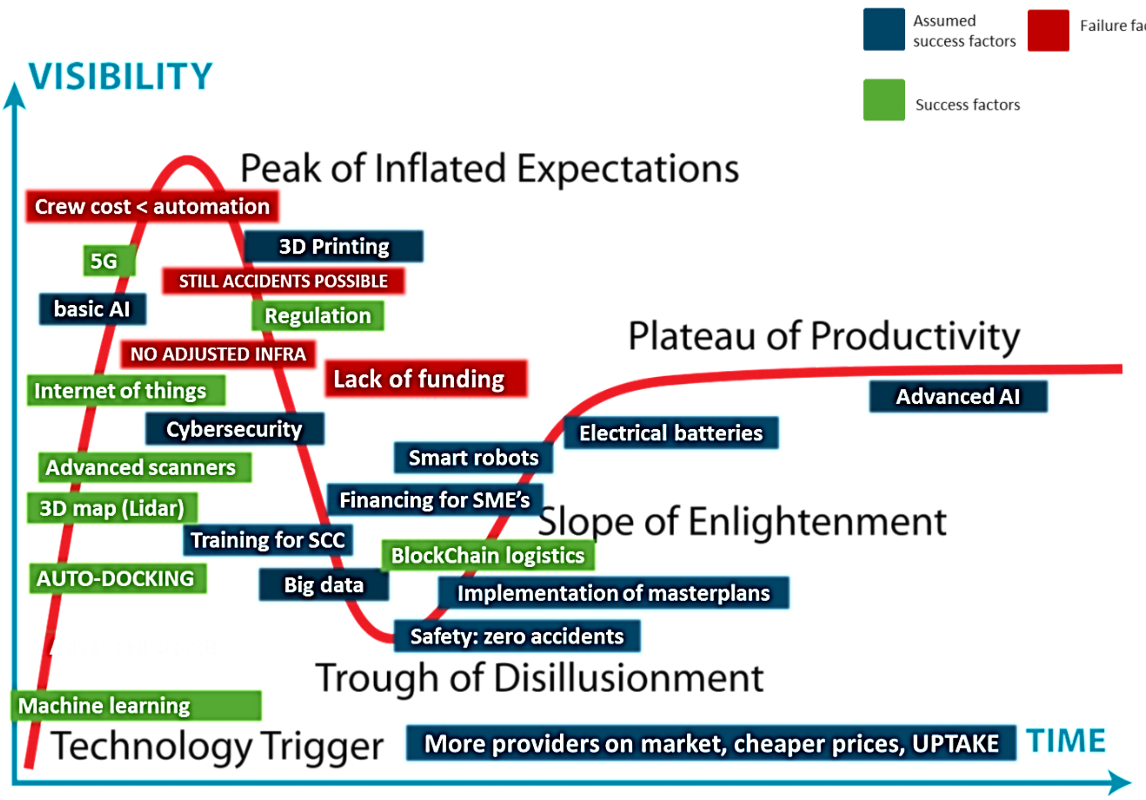


Figure 25: The innovation Hype Cycle of Automated vessels (towards level 5) in IWT
Source: own creation, inspired on methodology of Gartner[81], own interviews and expert meetings

The presented hype cycle is not an exhaustive summary of all necessary auxiliary innovations and success factors, nor is it bullet-proof. Even without electrical batteries (which is claimed by some as the most optimal power source for automated vessels), successful market uptake occurs or not.

2.6. Supporting or replacing human tasks

To have a fully automated vessel, several other developments need to be implemented in order to replace all crew tasks and to truly have an unmanned vessel of level 5. To summarize all the tasks that have to be replaced which are conducted now by humans on-board of a vessel, the qualification tables of CESNI/QP[82] present a detailed and useful overview (annex 3.1 shows the management level).

The competences are divided in an operational and management level[83]. For this analysis both competences are combined. Next to the competence description, the CESNI/QP table also presents which kind of knowledge the crew member has to possess, the method to demonstrate this competence and the criteria to evaluate the competence.

[81] Based on the example of innovation hype cycle of Artificial Intelligence by Gartner inc. https://www.datanami.com/2017/08/29/ai-fares-gartners-latest-hype-cycle/

[82] CESNI QP (cooperation between EU and the CCNR) is developing modern standards for crew requirements for the IWT. The EU directive 2017/2397 on the recognition of professional qualifications in inland navigation refers conditionally by delegated acts to the CESNI standards which are more detailed (including examination method) than the essential competence requirements in annex of the EU directive.

[83] The division between operational and management level are rather a simplification of the reality on board of the vessel and does not necessarily reflect any hierarchical division on board. It is perfectly common that a captain in certain situations performs operational tasks while a helmsman is navigating and thus conducting management tasks. But this distinction is rather irrelevant for an automated and unmanned vessel. Only the content of necessary essential tasks is important to link with possible innovations and to determine what a complete AOS on an unmanned vessel should be able to do in supporting human actions or at a certain point in time replacing all human actions.

Competences of the AOS on an unmanned AV (level 5) for freight transport
The AV should be able to: • **navigate the vessel** in full awareness of the ships integrity and limitations[84] ; implement technical certificates and cargo bill of lading with automated mooring devices, anchor winches, barge coupling devices; use the deck equipment (preferable automated), cranes and others; automated systems for bilge, ballast and piping; monitor operations and maintenance; • **scan environment and real-time situations**, weather conditions, current and react to this information[85]; • **determine optimal speed and use propulsion**; ecological, safe, according to traffic regulation, economical • **apply knowledge of designed hull protection** (e.g. inbuilt automatically moveable hull fenders or shore protection); • recognize and apply relevant **traffic regulation** such as SIGNI, RPN, CEVNI, ADN, IALA …etc. (recognizing blue boards, cones, etc.); handle and maintain the craft´s day and night marking system, signs and sound signals; buoyage and marking system; • use AIS and other **communication** with vessels, humans, waterway managers and other AV's and their AOS's[86]; collect & store data including backup and data update; follow instructions for data protection (Data-security and big data transmission); present facts using technical terms in the home country language and in at least one foreign language • **instruct shore based assistance** in pre-and after activities to connect or disconnect to facilities, or to lead specialized robotic applications scan, weigh and monitor cargo and take precautions concerning stability and safety;[87] • **load and unload** cargo, planning by itself or implement human planning according to ship, stability, integrity and limitations; prepare tanks or cargo space for loading with automated hatches and cleaning devices • **steer robotic maintenance and spare part replacement** or outsourced to human ad hoc manning; performing maintenance work on marine-, electrical-, electronic-, control engineering equipment to ensure general technical safety; • perform **damage control/analysis, identify errors** and failure identification with fallback systems and human-to-machine, machine-to-human and machine-to-machine interfaces; manage **alarm systems** on board to warn passing ships, and able to recognize alarm systems on other ships • use automated systems to assist in **rescue operations**; automated **fire identifier and extinguisher**

Table 30: Competences (non-exhaustive) of the AOS replacing a crew
Source: Own creation based on the competences tables of the CESNI QP working group (2018), non – exhaustive.
The management competences are mentioned in annex.

The tasks and competences (*Table 30*) on a freight vessel that an AOS shall need to perform in order to reach level 5 of automation,[88] has to guarantee a comparable (or higher) service level as offered by

[84] The AV should take into account geographical, hydrological, meteorological and morphological characteristics of the main inland waterways; plan a journey and conduct navigation on inland waterways including being able to choose the most logical, economic and ecological sailing route to reach the loading and unloading destinations taking into account the applicable traffic regulations and agreed set of rules applicable in inland navigation. Navigate on European inland waterways including locks and lifts according to navigation agreements with agent; respect and apply traffic regulations applicable to navigation on inland waterways to avoid damage; consider economic and ecological aspects of the craft operation in order to use the craft efficiently and respect the environment; take account of technical structures and profiles of the waterways, and use precautions; work with up-to-date charts/maps…etc. More detailed competence description can be found in the annex.

[85] AOS should scan the changing environment and act accordingly while knowing the effects of water movement around craft and local effects on sailing circumstances including the effects of trim, shallow water relating to craft's draught.

[86] AOS should be able to communicate with all available devices, and the shore control centre. The AOS includes also an on-board interface for human interaction in order to intervene if necessary. Communicate present facts using technical terms with knowledge of and ability to use the required technical and nautical terms as well as terms related to social aspects in standardized communication phrases; Collect, save and manage data with regard to data protection laws. Knowledge of the use of all the craft´s computer systems and ability to collect and store data in accordance with applicable legislation.

[87] According to relevant national, European and international regulations, codes and standards concerning the operation of transporting cargoes and involving loading, unloading and transport operations; compose stowage plans including knowledge of loading cargoes and ballast systems in order to keep hull stress within acceptable limits; control loading and unloading procedures with regard to safe transport; differentiate various goods and their characteristics in order to monitor and ensure safe and secure loading of goods as laid down in the stowage plan; respect the effect on trim and stability of cargoes and cargo operations; check the effective tonnage of the craft, use stability and trim diagrams and stress calculating equipment, including ADB (Automatic Data-Base) to check a stowage plan; know the function and use of the ballast system; manual and technical methods of determination of the cargo weight on various types of craft; the possible detrimental effects of inadequate cargo handling; effective communication and working relationships with all partners involved in loading and unloading procedures; use the technical means for handling cargoes in/from craft and ports, and labour safety measures during their use; establish procedures for safe cargo handling in accordance with the provisions of the relevant safe working regulations; determine stability, trim and stress tables, diagrams and stress-calculating equipment.

[88] competences concerning social behaviour, health protection, crew team building, on-board training, alcohol and drug use, social legislation and administrative requirements are excluded

a conventional vessel. If these tasks are outsourced to other companies specialized in ad hoc manning for berthing and (un)loading, then a different business plan is needed which depends on the costs of these outsourced services in order to be still competitive against existing manned or conventional vessels. Passenger vessels are excluded from the analysis because of the focus of the research on freight transport. Passenger or cabin vessels have an extra complexity where automated PSD's have to deal with passengers' behaviour and preferences.

In the first line of competences, several challenges for automation engineers and developers are already put forward. A ship has to moor, unmoor and in some cases couple with other vessels[89] in a safe and reliable manor. Reliable scanners (e.g. weather conditions) are needed, linked with the AOS of the AV, delivering information to initiate on-board responses to adjust to suddenly changing conditions. Not only visual information is needed; also smell can be useful (e.g. tank leaking) to avoid dangerous situations.

The crew is required to know CEVNI (UNECE, *Code européen des voies de navigation intérieures*) or other police regulations (RPR of the CCNR). An AOS should also be aware of all the different waterway signs and signals as described in the SIGNI (UNECE, *Signs and Signals on Inland Waterways*), IALA (International Association of Lighthouse Authorities, on maritime waterways) and navigate according to existing traffic rules.

One of the mentioned tasks is to install fenders on the necessary height to protect the hull during mooring or berthing. Some vessels (e.g. MS Splendid) have wooden or rubber fenders that are designed into the hull, but most vessels have wooden fenders or even old tires (if allowed) manually. The possible problem of inbuilt fenders is that the fixed height cannot be used in all situations and also could have a low lifespan. Infrastructure managers or terminal operators could choose to implement fender systems at the docking stations. Some designs of automated docking stations keep the ship at a safe distance from the wall.

Another challenge occurs during loading and unloading. Preparing these processes takes some time. For unloading a tanker barge, it is necessary to safely connect the rubber shore pipelines with shore installations. Other tasks concern cleaning, maintenance and checking the equipment that is needed during loading and unloading. In case of automation, these tasks can be outsourced to shore teams in the assumption that they have sufficient knowledge of the vessel to conduct on-board operations. Furthermore, during loading, the crew assists the management in monitoring the safe and stable loading of the cargo on-board. From the moment, when the cargo is loaded on the vessel, it becomes the full responsibility of the captain. If a vessel becomes unmanned, assuming that all essential tasks are automated, there is an important legal question concerning liability and responsibility that remains.

At the management level, several essential competences are required that also include the interaction with actors at shore. The transport contract with the charterer or customer determines the programming of the trips' AV. During the execution of the contract or during the trip, 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 vessels and especially pleasure crafts and even smell could present potentially dangerous situations for ship, cargo and human life on colliding manned vessels.

Existing technical regulation requires for a number of manned barges on-board equipment such as mariphone, machinery and installations needed for lights, sounds and optical signs, domestic litter

[89] Prices were not given for maintenance and servicing according the recommended schedule. For automated unmooring and mooring, using a vacuum system, the total investment for four units will be in the first year EUR 1,800,000. The vessel needs additional minor structural upgrades in order to arrange the mounting layout for the mooring units. For tanker vessels, complying to special requirements of the ADN, an additional EUR 50,000 is added for each unit. Automated mooring devices are on the market, but not always operational (walls at most locks are not always ideal) and relatively expensive compared with the total investment cost of a vessel of 110 m in this example.

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 has to 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 are able to 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.).

On the 8th of August 2018, the Russian government announced that they would define the concept of unmanned vessels for sea- and river transport[90] within 3 years, while making an interesting distinction between external captains, standards for e-navigation and the use of information systems. In the CCNR countries, the juridical status of all the necessary information systems and what is called in this research AOS's shall be an important issue to tackle in order for the innovation to be successful. The external captains need specialized training in the first phases of automation (level 2-5) where human decision is still important until it becomes merely intervention in case of emergency and system failure.

Not all tasks should be replaced at once, nor does that seems feasible at this stage. Technological advancements, regulations and basic economics, should provide an answer as to whether all human tasks should or could be replaced by robotics or by outsourced companies that visit the vessel, or whether a minimum crew still remains on-board. All of these scenarios could possibly need standards and legal definitions. As an example, mooring and unmooring could be done by automated docking stations (on shore or on the vessel), by an ad hoc human crew put on board before berthing or by people at the terminal or other shore installations (e.g. locks). In the scenarios where human intervention is still needed, the vessel owner/operator (VO/O) should judge if specific knowledge and experience of the vessel is crucial to safely moor and unmoor. In a fleet where there is a lack of standardization in vessel design, this could present some practical problems but which are still manageable if taken in account sufficiently in advance.

[90] Korolev, I. (2018), In Russia unmanned vessels are being legalized, http://www.cnews.ru/news/top/2018-08-19_v_rossii_legalizuyut_morskie_suda_bez_ekipazha

3. Systems of Innovation Analysis

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, but there is a difficulty in defining the concepts that are used (e.g. level of automation). The SIA helps to define these concepts further (e.g. which level of automation is feasible and what are the barriers). The main focus in this analysis is on fully automated navigation backed by an SCC.

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. But this list is probably not exhaustive and can change rapidly.

3.1. Current situation

Most of the current CCNR fleet is situated at the first level of automation (Table 29). 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 (level 5) requires a completely 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). Level 2 (and parts of 3) of an AV allows refitting existing vessels. 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).

AWS is in its initiation phase. The experiments that are currently being conducted could provide more information on how an AWS should behave in several situations. The focus of this development is more on automated navigation than on other automated processes as described by the CESNI/QP table of competences (Annex 3.1). Gradually, and as the innovation and its auxiliary innovation improve (if it does not fail), 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.

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.

A number of 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*[91]. The *MS Jenny* was used as demonstration ship to test four support systems: the bridge 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 manoeuvers; 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 a number of insight but no PSD's 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-controlled[92]
- *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
- *"Autonoom varen in de Westhoek"* or autonomous sailing in West-Flanders: small experiment of unmanned sailing [93]
- *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-keelcrab*[94] are currently on the market for maritime vessels.[95]. 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. Automated docking in all situations is needed to replace these tasks and to make AV's 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, AV's are not yet operational in all circumstances.

Beyond inland navigation, developments in other sectors should be looked at. 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

[91] Guidance and assistance systems for increasing the safety of navigation on inland waterways. The LAESSI project was funded by the German Federal Ministery 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/

[92] https://novimar.eu/

[93] For the project "Autonoom 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/autonoom-varen-de-westhoek

[94] http://www.keelcrab.com/en/

[95] 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

iron ore[96]. 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 could ultimately lead to innovation failure for the IWT automation. Moreover, if inland navigation does not evolve towards more automation and has to 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 center, refinery, sea vessels after transhipment 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 centers, 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 center or a ship yard nearby. This evolution or supportive innovation is not taken in account in the analysis and goes beyond the scope of this research; however it is still 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 at the moment 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*[97] 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, a number of the mentioned tasks by the CESNI/QP table (annex 3.1) could already be automated by existing technology. It will be a matter of mainly time and

[96] Retrieved from http://www.riotinto.com/media/media-releases-237_23264.aspx; https://en.wikipedia.org/wiki/Zarya; https://waymo.com/;

[97] https://sea-machines.com/

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.

The SIA matrix (Table 31) 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[98] 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 at level 5 (Table 29) which is considered to be in the initiation phase with small scale pilot projects.

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

Table 31: Systems Innovation matrix of the initiation phase of a fully automated and unmanned vessels
Source: own creation, 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 provide sufficient infrastructure (mooring problem), other public actors need to guarantee cyber safety, regulators should allow for the new technology to be developed and solve the legal issues concerning liability, crew and technical requirements. Shippers, forwarders and vessel owners should also provide a level of infrastructure and learning capability to be able to work with the new technology.

The infrastructure for a knowledge network of institutions is identified at a global level. Hard institutions and the lacking of mooring infrastructure are important barriers for the AV but do not prevent the development and implementation of small survey vessels. At 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 when implementation is reached. Companies such as Seafar and the Shipping Factory are identified as innovative companies with the capability to initiate pilots and support research. Governments and port authorities also provide funding and organize or facilitate pilots.

It should be clear by now that a fully automated vessel needs a redundancy of robotics, automated systems to replace crew members (unmooring, repair and maintenance; loading and unloading procedures and cleaning) or outsourced activities by an ad hoc crew. Some of the needed robotics are

[98] Next to the InnoSutra project as referred to in deliverable Literature review, Woolthuis et al also refers to SIA (Woolthuis, R., Lankhuizen, M., Gilsing, V. (2005) A system failure framework for innovation policy design, Elsevier, Rotterdam University, Technovation, 25: 609-619. https://ac.els-cdn.com/S0166497203002037/1-s2.0-S0166497203002037-main.pdf?_tid=9a1a3186-a531-491c-823e-c79dcda2b314&acdnat=1535130716_d6c735d41ae767059a41bb2c9d7e7189

innovations that are already on the market for the maritime sector. However, they still have technological challenges and come with a relatively high cost.

3.3. Discussion

Most actors are (semi) large companies, ports, waterway managers and research institutions that are involved in the development of automated vessels. 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 outdated infrastructure for unmanned vessels. The possibilities for barge convoys and platooning seem also feasible in the short run.

Another key issue is the perception of the public. The window of opportunity and all the expressed interests from companies and governments (worldwide) in automation of vessels and vehicles could be threatened by fatal errors with significant exposure. In the end, automated vessels or vehicles do 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.

3.4. Initial conclusions

The IWT fleet is considered to be in general at the end of level 1 in the automation scale (Table 29), with systems to assist in steering such as the auto-pilot and AIS. Some elements 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 according to some interviewees moving very rapidly. Within two or three years, it could be possible to implement an unmanned helm or AWS (only navigation) as a commercial product if regulators agree and with or without a SCC as fallback system according to several respondents in the interviews. A fully unmanned vessel without crew to intervene also depends on further robotic developments which should be tailor-fitted for the IWT and infrastructure adjustments. The latter can be replaced by (outsourced) ad hoc human crews with sufficient knowledge of the uniqueness of every unstandardized IWT vessel if the new fleet of AV's is not standardized.

Automated vessels which do not have to comply with European regulation, such as the depth-scanner boat (*de Tuimelaar*) in the Antwerp port or small river ferry boats, could be implemented faster. They do not require loading or unloading procedures, are less dependent on market demand, have fixed trajectories and could easily be moored or unmoored on shore (same points for departure and arrival, no locks) or with automated docking stations (with shore power combined) such as in Norway (passengers ferry "Folgefonn").

The main issue that innovators point out is the regulation bottleneck that they encounter. They claim that technology is already there. In this case, there is a noticeable window of opportunity. Hence, the Netherlands and the Flemish region decided to transform their waterways into one transnational experimental zone for new 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 at 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.

The policy decision makers play a crucial role in granting derogations and adjusting regulation to further develop and implement this innovation. If automated vessels have to comply with existing crew regulation according to their exploitation mode (A1, A2 or B), the business case behind this innovation could be weakened and lead to failure.

It becomes clear that automation is not only one device, but rather an integrated set of advanced subcomponents and devices (PSD's) 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.

3.5. Detailed analysis

The SIA matrix shows only the initiation phase as no automated vessel can be bought on the market yet (implementation phase) or is being developed (yet). The matrix shows what initiatives could be taken in reference to the SIA structural categories within the innovation network.

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 needs a complete make-over. Bollards ought to be supported 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, cranes, should all be revised and upgraded in order to attend unmanned freight vessels (both liquid as dry bulk, containers, project cargo, etc.). Bunkering facilities should be rethought and redesigned for automated use. The communication infrastructure should make it possible to safely communicate with unmanned vessels. In reality, 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 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 million[99]).

The digital structure could be even more challenging concerning big data exchange and data security. A remote-controlled vessel could be vulnerable for hacking. Policy could play an important role in building a safe and secured digital infrastructure, however this issue goes broader 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.

A.1. Automated docking systems

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.[100] The first generation systems were tested

[99] https://www.marineinsight.com/shipping-news/gard-evolves-insuring-sailing-ships-autonomous-ships/

[100] In May 2015 this technology was recognized by the OECD. At 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.

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 has to mature. Also the maritime design has to 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 bollard.

For a ship at level 5 (fully automated and unmanned), infrastructure needs to be adjusted. 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 Zeeland company, called “Mooring Systems Limited”, with the first “IronSailer Series I” on the rail passenger ferry “Aratere” in Spain[101].

Examples can be found in Melbourne, Dover, Salalah (Oman), Devonport (Australia), Picton (New Zealand), Helsinki (Finland) or in St. Lawrence Seaway (Canada), 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 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[102].

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).

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 a vertical guiding system attached to a bollard[103]. 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.

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

[101] http://www.cavotec.com.ua/download/cat9/AMS.pdf

[102] http://megastar.tallink.com/the-west-terminal-2-will-have-the-first-automated-ship-docking-system-in-the-nordic-region/

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

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 at the shore, the issue of liability could be the reason not to use it. If something goes wrong, the berth operator could become responsible[104] 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 (Table 29) 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.

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 be determinant for the diffusion of the innovation.

B.1. Hard rules

As in maritime transport, a number of IWT regulations needs to be addressed in order to make the development of automated navigation possible. Legal definitions and other regulatory aspects have to be addressed by all actors in the multileveled governance 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. Table 32 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 (ship-owner and other commercial partners)	Other rules (criminal, social, public law etc.)
National		e.g. Belgian law of river chartering (Wet op de binnenbevrachting °1936)	Labour provisions
River Commission	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 32: Layers of relevant affected IWT crewing and technical legislation
Source: own compilation, structure of table is inspired by AAWA, position paper (2016:55)

The CCNR recently launched a proposal for a definition of automation (Table 29) in order to avoid a fragmented definition whereas autonomous, smart and automation are being used as interchangeable concepts and to start the legal debate at the European level.

[104] 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

Regulation is expected by many interviewed innovators to be a bottleneck to enroll 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.

Furthermore, there is no clear funding mechanism. Countries can provide financial support according to EU rules (such as *de minimis* rules) next to rather limited EU funding programs (such as Horizon 2020 and CEF) for the IWT. Other institutional actors such as the River Commissions do not provide financial aid. In other modes, several projects are funded such as CARTRE[105], AutoMate[106] and SCOUT[107] 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 "Autonoom 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.

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. Also, 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 with regard to 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 competences[108] 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

[105] https://cordis.europa.eu/project/rcn/206011_en.html
[106] https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/automated-road-transport/automate
[107] https://cordis.europa.eu/project/rcn/204978_en.html
[108] including training and appropriate sufficient level of ICT knowledge which could be needed in overriding the system in case of system failure

be kept aligned and open for derogations in order for the innovation to be successful. The lack of alignment in both soft as hard rules can represent additional barriers as the innovation proceeds.

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/O 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 big company with several vessels, which explains why accommodation is usually less important.

The degree of commitment of a VO/O to its vessel, could be of importance in comparing with an external captain in a SCC. For most VO/O's 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/O could feel less attracted to work on an automated vessel with merely a fallback monitoring function. The existing VO/O's could find it less appealing to work in a SCC. In the medium-long run, the VO/O 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 as a consequence 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 reeducated for other assignments in a strong automated and more complex world. But 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 in order for the innovation to be successful.

It is definitely 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 ports and customers. There might be ports not willing to accept fully automated vessels, but as ports such as Rotterdam and Antwerp are organizing together with waterway managers, experiments with automated vessels, port resistance for the moment looks most unlikely. It is also possible that some customers are not willing to 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. Whereas numerous drowning persons are saved each year by crew members of passing-by vessels, 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 could. Also, when a small boat such as a fishing boat or a yacht suddenly crosses the trajectory of an automated vessel and evasive maneuvers are at hand, the behaviour or choices of the automated vessel determine the outcome of such situations. This outcome could influence public opinion and increase resistance if not dealt with properly. Too high 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. Also, If the innovator is too strongly linked, vital information outside the network can stay hidden.

C.1. Weak network

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 outcomes[109].

IWT is a relatively small sector at the European level and most EU-countries do not have a strongly developed waterway network. The institutional network at the European level reflects this reality which is further analysed in the policy analysis.

At 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 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

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

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 behind, 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.

4. SCBA

Because of the fact that fully automated vessels are not implemented (yet) and that it is not clear yet if all mentioned essential tasks can have the necessary automated counterparts developed to be tailor-fitted for IWT. Furthermore, the analysis is based on a small sample of existing and available material. Despite the relatively high level of assumptions, this SCBA is able to give first insights into quantification of the cost and benefits for enterprises as well as the for society of an automated vessel.

In this analysis, it is assumed that a fully automated unmanned vessel exists with the support of an SCC. This assumption includes several elements as the presence of training centers, 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 analysed with the question if the loss could be compensated for by 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. But again, this futuristic view can offer inspiration for further research.

The potential **social benefits** lay first of all in safety and fuel efficiency (the latter is also a private benefit). Some might add that the presence of a competitive inland navigation is also a benefit for society and if inland vessels do not evolve while other modes do, the sector might lose market share. A loss of market share or modal split share would be a social cost because of the modal shift towards road haulage. 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. But a *Schumpetarian* view also includes the creation of jobs in the long run. More technicians will be hired, operators could work in SCC's and as regulation is not expected to change rapidly, the mandatory number of crew members, thus the employment in the inland navigation, will not be affected in the short run.

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. Further automation could be a social benefit for the manning problem instead of a social cost.

For a cash flow analysis and to establish if an automated vessel could be considered a positive business case, it is important to look again at the definitions in the literature review of this case analysis. Not all levels are considered possible in commercial inland navigation any time soon due to regulatory limitations and too expensive robotic technology that is possible in theory and perhaps in prototype but not already commercialized or feasible, especially if the innovation depends on infrastructural adjustments at shore side.

Level 2 of Table 29 (*partially automated*) is considered in this research to be feasible under derogation of the Rhine regulation. Level 3 until 5 are assumed to be only possible in practice if infrastructure, regulation and all necessary on-board robotics are installed. Most of the interviewees are convinced that automation in IWT (reaching the last level) will be gradual and follows certain stages of automation. For every stage and if all data is available, an SCBA is possible.

4.1. Approach

The costs and benefits of the actors will differ. Table 33 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, which is the innovator; the VO/O that buys the innovation; and the rest of society (individuals). The benefits and costs can be private and social.

Actor / CBA component	BENEFIT		COST	
Companies (the innovator)				
AOS development			X	
AOS operation		ΔR_p	X	ΔC_p
Service rate and price of installation	X			
Customers (public and private vessel owners)				
AOS devices			X	
Infrastructure			X	
Maintenance and repair			X	
Safety	X	ΔB_s		ΔC_s
Time	X			
Fuel Consumption and emissions	X			
Individuals				
Safety	X			
Time	X			
Fuel consumption	X			

Table 33: Actors and their direct costs and benefits of automated navigation
Source: based on Aronietis R. (2013)

According to the methodology, the cost components are grouped to fit the sides of the cost benefit equations:

- Industrial-economic side ($\times$ = private net benefit), and the
- Welfare economic side (γ= welfare net benefit)

The thresholds to achieve a successful innovation are derived of following equations:

$$\begin{cases} \Delta R_p - \Delta C_p + S_p > \times \\ \Delta B_s - \Delta C_s + S_s > \gamma \end{cases}$$

With ΔR_p equal to the change of revenue because of the innovation and ΔC_p being the changed costs for the innovator. ΔB_s symbolizes the changes in benefits for the society and ΔC_s relates to the costs for the society inflicted by the innovation. As mentioned in the methodology part, the S_p stands for private subsidies if any. The S_s refers to compensation for those who lose from a public innovation if for instance when citizens are asked to move for the building of a high speed railway, they can be paid the value of their house as compensation. The thresholds $\times$ and γ refer to the minimum benefit that is required by the innovator to have a positive business case.

In this case, the costs both for society as for the innovator are paid by the direct customers and by the innovator. The benefits are divided over customers and individuals. Individuals could be passengers or the society as a whole. This latter benefit needs to be elaborated more. A more competitive, safer and more fuel-efficient inland navigation is 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.

4.2. Data challenges

As an AV does not yet exist, it was difficult to find empirical data concerning costs and benefits. A number of assumptions and uncertainties need to be addressed in order to explain the results of this case study.

It is difficult to find reliable accident data in inland navigation to calculate the safety benefit which is claimed to be the main benefit of automated navigation. If such a dataset exists, it is hardly accessible. Some past sources provide data such as the Dutch SOS database but show a relatively low number of accidents, until the data publication was stopped in 2013. It does show that if an accident occurs, it is mostly caused by human error. The German ministry has announced to develop an accident database for several years now and a limited dataset is being kept for the German waterways but is not published. Belgium and France do not show any interest in developing such a system yet.

An automated vessel can be programmed to abide the law, does not drink, is never tired or distracted. But to examine the safety benefit in a more empirical way, it should be possible to examine the situation more precisely before automated vessels are implemented. Further research (e.g. after the implementation phase of automated vessels) can then compare the null-scenario (as-is) with the automated vessels and examine the difference or added value from a welfare perspective of the implementation of automation in IWT. Or in other words, research can then provide information to help policy decide to further support or quite supporting a certain policy measure or private innovation.

Accidents in an automated world are assumed to be still possible. Only the type of accidents will change because of program error or system malfunctioning. The need for accident casuistry analysis systems will thus still exist in an automated world. Such a system could improve the innovation and avoid old and new types of accidents.

Another data problem lays 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 a number of elaborated assumptions. The market sensitivity in sharing data, typical for a rather closed innovation, was expected because of the fact that 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.

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.

4.3. Potential market for automation and innovators 'costs

The system development and the operation costs of the AOS are in the further proceeding of the analysis estimated and based on the available data and interviews which are described in following paragraphs. First the costs of the innovation are briefly examined from the perspective of the innovator. Secondly the potential customers on the IWT market are identified and finally the costs and benefits from a customers' perspective are closely analysed.

A. The costs from an innovator's perspective

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 (based on the calculations of MUNIN[110]and as an estimation confirmed by the company Seafar).

An SCC, as described by MUNIN (2015), includes five situation rooms, 45 working stations and 169 employees. It is rented as a service for a vessel. An SCC is equipped to provide service to 90 vessels at the same time which are 18 vessels for each situation room. In this case only one situation room is required and focused on.

Table 34 gives an overview of all identified costs of one situation room for a service to 18 vessels within a 24/7 operation. Costs are adjusted as such.

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 34: Annual costs of one situation room capable for 18 vessels at the same time
Source: based on MUNIN (2015), €/USD = 1.11, each SCC operator is assumed to be able to monitor 6 vessels

This overview of costs allows to estimate the cost for the SCC rate for one customer. The vessel size and complexity (e.g. IWT of dangerous goods) of the demand of the VO/O customer, also determines the costs of the SCC service. Bigger ships need more scanners, while ships with dangerous cargo need more specialization. The annual break-even price without financial costs, tax and depreciation, is 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.

110 The same exchange rate is used here as mentioned in MUNIN (2012, deliverable 9) of 1.11 USD for each euro which is the exchange rate from 20/05/2015.

B. Potential customers

The number of potential "AV customers" in freight transport is estimated at 13,692 freight vessels (including Push & Tug) according to the Market Observation report of the CCNR (Table 35) in the Rhine and Danube countries.

The IVR database (2018) accounts for 20,426 vessels and crafts for the entire European fleet of which 2,440 ships were registered in the passenger fleet (cruise ships, day cruise ships, ferries). When excluding dumb barges, pleasure crafts, yachts, pontoons, fishing vessels, the number of the total fleet is reduced to 19,410 vessels.

	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 35: 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)

The number of registered vessels is decreasing while the average vessel tonnage is increasing as newly-built vessels tend to be bigger in size on the Rhine market. Figure 26 shows this situation for the dry cargo fleet in the CCNR countries.

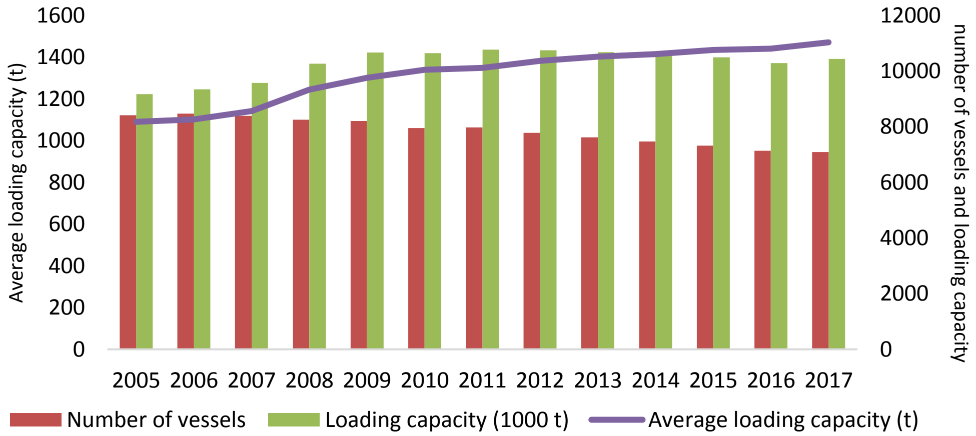


Figure 26: Evolution of the dry cargo fleet in Rhine countries
Source: WSV, German authorities (2018), Market Observation (CCNR, 2018). CCNR analysis based on data from national administrations. Note: For Germany, data indicated for 2017 are from 2016.

If this fleet evolution continues, the number of potential customers (existing VO/O's) for automated vessels is not expected to grow in the freight transport market. This is not the case for all market segments. The segment of passenger transport (e.g. river cruises) is currently growing in revenue and performance which attracts more players and thus potential customers.

4.4. Costs and benefits for investors

Table 36 summarizes the cost structure of a 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 are based on Van Hooydonck & RebelGroup (2015) and Prominent (2018) next to own estimations for the conventional vessel. The costs of the AV are based on literature review, interviews and a number of assumptions and uncertainties.

Based on vessel of 110m, dry cargo, mode B: S2, annual costs in EUR (current prices of 2015); reference case under Belgian law			
		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
	Terminal value (scrap value)	80,000	
Fixed cost		**493,159**	**677,006**
	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		**247,230**	**163,945**
	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 36: 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), Prominent (2018) and own estimations, interviews and national sectoral agreements (Belgium)

A. Revenue

For the first year, the conventional VO/O 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, as explained further).
- Difference in earnings between both vessels in the first year of operation is given by Table 37.

Behind the earnings estimation lays 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 then the shift between transport modes if one mode becomes cheaper than the other. Own-price elasticity measures the impact on demand for the 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 1,084,096

Table 37: Difference in earnings between AV and CV

B. Capital value

The capital value of the conventional vessel is estimated at EUR 2,000,000 (Rebelgroup, 2015). 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 the Prominent project. An average is taken for a diesel engine with CCRII 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 (genset) is assumed to have an average price of EUR 350 per kW[111] (Prominent, 2018). The genset generates a power of 32 kW[112] or 40 kVa with a power factor 0,8. The average price of the genset 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 genset. 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) has to be replaced (minimum once). The payback time of the loan is 15 years in the base scenario.

D. Terminal Value

The terminal value after the end of the lifespan of the vessel is estimated at EUR 80,000 as scrap value according to prices of the initial year of investment. For the automation systems, the terminal value is estimated to be zero and the rest of the vessel has the same terminal value as the CV. In reality, the terminal value depends on the scrapping market price or the market of second hand vessels. But for simplicity, the terminal value is fixed in this model.

E. Maintenance and repair

The maintenance and repair costs (M&R) are given by 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. So what cannot be automated

[111] 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

[112] According to Royal Haskoning as cited in CBRB (2010), the average diesel genset has a range between 10 to 50kVA or with a 75% performance and a power factor" (p.f.) of 0.8 lagging

(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 have to 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 genset 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 locks[113]. Furthermore, the waterway managers have to 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 38. 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 38: 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) has to 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. Also the lacking of cyber-attack insurance which is not covered by traditional P&I and hull insurances, could explain a higher risk premium. But 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 at the moment.

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

[113] 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.

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 cover[114].

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. In case of the AV, it is assumed to be completely automated between the charterer and the VO/O with an electronic booking system that costs 1% of the digital charterers provision (cf. e-bargebooking case analysis).

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/O 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/O) 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 VO's. 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.

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 lays 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

[114] "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

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 this analysis 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.

M. Time benefit

Each hour that is saved of waiting time for loading or unloading, and queuing at a lock, reduces the costs for the business case. These costs include fuel for an electrical generator and also hidden costs (transaction and opportunity costs). The time benefit is generated by the possibility to improve (if regulation allows it) 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 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 are 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 due to the fact that it is usually done by the VO/O during his or her 'free time'.

O. Depreciation

To calculate the annual depreciation, the value of the ship at scrapheap is subtracted from the initial value of the ship and divided by the depreciation period of the ship.

In case of a new conventional vessel value of EUR 2,000,000 with a lifespan of 40 years, and the assumption of EUR 80,000 of scrap value or lowest terminal value, the annual depreciation would be EUR 48,000.

For the AV, this would be annually EUR 145,500 with a comparable terminal value. In this case, the ADS and AWS are assumed to be fully depreciated after 20 years or half the lifespan of the vessel. In this analysis, the AV is assumed to have bought back-up hardware that is again assumed not to be obsoleted after the life span of the first and depreciated hardware.

P. 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 has to 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 onboard 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 has to 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 SCC's 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/O, 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 in 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.

Q. Fuel Cost

Efficient programming of the AOS claims to 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. In a later phase where automated vessels could remove domestic areas and wheelhouses, additional fuel consumption reduction can be achieved. According to Backer van

Ommeren E. (2011)[115], 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

The VO/O 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. So 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/O on a conventional ship will change behaviour if he might expect interesting return trips at destination, a current change or an upcoming low water depth period, making the additional costs of sailing faster interesting.

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 oil[116]. 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 less important for automation. A more simplified approach for the fuel cost estimation is preferred here where also the bunker-adjusted factor is included.

Based on a relatively short timeline of gasoil prices for the inland navigation (CBRB, Contargo, 2018[117]), it was possible to generate trends until 2060 for the purpose of the SCBA. 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 by 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 higher price increase scenario. The prices in Figure 27 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).

[115] 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
[116] https://www.iea.org/etp/etpmodel/assumptions/
[117] https://www.contargo.net/nl/goodtoknow/baf/history/ from 2002 until 2018

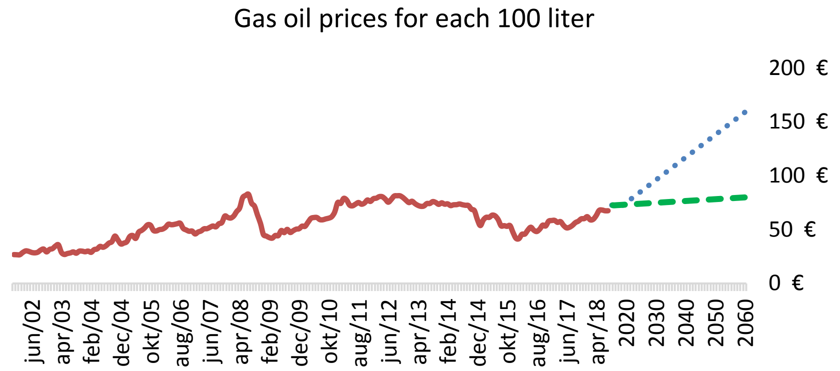


Figure 27: Estimated fuel price (gasoil)
Source: own calculations based on CBRB, Contargo (2018) and compared with RTS of IEA (2018).

To continue the analysis, a conventional and unmanned vessel are both described using gasoil fuel in a scenario. The conventional vessel has an average fuel use of 150 liters / hour (including loaded and unloaded, up- and downstream with on average 60% of maximal power use).[118] 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 which is an uncertain estimation (Backer - van Ommeren, 2011: 13; Hulskotte, J. et al, 2003[119]).

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.

The MUNIN project removes a 20-head crew from the vessel and claims to achieve a fuel reduction of 40% combined with lighter design (Kretschmann et al., 2015). The fuel reduction for an IWT AV is assumed to be lower and less significant than for the maritime example. All these factors combined, including the 13% of Backer - van Ommeren (2011), an rough estimation of 20% is used for potential fuel reduction on a 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 taken in the

[118] Some studies suggest that the ideal propulsion for automated and autonomous vessels is electrical. To keep the SCBA clear, only one innovation (automation) is taken in account. Also no data was found for an fully electric IWT vessel.

[119] Hulskotte, J., Bolt, E., Broekhuizen, D. (2003), EMS-protocol Emissies door Binnenvaart: Verbrandingsmotoren, as mentioned in Backer van Ommeren, E. (2011)

analysis is 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 liter. For the CV, 1,500 sailing hours are estimated with a fuel consumption of 150 litre of gasoil.

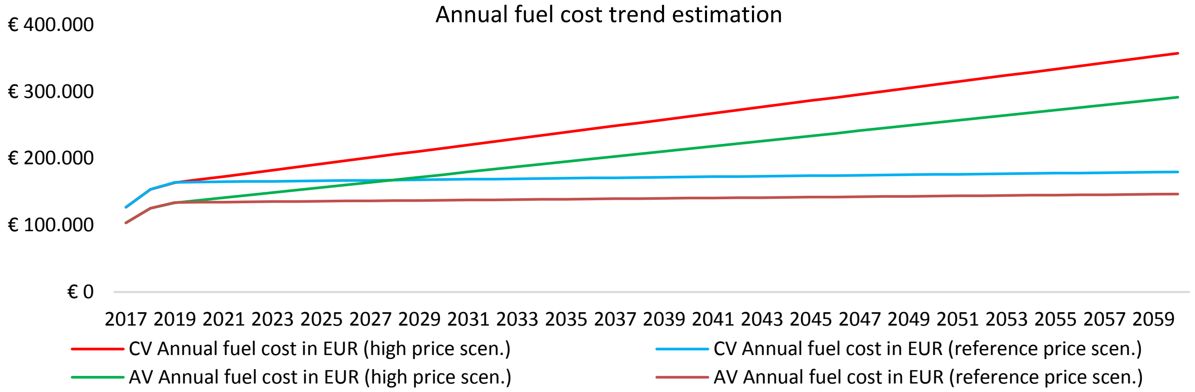


Figure 28: Annual fuel cost trend estimation for the AV and CV
Source: own calculations based on average annual prices of Contargo

4.5. The net present value of the private costs and benefits

The net present value (NPV) of investing in the AV will be determined in this part 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 completely in Annex 3.2. The cash flow statement is based on the revenue as assumed and the different identified cost components. Table 39 shows the method to calculate the cash-flow of the AV given the described assumptions.

Earnings	1
Operational costs	2
Insurance	3
Overhead	4
EBITDA	5 = 1 – 2 – 3 – 4
Depreciation	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 39: Calculation of the free cash flow
Source: van Hassel (2011)

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/O 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 bigger ships) and for more bargaining power at the side of brokers and/or VO/O's. 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 as said, this is an additional innovation, that lays outside the scope of this case analysis.

In this analysis, two perspectives are used with regard to the NPV. The enterprise perspective (Higgings, 2007 in van Hassel, 2011) 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:

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

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%)

4.6. Scenario 0: Conventional Vessel

The first scenario describes the investment in a conventional vessel of 110m according to the identified costs. The scenario gives a possibility to make a comparison inside the model with the business case of the AV and shows some important differences in costs. This null scenario provides insight in a situation where the innovation is not implemented.

A. Assumptions in scenario 0

- 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)[120]
- Discounting factor of 5.35% or WACC is the minimum where the return on investment is interesting 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 a 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 with all regulation
- Lifespan of the vessel is 40 years
- Terminal value is set on EUR 80,000

[120] Following the findings of van Hassel (2011). This rate implies the opportunity costs as calculated by NEA, 2003.

B. Cash flow analysis

The annual cash flow and the cumulative cash flow evolution of the CV from private equity and enterprise perspective are shown by *Figure 29*, which includes an assumed scrapping value at the end of the life-span. The adding of the terminal value of EUR 80,000 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.

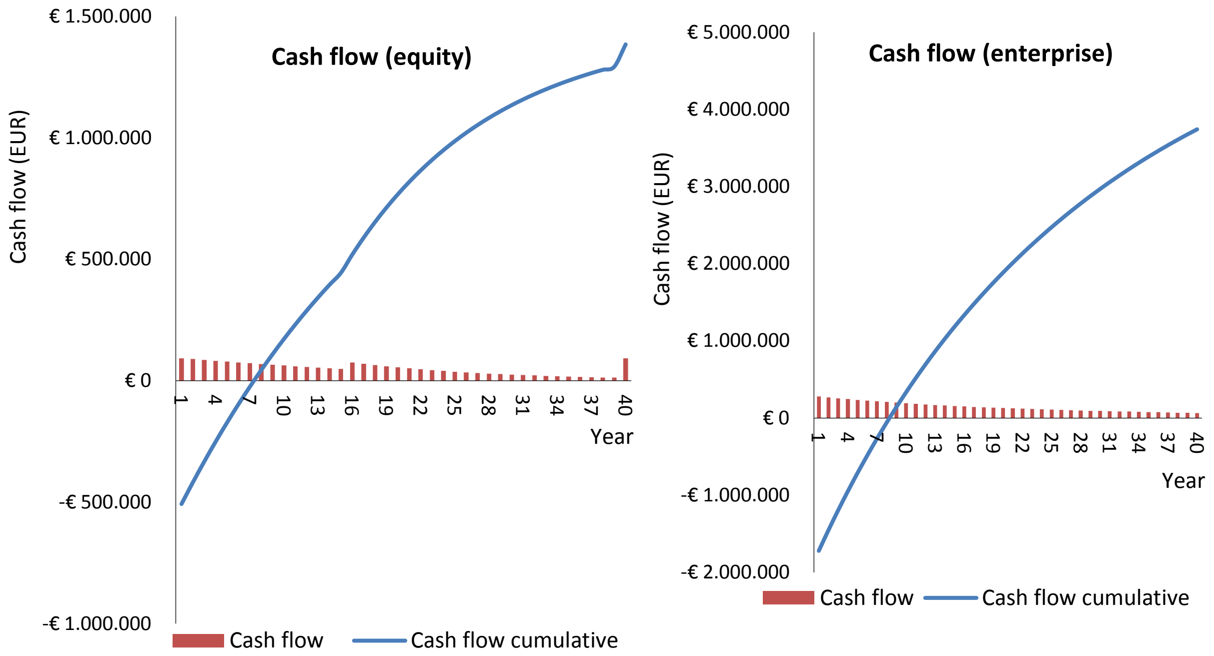


Figure 29: Evolution of cash flow of one CV (equity & enterprise) with 15 year loan
Source: method as applied in van Hassel (2011)

4.7. Scenario 1: Automated vessel

The second scenario describes the investment in an automated vessel of 110m according to the identified costs. This scenario explores the possibility of the AV. Further scenarios are variations on this. Variations include different inputs concerning payback time for loan, earnings and fuel cost scenario.

A. Assumptions in scenario 1

- 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)[121]
- WACC is 5.35%.
- Full loaded (payload) for every trip and a 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.

[121] Following the findings of van Hassel (2011). This rate implies the opportunity costs as calculated by NEA, 2003.

- Lifespan of the vessel is 40 years. The shorter lifespan of the automation technology is included in the capital value.
- Terminal value is the same as with the CV.

B. Cash flow analysis

The annual cash flow and the cumulative cash flow evolution of the AV in this scenario from private equity and enterprise perspective are shown by 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. This value can be adjusted as in other scenarios. Fuel cost is still expected to increase relatively strong during the lifespan of the vessel.

Figure 30 shows that from an equity perspective, there is a sudden increase in cash flow in the last year The adding of the terminal value of EUR 80,000 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.

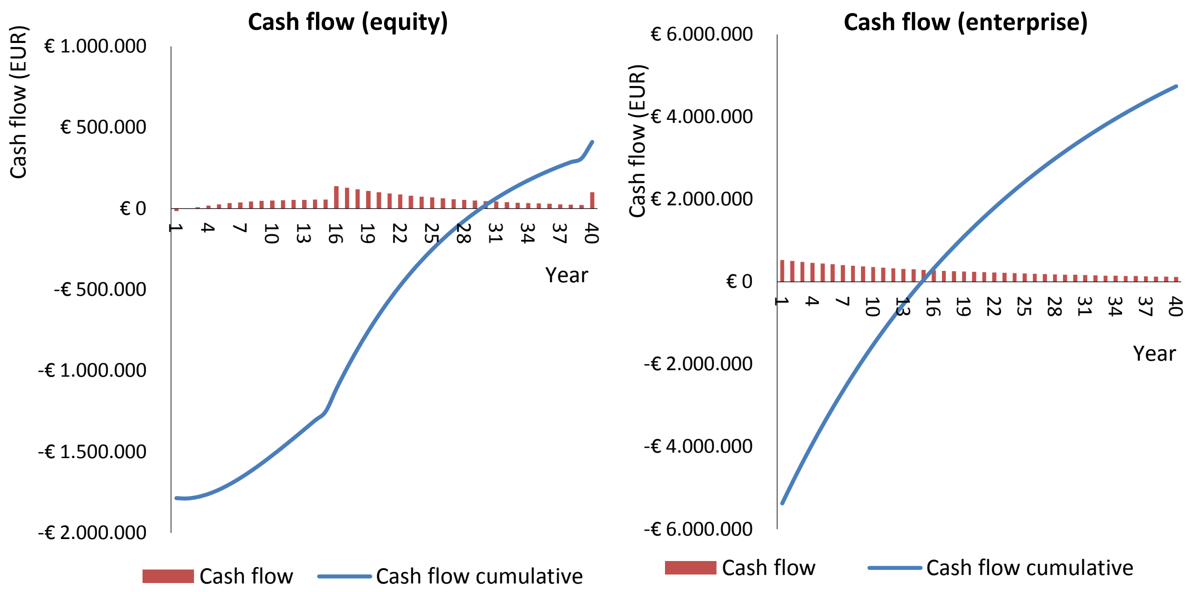


Figure 30: Evolution of cash flow of one AV (equity & enterprise) with 15 year loan
Source: method as applied in van Hassel (2011)

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 relatively high NPV of EUR 4,744,269 compared with the NPV of the null scenario of EUR 3,741,767.

4.8. Sensitivity analysis of private business case

This sensitivity analysis shows how the uncertainty of the developed model can be reduced by changing the inputs in different scenarios within the approach of scenario 0 and 1.

Scenario 2 shows the situation for the AV of scenario 1, when the loan payback time is 25 years instead of 15 years. The results are higher NPV's 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 NPV's 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 a IRR of 5.5%.

Scenario 5 shows what happens if scenario 1 was applied on the investment of five AV's. In this scenario, it is assumed that the SCC is able to 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 NPV's 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 CV's is also analysed.

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 a 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 AV's 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 broker 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 brokers is shown by the changing NPV's in the following table according to different rates and based on scenario 1. It is clear that only in some scenarios the NPV_e (equity) goes 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 40). Scenario 9 describes further the output if the provision of 7% is added in 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 40: 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 at the assumed level. In reality, the freight rate could be much more volatile and is 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 interesting 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 for the vessel. In reality, 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. The following table 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 in reality could be slightly the case. As mentioned by Backer - van Ommeren (2011) an estimated 13% of the total fuel consumption, powers the genset for cooking, heating, lights, living appliances, etc. More crew members could increase these costs, but as said in this scenario this is not taken in account.

Number of crew members on the CV	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 41: Difference of crew members of the base scenario compared with the AV

Before examining deeper the difference with comparable CV scenarios with every highlighted scenario, *Table 42* shows a summary of the results of all described scenarios so far.

Scenario	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Vessel	CV	AV	AV	AV	AV	5 AV's	5 CV's
Payback time (years)	15	15	25	15	15	15	15
Fuel cost increase	high	high	high	small increase	high	high	high
Earnings	high	high	high	high	Low (103 trips)	high	high
Charterer provision	7%	1%					7%
SCC cost in EUR (year 1)	0	190,960				286,440	0
Crew cost in EUR (year 1)	272,800	0				0	20
NPV in EUR (equity)	1,384,550	410,915	565,858	642,372	-2,143,143	5,968,490	6,922,750
NPV in EUR (enterprise)	3,741,767	4,744,269	4,889,341	5,301,335	139,807	30,789,368	18,708,837
IRR (equity)	22%	11%	12%	11%	5%	13%	22%
IRR (enterprise)	15%	10%	10%	10%	5%	11%	15%

Scenario	**7**	**8**	**9**	**10**	**11**
Vessel	AV	5 AV's	AV	AV	CV
Payback time (years)	15	15	15	15	15
Fuel cost increase	high	high	high	high but lower consumption	high
Earnings	high	high	high	high	high
Charterer provision	1%		7%	1%	7%
SCC cost in EUR (year 1)	95,480		190,960	190,960	0
Crew cost in EUR (year 1)	0		0	0	409,200
NPV in EUR (equity)	1,239,261	7,625,181	-154,436	718,094	201,202
NPV in EUR (enterprise)	6,240,154	33,781,136	3,723,318	5,304,682	1,604,795
IRR (equity)	13%	14%	10%	12%	11,35%
IRR (enterprise)	11%	12%	9%	10%	9,99%

Table 42: Sensitivity analysis of possible business cases for the CV and AV (only private internal costs)

To compare all scenarios of the sensitivity analysis with a more comparable reference scenario of the CV, the difference in NPV and IRR shows the added value of the innovation. These differences are here expressed by $\Delta IRR_{CV\text{-}AV}$ and $\Delta NPV_{CV\text{-}AV}$ for both equity and enterprise perspective, according the following formulas:

$$\Delta IRR_{CV\text{-}AV} = IRR_{AV} - IRR_{CV}$$
$$\Delta NPV_{CV\text{-}AV} = NPV_{AV} - NPV_{CV}$$

These formulas are applied on every scenario where the same input is changed for both the AV as for the CV as mentioned in Table 42. Scenario 0 for the CV is comparable for AV - scenario 1, 7 and 9. Scenario 6 where five CV's are taken in 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 also compared with a comparable CV case (100 trips). The formula results in the values that are given in Table 43.

Sensitivity analysis	ΔIRR_{equity}	$\Delta IRR_{enterprise}$	ΔNPV_{equity} in EUR	$\Delta NPV_{enterprise}$ in EUR
1	-11%	-5%	-973,635	1,002,502
2	-13%	-5%	-871,214	1,098,397
3	-12%	-6%	-1,025,826	876,889
4	**-1%**	**0%**	-1,497,340	55,300
5	-9%	-4%	-954,260	12,080,530
7	-9%	-4%	-145,289	2,498,387
8	-8%	-4%	**702,431**	**15,072,299**
9	-12%	-6%	-1,538,986	-18,449
10	-10%	-5%	-666,459	1,562,909
11	0%	0%	209,713	3,139,475

Table 43: Added value of the AV compared with the reference scenario of a CV
Scenario 6 is not mentioned in the table, because this scenario is used as reference scenario for scenario 5 and 8.

Table 43 shows that scenario 11 scores better than the reference scenario. Increasing the crew from 4 to 6 FTE, gives the same IRR and gives more NPV for both perspectives. The ΔIRR in scenario 4 is also close to its CV – counterpart. But in this scenario, both the CV and the AV do not meet the requirements from an equity perspective concerning the IRR and NPV. Scenario 8 where the SCC provides a relatively cheaper annual service rate and where scales of economy are made for five AV's, the NPV becomes significantly higher in both perspectives and the IRRs meet the assumed conditions (>10% equity discounting factor an >5,35% enterprise). But for EUR 29.5 million for 5 AV's as initial total investment, a VO/O could decide to build 14 CV's.
The influence of the discounting factor also has to be adjusted in the sensitivity analysis in different situations to find out if there is no alteration of the results. Table 44 shows that an increase of 50% of the discount factor has a significant impact.

Scenario	**D.F. (equity) = 15%**	**D.F. (equity) = 5%**
0	558,229	3,755,452
1	-800,385	4,286,022
2	-495,255	3,908,857
3	-688,017	4,886,629
4	-2,451,988	-571,666
5	-1,475,117	28,887,737
6	2,791,145	18,777,261
7	-265,608	5,864,363
8	-405,564	32,044,421
9	-1,165,374	3,208,792
10	-604,040	4,877,751
11	792,877	2,628,065

Table 44: Impact of discount factor on NPV in EUR

For the scenarios that describe variations on the basic null scenario of the CV, the discounting factor for equity does not show any negative results for the NPV. The scenarios with variations of the basic AV (scenario 1) are much more vulnerable which gives the height of uncertainty.

4.9. Initial conclusions on the private business case

It is shown, according to the scenario analysis, that there is a possible positive business case for implementing the innovation but within a number of mentioned and explained assumptions. Scenario 11 where actually the original null scenario of the CV is modified with added crew members (from four to six) all AV-scenarios perform better. When the crew is kept at four FTE's, the conventional vessel reaches a higher return on investment within the constructed model. The number of uncertainties concerning automation, but also the relatively low benefit in replacing the crew of a conventional vessel by an SCC service, gives less incentives to invest in a AV.

The uncertainties are not only related to the fact that a number of 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 investment is probably still higher than the investment in a CV as described in the null scenario. 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 on a CV to lower gradually the cost and/or enlighten the tasks on-board. Another argument that could persuade investors is when the innovation would become successful in the inland navigation and/or in other transport modes, the CV could lose market share. In the latter case, it is perfectly possible that a number of customers would prefer a crew on board and that the market of CV's will not seize to exist.

In a lifespan of forty years, it could be the case that fully-automated vessels will arrive on the market and that the innovation is diffused or not. First mover advantages could also be a strong argument to start investing in automation that is being developed. Leadership in technology, having a front seat in the policy cycle in determining the needed standards for the new technology, develop a reference case for all future AV's or being the first to learn from all mistakes during operation of the first AV, could lead to a sustainable market share and further cost reduction. Lieberman and Montgomery (1988) describe the first-mover advantages which could also be the case for the AV at this stage and which could determine the business case[122]. This invites more research and requires information from mostly closed innovation initiatives within the identified initiation phase of the AV.

The AV was assumed to have a diesel engine with stage II (CCNR classification). A number of efficiency gains could be implemented in the model concerning the engine and propulsion. The VO/O 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/O has proven a potential viable business case according to the assumptions within the model of the AV as elaborated in this research for the IWT but performs not better than the CV in comparable scenarios when the critical level of crew cost is not reached. In this model the critical level is 6 FTE's on a CV. If less than 6 are hired, the CV still performs better. When the number of the FTE's is equal or more than 6, the performance of the AV becomes more interesting and provides a better business case.

The first research question concerning the quest of a positive business case in IWT is answered in the AV case. From an industrial-economic perspective, the potential private profit × is considered positive, but there is only a real incentive if crew cost on the CV would reach a critical mass. *Figure 31* shows

[122] Lieberman M.B., Montgomery D.B. (1988), First-Mover Advantages, Strategic Management Journal, Volume 9, Issue Special Issue: Strategic Content Research, 41-58.

the identified innovation path so far. The SIA and the CBA provided a qualitative and quantitative approach to answer the first research question. The question mark refers to the social benefits which are explained in the next part of the analysis and which answers the second research question concerning policy.

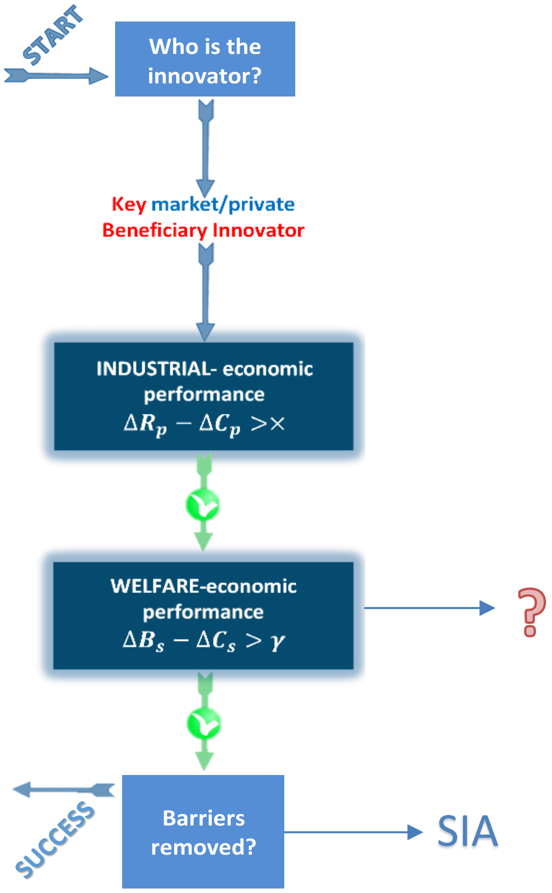


Figure 31: Innovation path of the AV
Source: own creation, based on Aronietis (2013)

4.10. Costs for society and impact on labour

The costs for society that are identified in this research are called external or social costs. After the identification of the external costs, the potential impact on the labour market is also analysed. The external costs are further elaborated. 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 to be adjusted 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. In this research it is assumed that the investments in public assets such as locks will be funded by 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 side[123]. To equip all mentioned locks in Europe, more than a thousand units are needed or an estimated investment of EUR 814 million which is 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. But 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. But as more and more locks become unmanned, remote controlled or even automated, this solution is up to policy makers of private enterprises to decide what is the most attractive option. In this research, it is decided to have a complete unmanned vessel without human intervention on-board and which is able to 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. But in this analysis, the SCC is kept private. Although the Rhine countries have their own inland navigation fleet (ferries, survey boats, river police, school ships, …etc.), they are not considered to be active in professional freight transport. A state-owned SCC is therefore not required. The control centers in locks can be perhaps relatively easily be upgraded to control the AV's, the ADS and even to communicate with the private SCC's.

The one-time investment in 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 ADS's 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. Assuming that 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. Emissions, up- and downstream and climate change

RICARDO-AEA gives an overview of marginal air pollution costs 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.

The annex on page 287 shows the full table for these external costs, but for the calculation in this study, an average is calculated as presented by Table 45, 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 tonkilometer 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. 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

[123] 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.

infrastructure that is needed to build, repair, bunker or maintain the vessel. To simplify the calculation, averages are used for all vessels.

	average load factor, tons		average cost
	bulk, tanker	heavy bulk	
Air pollutants € per 1000 tkm	2,543	2,957	**2,3**
CCC € per 1000 tkm			**2,3**
U&D €ct / vkm			**0,8**

Table 45: Average emissions and greenhouse gases of IWT
Source: own calculation of averages based on RICARDO-AEA (2014)

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. In reality 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) for the coming twenty years and compared with a scenario without automation. U&D emissions are not taken in account because they relate to vkm and cannot be linked with performance.

The differences in emissions and fuel costs, could be the main benefits of an AV compared with a CV. 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 lays 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 taken in account.

Another important remark is that an automated vessel as described in the design of the Yara Birkelandt, 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 in 3.2.A). 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 are 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.

Brown and Savage (1996) state that large disasters in maritime transport happen in a random Poisson manner. This is also true for inland navigation. In order to calculate the damage cost of major accidents, Brown and Savage took the average cost (of the oil spill) for a period of eight years based on the accident of the Exxon-Valdez. This method will be used in this analysis to estimate a safety benefit together with the available data referring to the disaster with the TMS Waldhof in 2011 (a summary of this accident can be found in the annexes) and together with the number of fatalities and injured on the Dutch waterways which is adjusted for the European level. 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 in account.

The period of eight years (as used in Brown et al., 1996) is adjusted to twenty years because of the lower estimated likelihood of large accidents happening in IWT. Finally, the percentage of insurance coverage (50%) is subtracted to estimate the external accident cost of the European inland navigation. The value of life is 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 Waldhof[124] 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 considered to be 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. Also here lays 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 definitely avoided.

Adding the own calculations of the accident cost for IWT as developed in this research, the average accident cost for each tkm, is estimated in this research at EUR 0.000167 for the EU-28 (based on 2017 values).

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 new 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 causalities. According to most reports in both inland navigation and maritime, human error is a dominant cause of accidents. Automation has the potential

[124] https://www.elwis.de/DE/Service/TMS-Waldhof/Unfalluntersuchungsbericht-hohe-Aufloesung.pdf?__blob=publicationFile&v=3

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 were with recreational vessels than with freight IWT). Furthermore, to avoid all human casualties on the waterways, the recreational vessels should be unmanned also 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.

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 of the fact that repair, replacement and other tasks are possibly internalized by the insurance premium of the AV and/or CV VO/O. 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 considered to be zero.

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.

E. The labour market

The potential impact of automation on the labour market of IWT is examined here to establish if it would be a cost or a benefit. According to Negenborn (2017), especially the smaller ships can relatively benefit from automation, because of the fact that personnel costs weigh heavier in the cost structure than on bigger ships or companies. In absolute terms, the possible cost reduction is higher on a bigger 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.[125]

A number of 44,518 people belong to a crew in the European IWT (European Commission, 2018)[126]. The majority of them is 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). According to Panteia (2015)[127] this division is also noticeable for crews in IWT. Almost 32% is estimated to be older than 50 years in the sector. This is specially the case for the self-employed/boatmasters or VO/O'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.[128]

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. But with the ageing of the average crew, the replacement of retired people will be challenging. Furthermore, a possible benefit lays 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.

[125] 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/O's to choose a small vessel instead of a big one.

[126] European Commission (2018), 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

[127] 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

[128] https://www.inland-navigation.org/observatory/crews-skills/labour-market/

The labour market situation of introducing automated navigation is shown by 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).

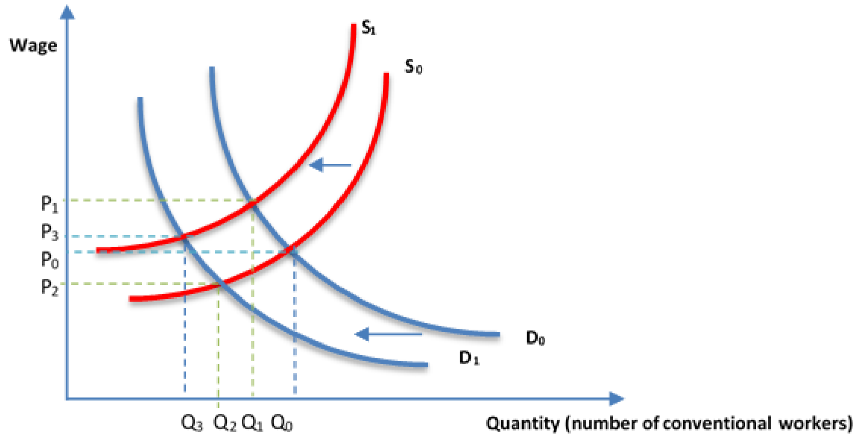


Figure 32: Impact on conventional labour market of automated navigation
Own creation, based on economic theory

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 elasticities[129] are involved.

As the conventional crew is gradually automated, a new kind of worker profile emerges. The digital boatmaster 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 boatmaster 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 taken into account.

[129] 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.

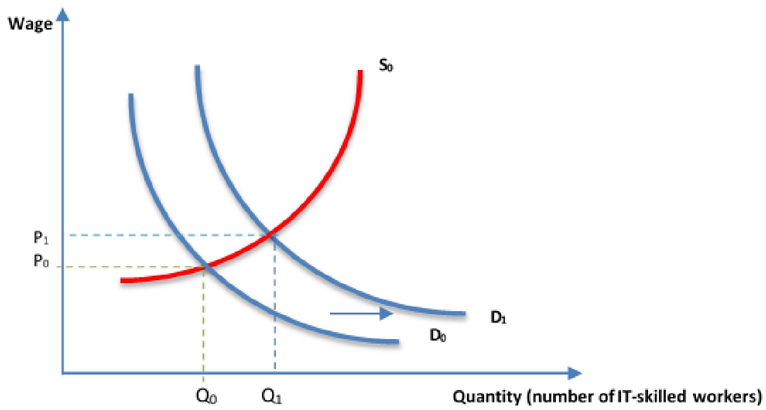


Figure 33: Automation and the new working force
Own creation, based on economic theory

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.

4.11. Net present value of the social costs and benefits

After the analysis of the identified private costs and benefits of the innovation, it becomes possible to build further on different scenarios including social costs and benefits. The external costs are added to the scenarios with the AV as analysed.

A. Scenario 0 and 1: Assumptions

The CV in the developed model has per trip a payload of 3,000 tonnes for a distance of 100 km. Every trip the vessel sails 300,000 tkm. The identified social 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. Internalization of external costs lays 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 cheaper 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.

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. But as said, this lays outside the scope of the case analysis and invites further research. The main focus of this part of the analysis is to estimate the difference between the external costs of the AV and the CV and to show, if according to the built model, there is a social benefit. 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 social 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.

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 in account.

Table 46 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. 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.

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 46: Internalization of social costs in the business case scenarios 0 and 1 (expressed in EUR)

When repeating this analysis, it could be kept in mind that the external costs are calculated according to the number of tonkilometer 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 47: External costs for the AV in EUR/tkm

4.12. Sensitivity analysis with external costs

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 gives more insight in the social benefit. 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 by Table 48. The external costs become for the VO/O 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 and the accident benefit is not significant. The emission cost is in all situations more beneficial because of the assumed lower fuel consumption.

vessel	scenario	accidents	infrastructure	emissions	total external costs	ΔCV - AV
AV	CV performance, 0% infra	0	138000	342000	480000	16%
AV	CV performance, 12,5% infra	0	155250	342000	497250	13%
AV	CV performance	0	172500	342000	514500	10%
AV	0%infra	0	157623	383724	541347	5%
AV	12,5% infra	0	174191	383724	557915	3%
CV	0	7497	138000	427500	572997	0%
AV	1	0	193545	383724	577269	-1%

Table 48: Results of external cost analysis

4.13. Initial conclusion for the social business case

The full analyses of the social costs, showed social 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.
If policy would decide not to invest in the suggested automation infrastructure and the AV should be able to pass a lock safely and reliable with the on-board equipment, the difference of total external costs between the CV and the AV lay between 5 and 16%. If policy would invest for half of the automation infrastructure as suggested, then the social benefits would lay between 3 and 13%.

The threshold for the policy makers is perhaps not sufficient with only a 16% improvement of social costs in best case scenario. And also another potential social benefit of the automated infrastructure is not completely revealed by the analysis.

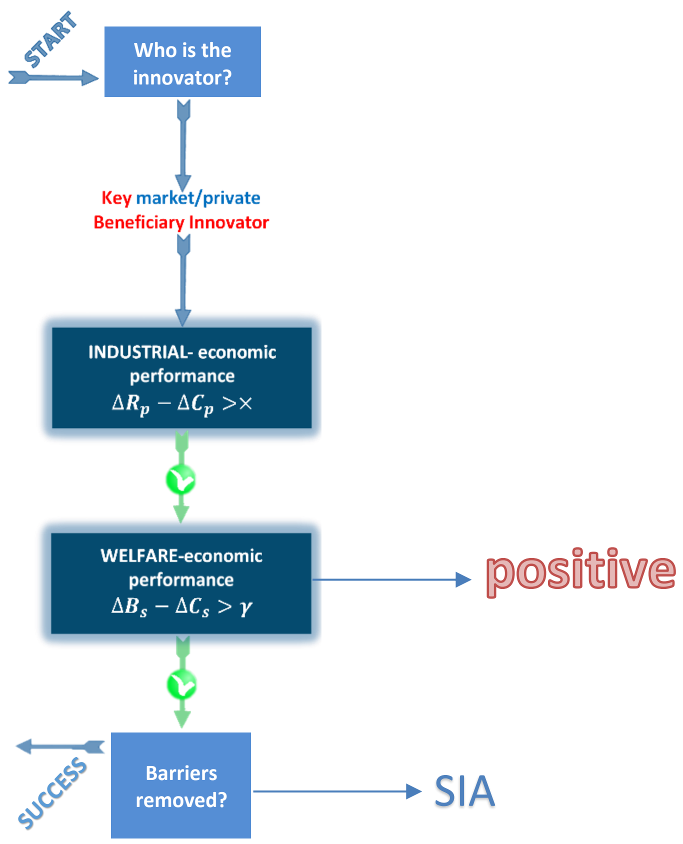


Figure 34: Conclusive innovation path of the AV
Source: own creation, based on Aronietis (2013)

The question what would happen if IWT would not automate while other modes and their interfaces in the supply chain evolve, still remains. If other modes become fully automated and unmanned, this could attract or shift volumes from a conventional IWT. The possibility of this hypothetical mode shift, depends on several factors such as the growth of the demand for transport, the cross-price elasticities between the different modes. If the external costs as described by several authors and further developed for the AV in this research, would remain the same values, every loss of volume of IWT to other 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/O by reducing the ADS or ad hoc on-shore lock human personnel for mooring operations. The latter invites further research. But within the built-up model there are social benefits quantified and there is no incentive to resist the innovation from a welfare perspective.

5. Policy Analysis

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).

Because of the fact that automation is still in the initiation phase, and that the political debate just started for inland navigation, quantification of all costs 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 governance model has an impact on the compliance costs of an innovative firm.

In case of automation the CESNI standards are relevant in describing the minimum safety level that automated operation systems of different automation levels should maintain. Also the scope of the relatively young institution of CESNI has to be taken in account.

5.1. Costs of policy

As described in the methodology section, following costs are identified: compliance costs, information costs and enforcement costs. As the public debate in Europe just started, it is difficult to estimate the cost of the related phase in the policy cycle. Nor is it easy to estimate the costs that the innovator has to pay concerning the policy because of the fact that the innovation is not on the market yet and no legal standards are written.

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 all are innovation elements without any IWT standard or defined policy.

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 innovator is likely to be used as a base for further policy. A pro-active innovator in this innovation will have the opportunity to be significantly involved in writing the policy and indirectly in co-defining what future competitors should comply to.

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 have to comply or be consistent with existing or preceding policy.

Every policy level in IWT policy model can create policy at this moment. MS can make their own policy, UNECE can write resolutions, CCNR can amend its regulations and technical standards and the European Commission can establish its own definitions of automated vessels without legal or institutional conflict. There is a 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 fragmented among several policy actors with a not-that-distant past of institutional tensions. Nothing to comply to, gives opportunity to institutions to give their core competences more significance or to reinvent themselves.

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. But 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 past experience in dealing with the 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.

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, but their scope is only national, regional or even local such as a port authority and limited by precedent regulation from above.

In case of automation, if innovators would only lobby at regional levels, the market will 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) would get the most advantages of the policy system. On the other side, it will of course take more time and preparation which needs additional capability at the side of the innovator.

In this phase of the innovation, policy actors could help lower the compliance costs and regulatory burden for businesses by spending sufficient attention on:

- Consistency 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;
- Having a short line of communication and structural coordination between all policy actors;
- Broadly disseminating funding options.

B. Enforcement costs

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 governance 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. Enforcement costs that are too high, decreases the incentive to comply.

If the safety standards that would be developed for automated vessels are not enforced, the incentive to comply will decrease (lower compliance cost). If some would perhaps find a lack of enforcement ability from the authorities as interesting in the short run, this could eventually lead to more uncertainty on the market and less safety.

The AV relies on a number of manufacturers of software and hardware systems that have to meet a certain level of standards for safety and reliability. It could be 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. If a specialized public or private (or both) actor would create the standards, the enforcement of these standards should then be legally binding.

The enforcement costs in the current policy model of IWT are put at the level of the river policy of every IWT country. For automation, it is too soon to calculate the enforcement costs without regulation, but additional investments in data-sharing between police forces at a European level seems crucial to tackle the upcoming digital challenges with AV's. Police should be able to communicate with the AV and the SCC behind the AV and have sufficient knowledge in dealing with data-security, internet between things and of course the regulation that probably will be developed. In an automated supply chain, the river police will not be sufficient in enforcement regulation. At a European level, cybercrime will probably become a bigger treat for safety and efficiency within the supply chain with higher costs of enforcement. Also practical issues, could increase enforcement costs, if for example, the SCC is in another continent and the shore controller needs to be interrogated or arrested. On the other hand, the enforcement costs also have a reduction because of the possible received data of the vessel, less area to inspect, no human error (on-board) and less overall work in monitoring the rivers. In the case of Belgium, river police is usually manned with four people on an inspection ship. With an automated IWT, these vessels also become automated and reduces the crew to the essential manning performing police tasks.

C. Policy credibility and asymmetrical information costs

The credibility of the governance model towards business is an important parameter. When political promises that are made concerning funding, implementation of needed infrastructure, changes or updates in regulation, are not kept, this could lead to a failed innovation. If an automated unmanned vessel which is not yet on the market but in an experimental initiation phase, loses the support of policy (currently a number of projects are funded and legislators are starting to debate which legislation should be updated and adjusted), the innovation could also fail. Concerning government funding, most of the interviewed innovators in the interviews claimed that they developed a positive business case without public subsidies or support, but if public funding is possible, the business case is only more positive.

For the identified experiments that are being done in automated inland navigation, public institutions are mostly the main funder and/or customer (except for Shipping Factory, Xomnia and the identified ADS developers). The technology which is needed for an automated vessel in Europe is mainly developed by private companies. Most of the computer technology that is used originates from China, South-Korea and Japan expressing the global window of opportunity and backed by U.S. military breakthroughs in automation technology. Even if the innovator is not a global private player but a public actor, the problem of asymmetrical information remains and manifests itself between levels within an organization or at a micro-level between persons. Full guarantee of avoiding asymmetrical information is not possible, but there are ways to decrease the costs in every phase of the policy cycle.

As mentioned, the window of opportunity in automated shipping manifests itself globally. If the European multilevel governance model for IWT does not prove to be a valid and efficient partner on a regular basis, the innovators could easily go elsewhere and those who do not, could fail because of the regulatory bottleneck. An efficient and effective governance that keeps its promises, is difficult to quantify and invites political bias. But the importance of such a governance, is vital to avoid failed innovations.

The cost of asymmetrical information would increase in the worst case scenario if IWT shifts the focus to productivity and reliability rather than safety. The multilevel policy model needs more specialized and dedicated experts (internal or outsourced), to lower the risk for asymmetrical information. 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 bigger 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.

In an automated world, asymmetrical information costs become a major 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.

In this analysis, 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 when the institutional setting becomes more integrated towards one regime (dominant of centralized). Due to a lack of sufficient data, a more quantified approach was not possible.

D. Fragmented and/or supranational approach

A fragmented scenario where EU-MS are more competing amongst each other than cooperating, has its costs and benefits. The challenge to become the first country with AV's is the main focus of national and regional actors. Cooperation and coordination between countries happens mostly bilateral.

The identified costs of this scenario are the following:
- Compliance costs coming from suboptimal policy for cross-border externalities;
- Higher prices (relatively) to by the innovation because of further reduction of already small market through differentiated and national regulation (lower supply), no large levelled playing field. Less quality and smaller learning capacity on state level and less expertise within national governance;
- Social costs because of potential mode shift. Weaker position against Pan-European/international regulated modes of transport and weaker link within global supply chain because of fragmented policy and standards;
- Financial costs. Only national/regional funding possibilities from states in lack of European or higher level funding;
- Cost of asymmetrical information between MS

The identified benefit is:

- Reduction of compliance costs: Policy speed within a less complicated policy cycle. Regulation could be faster implemented and more accessible to comply. Lobby and agenda – setting can be easier and cheaper for the innovator.

Asymmetrical information can be both a cost or a benefit. National or regional policy is closer to an automation experiment than higher levels, but has less means in supporting the innovation (e.g. funding). The close-by advantage could deliver more information but not necessarily. Higher levels could have more means to reduce risk of having asymmetrical information. A single country has relatively less means for monitoring costs and evaluation, enforcement and inspection, than a higher level, but in reality, this is already the case because of the national competences of police and inspections.

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 non-compatible equipment with technology from neighbouring countries, which increases the compliance cost of the private innovator and which makes enforcement differential amongst MS.

E. The challenge of liability in automation

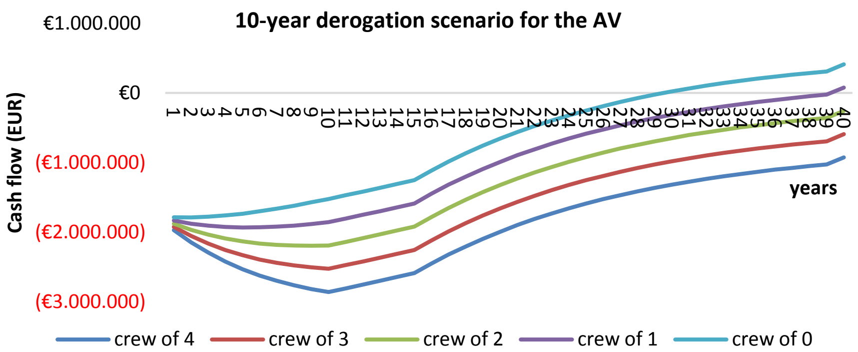
The CCNR started the debate in August 2018 in the Working Group of the Rhine Police Regulation (RPN) concerning the search of a legal definition, liability issues and other potential regulatory problems. During the finalization of this research (December 2018), the CCNR accepted the definition of the automated vessel as already mentioned before and seems to take the lead in the AV regulation, but liability issues still remain. This is not only the case for completely unmanned vessels in dividing liability between an SCC and the vessel owner, but also in other modes.

On a CV, the captain which is usually the VO/O is liable for the vessel and the cargo during the trip and remains on-board most of the time. Relevant legislation and treaties such as the CLNI (Strasbourg Convention on the limitation of liability in inland navigation), the RPN and the police regulation (RPR and CEVNI) next to national legislation, have to be amended for AV's, but this invites further juridical research and analysis. The liability issue is explained more in the SIA part of this case analysis. For this part of the analysis, the uncertainty because of lack of definition of liability for the AV, increases the compliance costs for the innovator.

F. The impact of policy on the business case

If policy makers decide not to allow unmanned vessels and require the mandatory crew size, 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 close to the assumed threshold of 10% discounting factor. In another scenario, the regulator could decide to give a derogation from the regulation 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 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) during a ten-year derogation period to have one to four crew members on board (Figure 35).

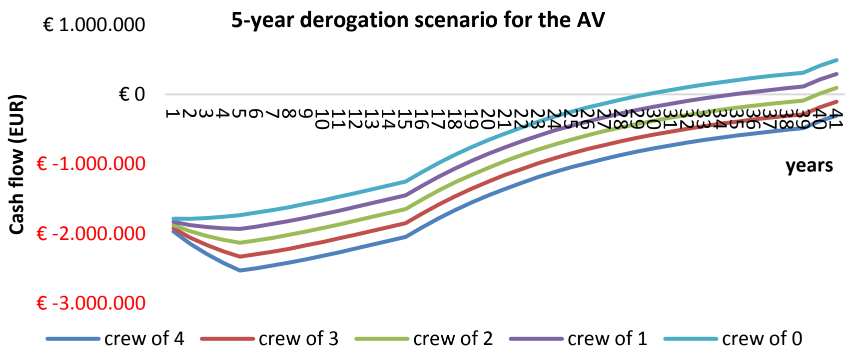


Number of crew members during 10 years	IRR(ent)	IRR(equity)
4	8.01%	8.25%
3	8.45%	8.82%
2	8.92%	9.45%
1	9.42%	10.17%
0 (scenario 1 of the AV)	9.94%	10.99%

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 Figure 36 shows, 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 crew members during 5 years	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 has 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. Policy makers have developed technology-friendly procedures such as the possibility of derogation. The timing of the derogation method and the posed conditions have a direct impact on the free cash flow of the AV.

6. Conclusion

The further automation of the IWT is a gradual process that focuses on each component of the operational and management tasks on board of the vessel. 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 center and could show promising results for other implementations. A fully automated vessel that could be unmanned, needs a redundancy of robotics and advanced subcomponents. Several parts exist already in maritime but are not yet tailor-fitted for IWT, nor are they integrated in to one solution. The focus of the development of the automated vessel is, in the short run, on further automation of the navigational tasks which would reduce the workload for a helmsman.

Access to and the cost of the needed capital by IWT-companies determines both further research of automation as the development of AOS as commercial product. But infrastructure, both digital and physical, both public and private, needs to follow. Hard and soft institutions should be in place, in order to allow market uptake such as regulation. Cooperating multilevel governance actors need to facilitate and create one level playing field on European level instead of several legal regimes for the emergence of this new market segment.

There are several perspectives to look at an autonomous or automated vessel. A system of innovation analysis and SCBA can be done for every component or subsystem of this kind of complex innovation or in a more generalist rather simplified way as described in this analysis. Knowing that if one of the components fails, the entire autonomous or automated vessel has a problem to continue operations and will need in worst case scenario a crew to fix the problem. Every component, especially the robotics, have their own company and innovation network behind them that usually goes further than only the Inland navigation market.

If the same approach is used as in ES-TRIN, devices would probably correspond to the common safety standards for the IWT. Every component presumably needs a special derogation procedure that needs time to prove the safety and reliability level convincing policy makers to write standards for a robotic dock locking system or robotic maintenance units. All these things need time to mature, before the new technology can be pulled on the market and can be taken from the shelf. Despite time restraints, lack of sufficient data and a number of assumptions because of the initiation phase of automated vessels, this was the first attempt to examine AV's in IWT with SCBA and SIA.

Further research is necessary to explore broader possibilities and more scenarios. Every vessel, business structure, cargo (type and volume) and crew formation can deliver other results in performing a more detailed cost-benefit analysis. The CBA of an automated tanker fleet can give other results as does an automated vessel of level 4 compared with a vessel of level 3. Also 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 private costs. Also the total logistic cost can alter the business case which was not included in the research and which invites further research.

The policy analysis, shows the differences between a fragmented approach (every Member State takes care of its own regulations) and a supranational approach in dealing with upcoming externalities that concern automated IWT. A fragmented approach could lead in worst case scenario to an increased enforcement cost in dealing with different equipment. Quantification of the identified policy costs from innovator and policy perspective was not possible during this case research. To perform a more quantitative analysis more data is needed, but the debate concerning the need for a coordinate approach for automation can be supported by identifying the costs and benefits of different policy approaches on the European level.

Policy has an impact on the business case of the private innovator. Regulation could be needed to level the playing field for all actors and to give more legal certainty to the innovation. Policy makers have developed technology friendly procedures such as the possibility of derogation. The timing of the derogation method and the posed conditions have a direct impact on the free cash flow of the AV.

In case of automation, there is a social benefit concerning the reduction of fuel use and consequently the emissions. Accidents costs, although already relatively insignificant, decrease because of the removal of human casualties. Infrastructure cost remains the choice of the policy maker. 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.

7. Further research in automation

This research 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 perfectly sound to assume that sustainable personal relations between customers and service providers and the presence of the captain on-board still will be preferable by a number of customers. In passenger transport and dangerous goods, this could certainly be the case. Manned vessels could still add value on their services from this perspective according to the preferences of the customers, but a required level of automation will have to be in place.

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 evenly be threatened. The potential impact of other modes is an interesting subject for future research.

Fully automated navigation systems and other automation devices that could lighten the workload on board of the vessel, have on the short run more chances to emerge commercially on the entire IWT market than a complete unmanned vessel. The reduction of transaction costs for the captain and the helmsman could lead to shorter working hours. The crew only has to 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 could be relevant to research the labour circumstances and the impact on safety if the boatmaster will operate from an on-shore (remote) control center. Will a 'gamer' be sufficiently (e.g. mentally) linked to the vessel?

The upcoming years, military innovation will become presumably commercialized. The automation technology that is used in Afghanistan and Iraq could bring fundamentally changes to the transport sector and could be more disruptive than the Global positioning system (GPS) for the market of conventional paper maps. The impact from this kind of innovation on the supply chain or on transport modes invites further research.

At this moment it is too soon to calculate the real full cost of an AV. To many essential components are still in initiation phase and the development phase will improve and integrate further these components before a complete AV will go on the market as an on-the shelf product. Some components will gradually arrive on the market and be used under human command. Automated navigation (automation of the wheelhouse) will need a reliable integrated system of scanners and other devices next to the necessary software. As a supportive system, this will come on the market within a few years and needs a time for machine learning even after it is commercialized. All possible circumstances should be observed and translated in data for the development of an AV. Eventually, level 5 will be reached when an automated vessel becomes fully automated and when it is able to solve situations where human boatmasters have to improvise based on their personal experience and capabilities.

The research scope focused on the Rhine fleet for the transport of freight. It was noticed that passenger transport experienced 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 measure if passengers would go on a river cruise without captain or operational crew. As long as there is a cook, a barman and perhaps a ships doctor, people are still willing to go on cruise perhaps, or would they still 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 definitely not proven that an SCC will be safer indeed. Challenges such as situation unawareness, data misinterpretation, capacity overload, reliable connectivity, liability 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 in the scope of this research.

The policy analysis, needs more quantified data in order to calculate the benefits and costs of different policy models. But in dealing with cross-border externalities in a relatively small sector such as the IWT, it sounds reasonable to believe that a transparent coordinate institutional level playing field is essential to allow an optimal innovation policy. The identified costs and benefits in the policy analysis, shows that a cost-benefit perspective on European policy in IWT offers interesting insights to improve policy. Future research could try and quantify the policy costs and benefits and help to improve policy.

VIII. Fuel alternatives: the LNG case

The last case analysis in this research applies the full methodology as used in the case of the automated vessel. This case analysis examines the possible positive business case of an alternative fuel such as liquefied natural gas (LNG) and answers the question what policy could do.

1. Introduction

The Paris agreement made it clear that every industry has to reduce its carbon footprint and emissions in order to reach the targets that were put forward to reduce the impact of climate change. There is still a broad unanimity in literature that IWT has a strong sustainable performance with low emissions and related external costs. But while other transport modes are rapidly improving their performance and decreasing emissions and fuel usage, IWT is threatened to lose its environmental advantages if current emission levels do not change. The average life-span of IWT engines is relative long and does not contribute to the necessary transition to cleaner engines. The transport sector is still strongly dependent 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 biggest emitter for more than 70%. Inland navigation is responsible for 13% of the greenhouse gas emissions and has a 1.1% share in transport energy demand (EC, 2014).

To address these challenges, the European Commission 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 Junker’ 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 fleet will have to adapt. Alternative fuels, after-treatment systems and green propulsion are possible solutions. Several research projects and even ships were funded with EU money. Next to alternative fuels, also a first EU project is ongoing concerning the development of an electrical barge.[130]

Due to time and data restraints, it was not possible to perform the analysis on all identified alternative fuels, but recent studies such as Prominent, provided a starting point for this research next to the in-depth interviews with engine manufacturers and vessel builders to start this research with a broad overview of existing alternative fuels and innovative propulsions. But the three analysis in this case are focused on LNG which gained the most attention the past decade and this innovation is being implemented on the market.

This innovation is closed and sensitive to competition, which partially explains scarcity of cost data, and a number of assumptions had to be discussed. The quantification of the costs and benefits is based on a broad literature review, interviews and own assumptions. These costs are fitted in a vessel model of a 110m tanker barge.

[130] 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.

2. Literature review and definitions

In 2014, the European Commission 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. The latter refers to the non-road mobile machinery regulation which covers 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 engines and the type-approval procedures to allow them to be installed in non-road mobile machinery. 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. An engine-family is defined as a manufacturer's grouping of engines which have similar exhaust emission characteristics. The application for the procedure for type-approval needs to be submitted by the engine manufacturer to the approval authority of the MS with an information folder and an engine in order to be tested by the responsible technical service. MS send a list to each other of all engine approvals on a monthly basis and if requested they provide more information. On a yearly basis, such a list is also sent to the European Commission.

The assessment of the NRMM 97/68/EC was prepared during six years with the involvement of different Directorate-Generals with competences concerning enterprise, employment, Transport (DG MOVE), Climate, Environment, Joint Research Centre and the DG Research and Innovation which shows that the document was prepared within a horizontal institutional governance policy. The revision of the NRMM was preceded by a technical review of the 1997 NRMM directive and followed-up with the commissioning of external studies and the preparation of emission inventories for various engine types. ARCADIS and RPA (Nwaogu T., 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. For IWT vessels, the matter is more complex than for a tractor or a lawn mower. Indeed, a vessel has usually two types of engines on-board. One or more engines are used for the propulsion system and another type is used to generate electricity. The latter is an engine with constant speed while the first one is a variable speed engine.

A large and recent source are the results from the European research project PROMINENT which also calculated costs-benefits and identified barriers for innovation uptake (Maes et al., 2015). The PROMINENT project was funded under the Horizon 2020 programme of the European Commission between 2015 and 2018 and was conducted by the 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. The total funding was EUR 6.25 million.

For the first analysis (SIA), a very useful basis is provided by PROMINENT in their first work package (Ecorys, 2015) where barriers and facilitating factors for innovation uptake of alternative fuels for IWT were identified based on desk research and expert knowledge within the PROMINENT consortium. According to this study (Ecorys, 2015) the following generic barrier categories or failure factors were identified:

1. Technical (immaturity of technology or lack of operational requirements),
2. Legal (unadjusted legislation),
3. Financial (access to capital or business case),
4. Knowledge (lack of expertise or skills),
5. Market (structure, conditions,…) and
6. Cultural (conservatism, old habits).

PROMINENT concluded in 2015 that LNG fuel[131], dual fuel[132], Stage V engines and hybrid propulsion with buffer battery were technologies 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*. The barriers were scored by a five-point scale by desk research and available knowledge of members participating inside the consortium. 14 technologies were identified and analysed such as LNG, dual fuel, GTL fuel, Right sizing, CCNR II engines, Stage V engines, Hybrid propulsion with or without batteries, SCR, Wall flow DPF, SCR and DPF, Fairway data, speed adaption and optimized track.

The interviews conducted during this research supported the findings in PROMINENT concerning the long life span of an average vessel (more than 30 years) as being a reason of the relatively slow uptake of new technologies such as replacing a new engine. Renovating the existing vessel and its engine is often more feasible for vessel owners than building a new one. But new is the fact that the European regulation has been adjusted sooner than expected, which was not yet the case during Prominent.

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 engine and a tank. 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 the TNO report, the well-to-propeller (WTP) greenhouse gas is 10% lower than diesel fuel chains, although further improvement is possible by lowering the high methane emissions of the engines. LNG offers benefits in reducing PM, SO_x, NO_x and CO_2 compared to diesel engines. The report assumes that in 2016, the standard would be Tier III and CCNR IV, but the European Commission decided to be more ambitious and to go for Stage V engines. For the future of LNG and to improve it further, it can be replaced by bio-LNG or LBG (Liquefied Bio Gas) without an expected impact on maintenance. One of the problems in LNG is the methane slip where 2 or 3% is emitted of the LNG as pure methane in the atmosphere, which is primarily caused by the lean burn operating principal of the engine, and also occurs during bunkering and distribution. Methane is a greenhouse gas or GHC that adds to climate change.

A technical report of the Joint research centre of the European Commission (Moirangthem and Baxter, 2016) identified LNG and Methanol as most commonly considered alternative fuels for the maritime and IWT sector. As a transition fuel towards an era of alternative fuels, ultra-low-Sulphur diesel is also mentioned[133] but the feasibility to provide the fleet is still to be examined. With new bunkering facilities and public support, LNG is considered the most promising by the JRC, at least for Europe. Methanol is also considered a preferred fuel. *The cost associated with retrofitting the engine for Methanol has been reported to be less 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).

[131] 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).
[132] '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)
[133] ULSDs are diesel fuels with very low sulphur content (15ppm mass basis), and low
sulphur residual fuel (LSRF) are diesel fuels that contains up to a maximum of 500 ppm sulphur.

The research program PROMOVAN launched by Voies Navigables de France assessed the real exhaust emissions of typical freight vessels during a normal operation (Pillot D., et al., 2016), but only a few hours of emission were monitored and analysed in small scale projects.

Studies, that were delivered in the framework of the LNG Masterplan, stated that the greenhouse warming potential of methane is about 21 times higher compared to CO_2. 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. But there is no consensus in literature about this factor. 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.

The building wave in the tanker fleet, mainly caused by the double-hull requirements, gave an additional opportunity to invest in new technology. In case of engines, most newly built double-hulled tankers are driven by a 3A stage (or CCNR 2) – diesel engine to meet current European requirements as mentioned in the actual regulation. Some major companies of engine builders confirmed this was the case. Another fact mentioned in the interviews was that the innovation concerning alternative fuels for IWT is clearly ahead of the developments in the maritime sector which is stated as lagging behind in meeting lower emission requirements despite the relatively low market supply of lower emission engines for the IWT.

EUROMOT, EBU and ESO stated during the policy development of the new NRMM regulation (Non-road Mobile machinery regulation) that the ambition of the European Commission to demand Stage V engines to be installed on new vessels (or as a mandatory replacement when a new engine is needed) from 2019 – 2020, requires a new European set of standards for these new types of engines. These regulatory factors would make it difficult to comply on time. The branch organizations, together with EUROMOT suggested to adopt the US standards for engines (US EPA tier 4) so that the market of engines would become bigger for the inland navigation by opening up the existing US market with a broader variety of engine supply. The CCNR defended the view of the sector in this case. The EC decided to be more ambitious and did not follow this point of view. Although still strongly aligned with US EPA tier 4 limits, the new NRMM limits include, for example, a particular number count and a methane slip calculation for both gas and dual fuel engines (Ponte, P., 2017).

2.1. Fuels and propulsion

The first distinction that has to be made 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.

A. Fuels

Diesel-hybrid propulsion, Diesel-LNG dual fuel – electric propulsion, diesel – electric with or without after treatment using diesel particulate filters (DPF) or Selective Catalytic Reduction (SCR), … the list of possibilities for the IWT goes longer. In order to reach environmental objectives or to reduce fuel consumption, alternative fuels and propulsion systems are interlinked in IWT. 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.

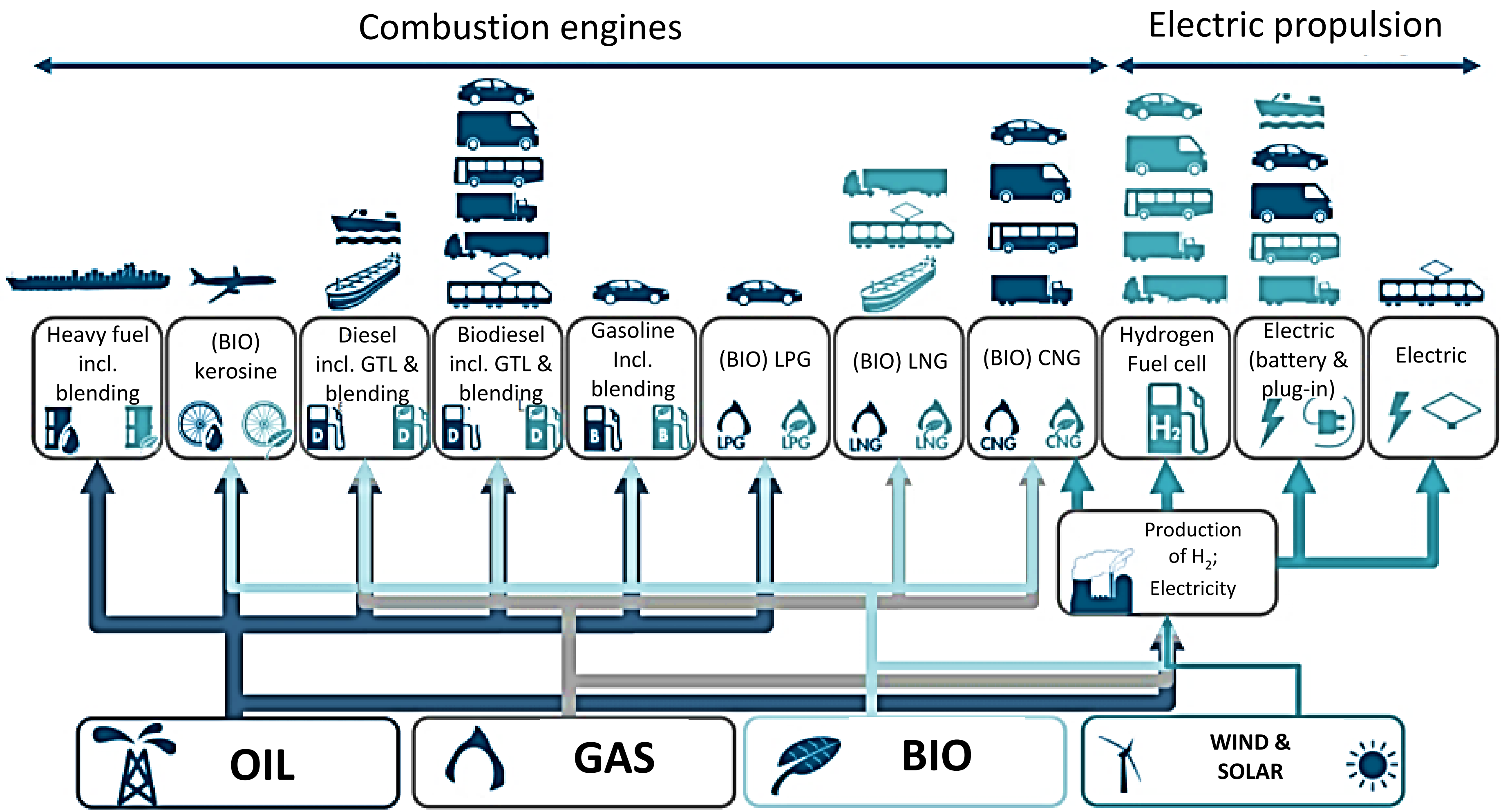


Figure 37: Overview of energy carriers and market segments
Source: Ministry of Infrastructure and Environment (2014)

B. Liquefied Natural gas

The past few years, transition fuels based on natural gas gained international attention for both the maritime as the IWT fleet. Natural gas can be liquefied (LNG) or compressed (CNG) and is already being used as a fuel in IWT. 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. LNG or liquefied natural gas, has to 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. 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). Also, other challenges arise in dealing with this transition fuel, which are analysed during the SIA.

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 (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. It can be expected in a positive technology scenario combined with new policies, that the natural gas losses will decrease over time. This does not only entail a private benefit (more gas to sell), but also has a public benefit (less methane emission in well-to-wheel distribution).
The impact of geopolitics and technology development are considered major determinants for the oil and gas prices. The oil price is affected by the strategy of oil producing countries (OPEC) and their collaboration with Russia in choosing to decrease or increase their oil production for world demand. The World Energy Outlook reports provide a broad overview in different scenarios, but a more detailed summary lays outside the scope of this study.

LNG is stored on board, in a cryogenic tank, which is, according to Falck RISC (2015), between 40 and 160 m^3. In IWT vessels, a tank of 40m^3 is the current standard. LNG is a mixture of carbon hydroxide with a high percentage of methane gas (more than 91%). 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. 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. Methane slip may be prevented with a methane slip catalytic converter (Panteia 2013 in Wurster et al., 2014).

In the case of LNG, two of the three vessels with 100% LNG failed for market uptake. Only dual-fuel engines seem, currently, to show modest successes. 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. 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. LNG 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). An installation where gas becomes LNG emits NO_x and CO_2. The storage of LNG also 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). 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 (N_2O) and 150 times lower than chlorofluorocarbons (CFSs).

C. DPF and SCR

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 NO_x. Not only the choice of propulsion and fuel determines the business case of a VO/O, but also the fact whether the technology can be used to refit a vessel or needs a new design of vessel, makes a significant difference.

D. Other fuels

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.

E. Propulsion

The propulsion of the engine also has an impact on emissions and greenhouse gases. The type of engine, the configuration, etc. all have costs and benefits and differ in performance and prices.

A duel fuel engine uses both conventional fuel and LNG (could also be CNG, LPG or biofuels) and combines the combustion of the conventional fuel and the gas into the air intake to power the vessel. 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 fuelhas 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).

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. There is also a difference in performance between a refitted or converted diesel Engine into a dual fuel. In addition, the methane slip can be further reduced in a newer engine because of an improved inlet and outlet valve overlap. The best option for each vessel depends on annual sailing time, average power, the ship type and the sailing area (Kruyt, 2012). The choice in propulsion also has an impact on the cargo. A monofuel LNG will require two LNG tanks of m^3. 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)[134]. 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) is capable of starting the engine.

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 Green Stream and Green Rhine) in 2013 which were the first 100% LNG or monofuelled vessels. 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 FlexFueler001 (bunkering vessel, 2018), MS Werkendam (2019), a tanker vessel of Somtrans and

[134] https://www.schonescheepvaart.nl/downloads/seminars/doc_1363970031.pdf

another 13 remaining RPG's of the Plouvier group that are announced for 2018-2019 and are being finished in Poland. The tank is up-deck in most cases or below deck as the MS Eiger-Nordwand which puts a container on top of the extra - hulled tank.

2.2. Costs & benefits from literature

ARCADIS 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 according to EUROMOT as mentioned by ARCADIS et al. 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). The following table shows an overview of all identified possibilities to improve environmental performance of the IWT in compliance with the upcoming regulation.

Area	Measure	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 49: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)

Another possibility to reduce emissions that is also dealt with in the Prominent project (2018), is right-fitting or right-sizing, which means that a number of vessels have an engine that delivers too much power that is needed. An engine with a lower power, uses less fuel. A number of 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 50). Also 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 50: Vessel types and average installed propulsion
Source: Panteia (2013)

The most exposed and highlighted innovation in this field is the dual-fuel engine with LNG. According to Deen Shipping, 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 oil[135].
- 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.
Within the recent project PROMINENT (2018), the capital costs are estimated at the values as mentioned in the following table. These costs were calculated after a thorough analysis of the fleet and vessel profiles, together with trip up- and downstream. Most values in the applied CBA in Prominent were estimated in 2015.

	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 51: Capital cost of LNG engine
Source: minimum and maximum prices estimated for 11 ship categories, based on PROMINENT 2018.

[135] 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.

Other benefits for the business case of alternative fuels, lie in the 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 also vessels with a CCNR 2 diesel engine get reductions.
Furthermore, there is currently no common approach between European ports in port due reductions. More collaboration between ports in this field could increase the effectiveness in price reduction strategies and really stimulate the shift towards alternative fuels, but this lies outside the scope of this research.
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). The cost of LNG is not only determined by the market price, but also depends on the bunkering location. An often used bunker list for fuel cost is the CBRB *brandstofcirculaire* 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).[136]
Since 2011, IWT vessels with conventional fuel have to pay for every 1000 l of gasoil a small fee of EUR 7.5. This fee is related to the CDNI (Convention of waste in the inland navigation) and is a payment in advance that aims to cover the deposit of oil waste[137]. The CDNI is only applicable in the MS of the CCNR (certain parts in France) and Luxemburg. Currently, the conditions for LNG are mentioned as a topic in the working program of 2018-2019 of the Conference of treaty members (CVP).

2.3. Auxiliary innovation

To fully comply with the NRMM of 2016, alternative fuels will need auxiliary innovation. Electrical vessels will need better performing and cheaper batteries. Hydrogen ships will need a cleaner and cheaper way to produce hydrogen. LNG will need to solve the methane slip issue with after-treatment systems to lower the methane slip which adds to climate change as an important greenhouse gas.
Most alternative fuels need infrastructure to bunker vessels. In the case of LNG, the size of the cryogenic tank costs cargo space. Also in this field, more compact solutions or innovations could be expected.

New after-treatment systems of existing diesel engines can be enough to reach the NRMM targets but that does not mean that the business case would be positive because of the global expectation and assumption that oil prices will increase significantly the following decades. The innovation hype cycle as presented in Figure 38 describes several factors that are needed, including auxiliary innovation, to reach market uptake of alternative fuels such as LNG.

In order to reach the plateau of productivity where the innovation is implemented and reaches market uptake, a phase of maturation is essential. After the technology trigger and the high expectations, the reality hits which is called the '*trough of disillusionment'(*Gartner, 2017*)*. In this phase, the engine builders as main innovators, users and investors are vulnerable. When all essential success factors are in place, the plateau of productivity can be reached, and the real first-mover advantage becomes accredited by the market uptake.

[136] https://www.evofenedex.nl/sites/default/files/inline-images/re/fb899df2a3abaeeb8a0056e7862df02/Gasolieprijs_ICE_Betaald_Advies_2011-06.pdf
[137] http://www.cdni.be/nl/gp_algemeen-eps-cdni_109.aspx and https://www.cdni-iwt.org/wp-content/uploads/2018/06/CDNI-2017-II-3_nl.pdf

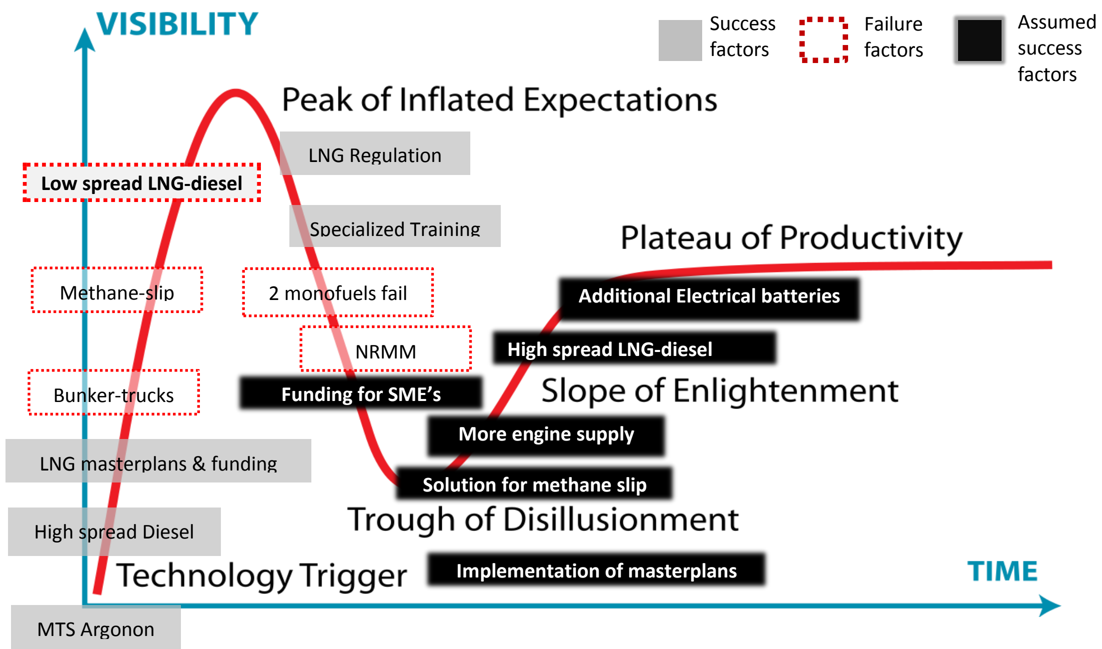


Figure 38: The innovation Hype Cycle of LNG fuelled IWT vessels
Source: own creation, inspired on methodology of Gartner[138], interviews and expert meeting, added with findings from PROMINENT (2018) CLINCH (2017), LNG Binnenvaart (2017), LNG Masterplan for Rhine-Main-Danube (2015)

The presented hype cycle is not an exhaustive summary of all necessary auxiliary innovations and success factors, nor is it without assumptions. The mentioned events are not all necessary to leading to market uptake. At the same time, if all assumed success factors would be implemented, market uptake would remain uncertain, but uptake chances would be assumed to be higher.

2.4. Failure of LNG mono-fuel vessels

In Figure 25, it is mentioned that two monofuel LNG vessels failed market uptake. When in 2013 the MTS Green Stream and TMS Green Rhine were finished at Peters Shipyards, enthusiasm and (inflated) expectations were significant. Under a fixed contract with Shell, a derogation from the CCNR and significant exposure in media (maritime award "ship of the year" 2013 for the MTS Greenstream), all factors seemed to be in place for a promising start for these innovative vessels.

According to the public bankruptcy report (Benthem & Gratama, 2017; Central Insolvency register, 2017), the companies behind the Green Rhine and Green Stream went bankrupt with an annual loss of EUR 2,591,432 (Green Rhine) and EUR 2,686,032 (Green Stream) in 2016. The main investor ABN-AMRO lost almost EUR 4,8 million after selling the ships to AMS B.V. The names of the vessels changed into Ecotanker II and Ecotanker III and are still operational in the ARA-region.

The total investment was EUR 15,1 million which was estimated to be approximately EUR 4 million more expensive than two 110m conventional MTS's.

The reasons why the 100% LNG vessels failed were summed up by the bankruptcy report as follows:
- Shipyard went bankrupt: support, know-how of vessel, disappeared.
- Number of technical problems on-board.
- Growing uncertainty for customers and their charters.
- Technical problems with cryogenic tanks, methane slip and other technology.

[138] Based on the example of innovation hype cycle of Artificial Intelligence by Gartner inc. https://www.datanami.com/2017/08/29/ai-fares-gartners-latest-hype-cycle/

Desk research and interviews delivered additional reasons:

- Spread evolved against expectations, impacting on business case; higher fuel cost than estimated.
- Slow implementation of bunkering infrastructure mentioned in masterplans: now mostly bunkering by truck.
- Ageing of LNG during periods of non-operation (faster vapourization or damping than conventional fuel).

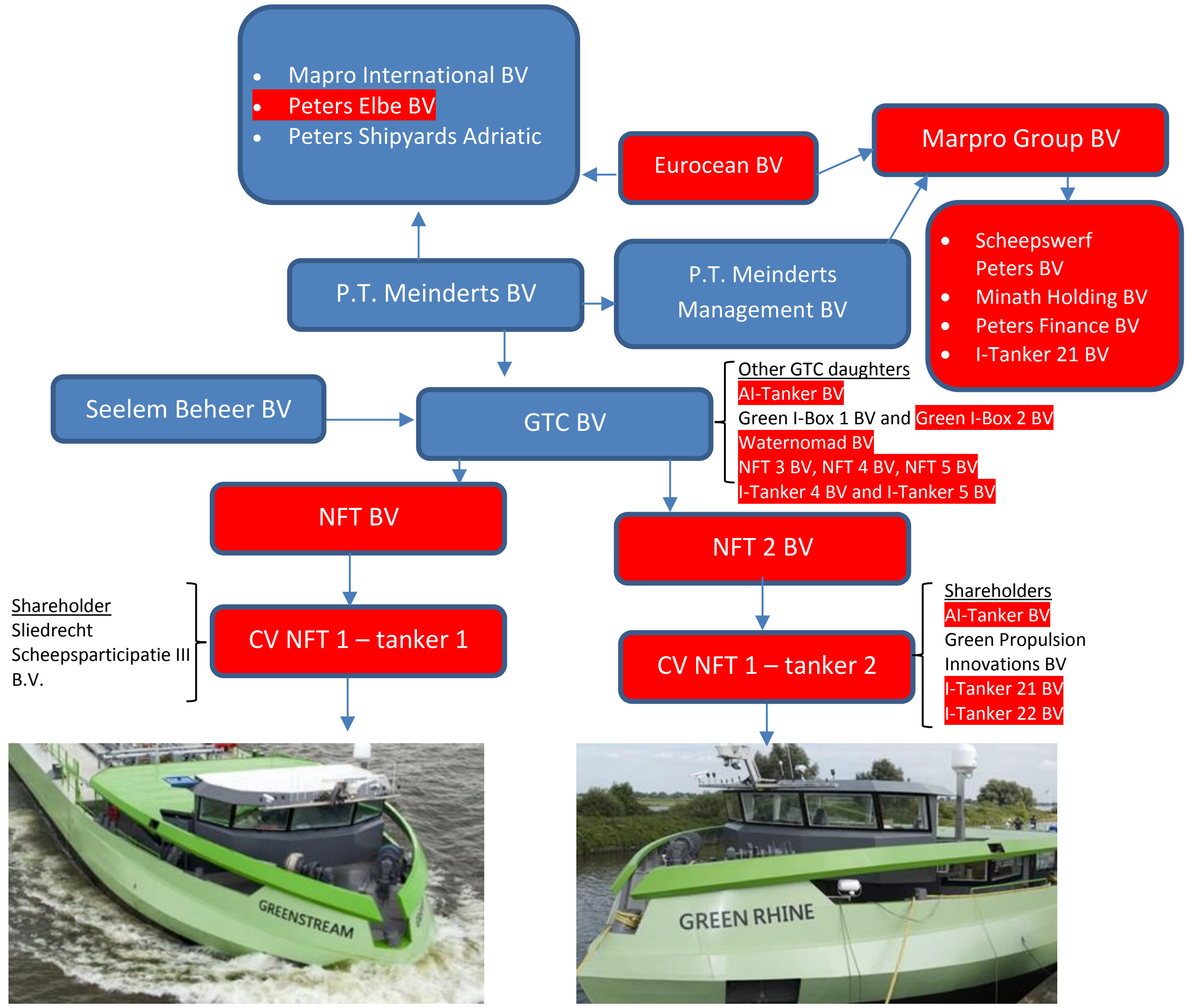
Both ships were supported by public subsidies. Most of the funding came from the Dutch government which provided several types of subsidies.

The LNG monofuelled tanker vessels (Green Stream and Green Rhine) had different companies as shareholders. Every vessel belonged to a separate company but which belonged to the same group of companies within a rather complex structure. The companies behind these ships were called NFT B.V and NFT 2 B.V. and belonged to companies and groups with always one or more shareholders. The final owner was P.T. Meinderts B.V. which was the main shareholder of GTC B.V. which in turn was the biggest shareholder of NFT B.V. and NFT 2 B.V.. The NFT B.V. and the NFT 2 B.V. were respectively the main shareholder of C.V. NFT I Tanker 1 (Greenstream) and of C.V. NFT I-Tanker 2 (Green Rhine).

The company P.T. Meinderts B.V. was also for 50% owner of Peters' Shipyard. The main rational behind this relative complex network, was to lower the business risk of the innovator and to strengthen the relation with the specialized shipyard. The consequence was when the innovation failed because of a bankruptcy of the shipyard, the accountability was complex to retrieve, which did not feed a positive investor image for inland navigation innovation investments. In this case, the shipyard owner, and one of the key players in the complex structure, is currently suspected to be hiding in Croatia (official receiver reports, Marsman and Manning, 2018).

The red shaded areas in Figure 39 show companies that were liquidated or went bankrupt following the bankruptcy of Peters‘ Shipyard which was the main cash flow generator for the holdings above and which was also the dedicated shipyard for the vessels with all knowledge in-house. The technical difficulties of the innovative ships jeopardized the supply reliability, and after the bankruptcy of the shipyard which made technical follow-up uncertain, the main customer Shell pulled out.

The ships were sold in 2016 to AMS BV and sail under the name Ecotanker II and Ecotanker III with a refitted electrical power system but still as 100% LNG – electric propulsion. The two owners of AMS were between February 2016 until 2017 member of the board of the NFT 2 BV and the NFT BV and claim to have removed the technological problems of the vessels. The Peters‘ Shipyard is now sold to the Bodewes group and Meindert BV is still involved as technical advisor at the Thecla Bodewes Shipyards.



Built in 2013 by Peters Shipyards B.V.
Initial invested capital = EUR 7.4 million
Loaned = EUR 4.05 million,
ABN-AMRO Bank N.V. lost EUR 2,394,916
Bankruptcy 26/07/2017 and sold in 2016 for EUR 1,700,000

Built in 2013 by Peters Shipyards B.V.
Initial invested capital = EUR 7,4 million
Loaned = EUR 3.9 million
ABN-AMRO Bank N.V. lost EUR 2,509,624
Bankruptcy 26/07/2017 and sold in 2016 for EUR 1,700,000

Figure 39: Schematic overview of business structure behind the monofuel LNG vessels
Sources: bases on reports of Marsman and Manning (2018), Drimble.nl (2018), Benthem Gratama (2018), Failissementsdossier.nl (2017), Schuttevaer.nl (2014), NRC.nl (2014). Images derived from Veth Propulsion, company's website (2018) and Binnenvaartkrant (2013). Possible indirect bankruptcy of supplying companies are not taken in account.

The case of the Greenstream and Green Rhine explains the strong possible dependence between the VO/O and the shipyard. The financial structure and the technical expertise could support, or in this case, almost terminate the innovation. Although still in operation, there has only been one other mono-fuel LNG since 2013 in IWT, the MTS Ecoliner of Damen Shipyard which received subsidies from the LNG Masterplan and is still operational under Deen Shipping.

2.5. Data challenges

In the framework of this research, 43 in-depth interviews and participation in numerous expert meetings, provided a useful safeguard and improved significantly the quality of data and assumptions. The interviews were taken under mutual guaranteed confidentiality and the derived data is anonymized.

Because of the strong variation of vessel types in the European IWT fleet, it is difficult to identify categories of vessel types 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. Data is usually undisclosed because of the business sensitivity and confidentiality towards other competitors. With the implementation of River Information Services, it should become possible to closer monitor vessels and to improve research. For the time being, a number of assumptions 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 of the fact that 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 CO_2 equivalent unit is used. But the conversion factor for the latter shows no unanimity in literature. The conversion factor lies between 22 and 34 of the CO_2 equivalent unit which means that methane is at least 22 times worse than CO_2 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 SCBA, 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 in reality even older. There was also a lack of engine data to estimate the limits of emissions for the Stage IIIa.

The 2006 CCNR study “Marktbeobachtung der Europäischen Binnenschifffahrt” gave the basis for the calculation of the EU limits together with data from EUROMOT (European engine builders association, 190 engines sold between 2004-2006 which are mostly between 8000 and 1,5000 kW) and Germanischer Lloyd (verification agency, emission factors for NO_x and PM). The typical annual operation hours were assumed to be between 3,500 and 4,500 hrs or 230 working days, with an engine operation of 15-20 hrs a day. The load factor was set at 0.5 to take into account for the full load up-stream and the low load down-stream operation. The swept volume or water displacement per cylinder lies mainly between 3.5 and 7 litres per cylinder class (EUROMOT, 2006).

2.6. Policy

One the most important policy programs of the EU for IWT is the NAIADES program (Pauli, 2016). The first edition, between 2006 and 2013, was focused on addressing challenges in six areas concerning infrastructure, market, fleet, jobs and skills, innovation and governance[139]. During the second edition, a working paper was added concerning emissions in the fleet[140] which broadened the policy objectives with an improved sustainability performance of the fleet and the preparation of infrastructure for LNG

[139] 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.

[140] EC (2012), 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

fuel use together with technical standards. Also the CCNR stressed the importance of sustainability targets as expressed in their “Vision 2018”.

During the preparation of the second edition of NAIADES (2011)[141] 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 system[142]” which also puts emissions more on the agenda. Until the adoption of EU Directive 2004/26/EC, which amended the NRMM Directive and set emission limits for IWT from January 2007 onwards, there were no EU-wide compulsory emission limits for inland waterway vessel engines. European guidelines to limit pollutant emissions from IWT were introduced but without real null base 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.

The problem of differences between EC and CCNR 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 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 definitely the aim of CESNI to complete the internal market for the IWT by levelling the set of regulations for all actors inside one regime instead of several. In the case of the engines, the small IWT market becomes a little bigger if all MS have to comply and enforce the same CESNI regulation and standards.

Table 52 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 lays outside the scope of this research.

[141] https://eur-lex.europa.eu/legal-content/EN/TXT/DOC/?uri=CELEX:52013SC0324&qid=1543239289640&from=EN
142 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

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		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 III A 2007 Small and normal engines V1:1-3		V1:1 = D ≤ 0.9, P > 37 kW V1:2 = 0.9 < D ≤ 1.2 V1:3 = 1.2 < D ≤ 2.5	5.0	**NOx+HC**	7,5 7,2 7,2	0.4 0.3 0.2
EC Stage III A 2009 Larger engines V1:4 V2:1-5		V1:4 = 2.5 < D ≤ 5 V2:1 = 5 < D ≤ 15 V2:2 = 15 < D ≤ 20, P ≤ 3300 kW V2 = 3 15 < D ≤ 20, P > 3300 kW V2:4 = 20 < D ≤ 25 V2:5 = 25 < D ≤ 30	5.0		7.2 7.8 8.7 9.8 9.8 11.0	0.2 0.27 0.5 0.5 0.5 0.5

Table 52: Pollutant emission limits for IWT
Source: based on Pillot et al, 2016; HC= Hydrocarbons; NOx=Nitrogen oxides; CO = carbon oxide, CO_2 = carbon dioxide; PM= particulate matter; P & PN = net power output; D = displacement

Starting from January 1st 2017, the new NRMM regulation[143] 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 that are shown in Table 53.

Emission stage	Engine sub-category	Power range	Ignition type	CO	HC	NOx	PM mass	PN
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh
Stage V	IWP-v-1 IWP-c-1	19 ≤ P < 75	all	5	(HC + NO_x ≤ 4,70)		0,3	—
	IWP-v-2 IWP-c-2	75 ≤ P < 130	all	5	(HC + NO_x ≤ 5,40)		0,14	—
	IWP-v-3 IWP-c-3	130 ≤ P < 300	all	3,5	1	2,1	0,1	—
	IWP-v-4 IWP-c-4	P ≥ 300	all	3,5	0,19	1,8	0,015	1×10^{12}

Table 53: Emission limits for main and auxilary 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 SO_2 emissions from IWT. Finally, the document refers to LNG as a potential fuel to reach Stage V of the NRMM and

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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 the IWT as mentioned in the recent NRMM are to be found in *Emission limits for the IWT Regulation (EU) 2016/1628* at the end of this case analysis.

Figure 40 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 NOx lays 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 NOx 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 the IWT) will introduce only one emission standard for the European IWT and makes the distinction between NOx 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 NOx 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 cycle[144] 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, 2016). 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 NOx limit (as in the NRMM for stage IIIa), the combined limit value for HC and NOx is reduced by 0.19 g/kWh and only applies for NOx 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 NOx and HC values). For this research the focus lays on vessels with a power above 300 kW (cat. IWP/IWA-v/c-4 in stage V).

[144] 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)

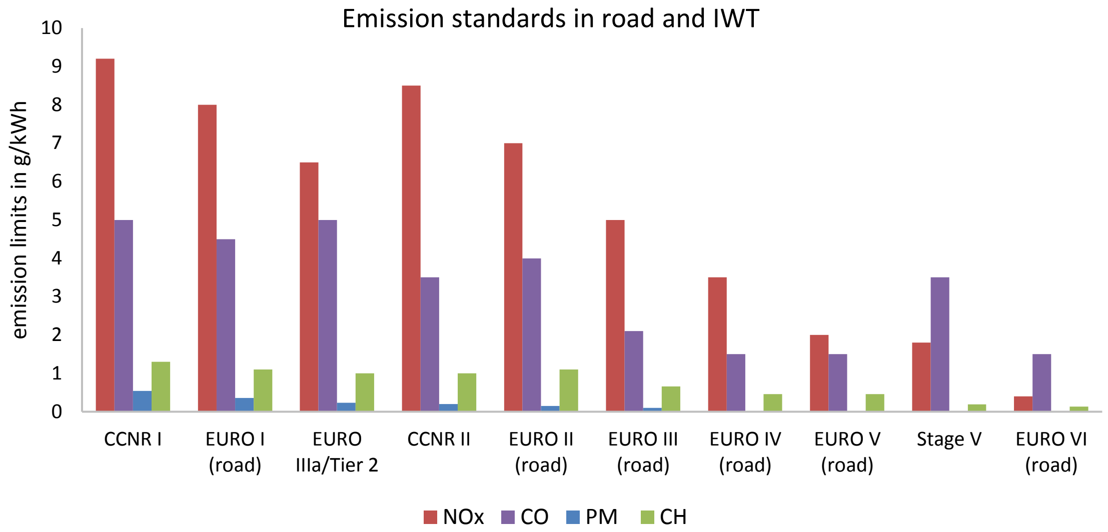


Figure 40: Comparison of selected emission limits from European regulations
Source: own compilation of Pauli (2016), DieselNet (2016), CCNR (2018), EC (2016)

Regarding the emission standards, it is easy to claim that IWT is lagging behind other modes. But 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 the 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.

During this analysis estimations are made based on the average annual power (expressed in kWh) as calculated in Prominent (2018) and a number of assumptions concerning emission factors, as explained further in this research.

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 VO/O's 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.

2.7. Potential 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)[145]. The power averages are calculated with the available data in the dataset. This part of the fleet is according to the IVR dataset, registered in the CCNR countries and Luxemburg. The Netherlands has the biggest 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 (*Table 54*).

	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[146]

Table 54: Tanker barges <110m in the European fleet
Source: based on IVR (2017)

This segment of the fleet, is mostly double-hulled which is also the main reason for the relatively young average age. According to the database, there are still 10 single-hull vessels[147] 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 above 110m. Since it became clear that major customers such as BP and ESSO preferred double-hull vessels (2008) and that policy soon followed, no single-hull tanker was built in Europe. Most of them were demolished or sold to Nigeria. This policy and behaviour of majors led to a building wave of double-hull tankers. Without going further into detail of the enforced implementation of double-hulls and cold[148] phasing-out of single-hulls, the relevance of this reference for this research, is that the tanker fleet already had recently done a major investment. This investment was enforced and led mainly to newly-built vessels instead of refits. It can be assumed that most vessels in this segment (>110m) have installed relatively expensive engines that correspond to CCNR II type engines. As said, most of these engines are as old as the vessel and follow the same estimated average building year of 2006. Engines in IWT normally have a longer lifespan than 12 years and the investment of the newly-built double-hulls presumably still has a relatively high leverage.

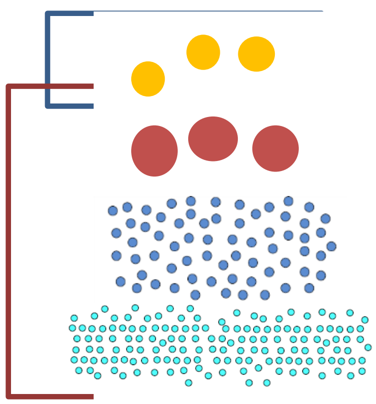
The total number of identified built and almost built LNG ships (dual and 100%) is identified at 23 vessels at the moment (2018), whereas 20 vessels are intended to transport liquid bulk. Those tankers will mainly be used in the ARA region and on the Rhine.

In total, 1,534 tankers of all sizes are registered (fleet of Luxembourg + CCNR fleet). Since 2011, more than 1.3% of the IWT tanker fleet in this region will run at least for 80% on LNG starting from 2019. Most of them are still first movers and are owned by bigger players in the market. Although subsidies are possibly included (EU-funding) in the business case, these have not found their way yet to numerous SME's.

[145] The dataset does not show engine manufacturers for 24 vessels and for 208 vessels the engine power is not given.
[146] based on one given value
[147] 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. The number of single hulls were updated and those that were demolished or sold to Nigeria were removed from the analysis as much as possible.
[148] Cold phasing out because of the lack of subsidies or financial incentives which made it more difficult for VO/O's especially smaller ones to invest in other innovation, and in the middle of difficult economic turmoil because of the financial crisis of 2008 and higher barriers in attracting funding of financial institutions than before the crisis.

Major IWT companies that were identified are mainly Plouvier Transport, which belongs to the Plouvier Group (2 LNG dual fuel MTS and 13 ordered), *Chemgas shipping* of *Reederei Jaegers* (LNG dual fuel MTS) and Danser (dual fuel containership). Victrol and Somtrans also are planning to build a vessel with a dual fuel engine. The mentioned companies cannot be considered to be SME's.

The business structure of IWT shows a relatively high number of SME's with only one vessel in the Rhine Countries and Belgium, but there are significant regional differences. Quispel et al. (2015), based on Eurostat data, 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. Owning only one vessel within one enterprise without any other activities, makes the business model vulnerable for market changes and lowers the capability to invest in innovation. The relatively high number of SME's with one vessel in the most important IWT countries, does not resemble the market power. For the latter, the organization of the market in relation with freight capacity becomes important. The organization of the market is divided into a primary and secondary market (*Figure 41*).



	Estimated number	Ratio
Charterers	250	1
Freight brokers, cooperations, large multiple vessel owners	221	1
Single vessel owners	5,700	25
Barges	12,800	58

Figure 41: The relation between charterers, freight brokers, vessel owners and the number of vessels
Source: based on Quispel et al.(2015). Numbers differ from IVR dataset used elsewhere in this research (different year)

According to van Hassel (2015), the tanker capacity, which is currently the main focus of the LNG innovation diffusion, is dominated by a number of actors in the primary market. Of all tanker vessels, 87.25% are linked to a freight brokers or a larger ship owner (with more vessels). The distinction between brokers and multiple vessel companies, is difficult to make, because larger multiple vessel companies are often also active in freight broking. A number of brokers and companies 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).

The structure of the tanker market differs from the dry cargo, because of the European Barge Inspection Scheme (EBIS) which comprises between 90 and 95% of the tanker market in IWT. This private initiative, as explained in the case e-bargebooking, makes it more difficult to switch freight broker and which, although intended for ensuring safety, consolidates the market dominance of freight brokers and larger players.

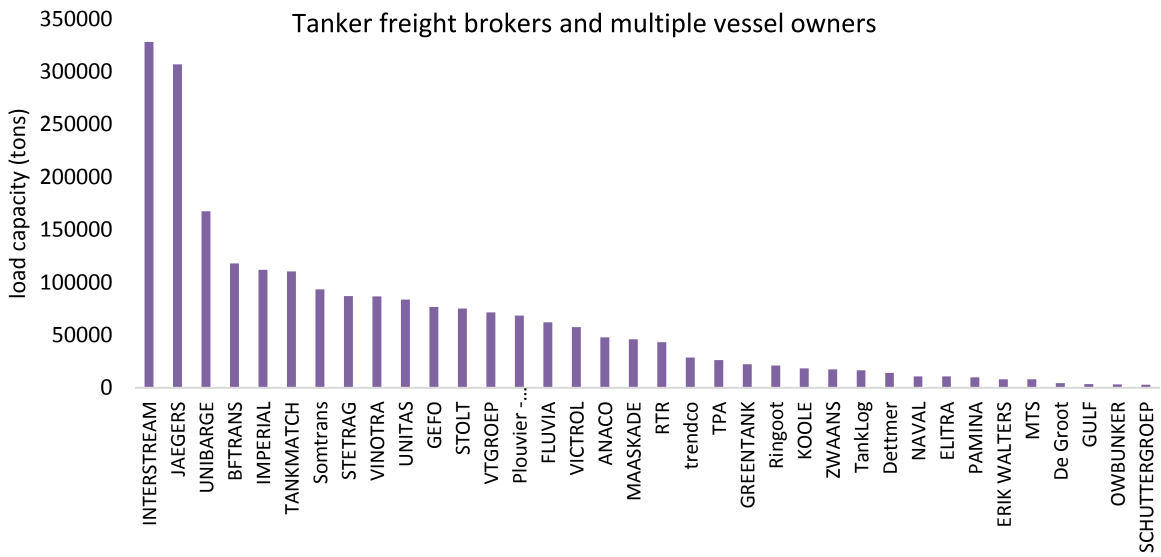


Figure 42: Multiple tanker owners and freight brokers according their capacity share
Source: based on van Hassel et al. (2017). Last update 2018. Data from fleet registers of identified companies

When preparing the SCBA 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 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 enforces 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. But this would increase investment costs for an assumed relatively high number of vulnerable companies (one-vessel companies). Knowing that ships usually stay on the market after bankruptcy and are able to 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.

3. Systems of Innovation Analysis

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 LNG dual fuel vessel. The innovation is first of all technological but has an organizational impact. Although the technology of a dual fuel engine is not new, the introduction of LNG as a fuel in IWT is. The organizational impact is explained by the absence of sufficient bunkering facilities which requires a change in organization of the vessel in function of the possible bunkering locations (ordering a truck on time) and the crew has to be trained in dealing with LNG. It also requires a more complex set of pre- and post-bunkering procedures.

The results are comprised of literature review, interviews with innovators and expert panels. The scope is the Rhine and ARA region (Amsterdam-Rotterdam-Antwerp).

3.1. Current situation

The regulatory barriers are removed in the European IWT for the use of LNG as fuel. Only the lack of infrastructure, the uncertainty of the price spread between diesel and LNG, the uncertain long term return on investment, and the relative high investment costs explain why not all VO/O or IWT companies invest in LNG engines. One of the possible transitional social costs, by announcing that from 2020 all new engines on vessels should be Stage V, more vessel owners could behave accordingly and invest in a cheaper stage 3a engine before 2020. But this would be a wrong strategy as more and more ports are becoming stricter with their own emission zones and regulation.

The enrolment of LNG-engines on the market of IWT is slower than originally expected. But in the segment of newly built tankers of minimum 110m in the Rhine fleet since 2011, the number of newly built LNG vessels is still proportional. 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 spread becomes larger (increasing diesel prices), the regulatory bottlenecks are removed and as the deadline of the NRMM comes closer, more investments in alternative fuels are expected.

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.

Other drivers of the innovation are primarily large LNG suppliers that want to enlarge the existing LNG market. 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. The first followers such as the Sirocco, and the Eiger were the basis for refits and all had specific designs. The GreenStream and GreenRhine were the basis for regulators to implement standards for monofuels. In the meantime, all these vessels had to be exempted for the existing regulation by an admitted temporarily 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 as long as 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 diesel (e.g. art. 8.01, RVIR[149]).

[149] *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)

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 at 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. 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. Also specialized organizations actively support the innovation through study work, lobbying at regulators and attracting public funding. The EICB, CBRB and others play an important role in the initiation of LNG in IWT. Several projects with EU funding emerged with a focus on LNG (Prominent, LNG Platform, Promovan, LNG Masterplan, etc.) that 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 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 the IWT, shows little interest in the technology. Expect for the MS Eiger, no dry cargo vessel was identified 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. 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 includes 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 kept older engines).

For small- and medium-sized enterprises in the tanker segment, it could be more difficult to invest in new engine technology after the double-hullization 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.

Table 55 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 SME's which comprises the biggest 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 [150].

In the initiation period, there is a lack of sufficient infrastructure, hard rules, lock-in effects (strong network) and a capability barrier at 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. At 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.

Actors / Institutions	Demand: VO/O's, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties lobbyists; manufacturers, ship yards, consultants, sector organizations	Knowledge institutes, funding, standardization bodies,
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 55: Systems Innovation matrix of the initiation phase of an LNG fuelled IWT vessel
Source: own creation, based on Aronietis (2013)
Legend: black shaded cells represent identified failure factors. Grey shaded figures show identified success factors

3.3. Development period

Every additional ship that follows the MTS Argonon also has to request for a derogation at the CCNR in Strasbourg and has to address the ADN committee in Geneva because of the differences between the LNG vessels[151]. Some of them were new designs (TMS Green Stream, 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

[150] Next to the InnoSutra project as referred to in deliverable Literature review, Woolthuis et al also refers to SIA (Woolthuis, R., Lankhuizen, M., Gilsing, V. (2005) A system failure framework for innovation policy design, Elsevier, Rotterdam University, Technovation, 25: 609-619. https://ac.els-cdn.com/S0166497203002037/1-s2.0-S0166497203002037-main.pdf?_tid=9a1a3186-a531-491c-823e-c79dcda2b314&acdnat=1535130716_d6c735d41ae767059a41bb2c9d7e7189

[151] 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.

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.

Other reasons for the slower pace to market uptake during this phase, are the market prospects and the price evolution of diesel and LNG. The Market Observation of the CCNR shows between the beginning of 2012 and the summer of 2015 a relatively low freight rate index for the tanker market. The periods of low water level, which induce a strong increase in the freight rate, were relatively short until the low water level in the summer of 2015, which led to an increase of the freight rate with almost 400 index points (index=2010), according to the CCNR and PJK International. After this period of low water level, the freight rate in 2016 dropped to the same level of 2010. *Figure 43* shows the index of the freight rate of PJK as mentioned in the Market Observation since January 2002 and June 2017 for the Rhine fleet compared with the water level that causes a seasonal effect on the market which will be further elaborated and explained during the SCBA in this research.

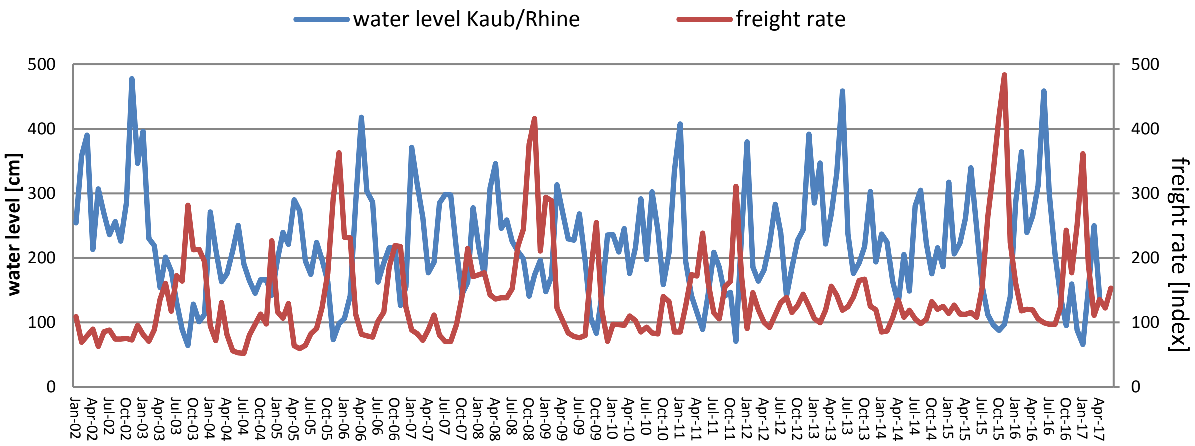


Figure 43 Freight rates of transporting gasoil and water levels
Source: Market Observation reports between 2002 and 2018, CCNR and PJK International

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 at 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-bargebooking, is generally weak to negotiate higher rates. Scrapping and exporting single hull tank barges are ways to decrease the oversupply, but these options are rather slow and limited to countries outside the ADN treaty. When a bankruptcy happens, the vessel is usually sold under the original value and remains active. The GreenStream and GreenRhine were sold for less than EUR 3,000,000 against a building price of almost EUR 15 million and are still operational. The market strongly depends on the demand for transport and has to 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 interesting.

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 have the legal framework to operate.

Table 56 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 adaptation of regulation is proceeding. The strong network lock-in effects are still in place and the focus lays 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 LNG Masterplan project proposed its final results concerning the gaps in the infrastructure. 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.

Actors / Institutions	Demand: VO/O's, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties lobbyists; manufacturers, ship yards, consultants, sector organizations	Knowledge institutes, funding, standardization bodies,
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 56: Systems Innovation matrix of the development phase of an LNG fuelled IWT vessel
Source: own creation, based on Aronietis (2013)
Legend: black shaded cells represent identified failure factors. Grey shaded figures show identified success factors

3.4. Implementation period

In this phase, the innovation has a regulatory framework and can be bought from the shelf. But as LNG implementation has found its legal basis, 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 CO_2 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 CH_4 not 25 times worse than CO_2 but 34 times worse, diminishing the claimed greenhouse gas reduction during the initiation and development period of the LNG as fuel for the IWT.

The price spread has increased but the geopolitical situation shows a number of 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 that make any forecast challenging. A fuel-based business case is therefore vulnerable because of the high uncertainty. This insight has made a number of 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 the 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 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.

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 57). Regulation is installed to allow further implementation of LNG and regulatory barriers are removed. But new research shows the underestimation of the methane slip and the effect on climate change. The European Commission is expressing 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 is becoming larger, more customers are expected to supply LNG as a fuel. The subsidies did not find their way yet to the majority of the market, but sector organizations and other actors such as EICB (e.g. total cost of ownership model) are actively promoting LNG and other greening options and are filling the gap as intermediary support for smaller individual VO/O's. The LNG engine and installation, as more engine builders arrive on the market, could become cheaper.

Actors / Institutions	Demand: VO/O's, large vessel owners, charterers, industry with own vessels	Shippers/ forwarders	Third parties lobbyists; manufacturers, ship yards, consultants, sector organizations	Knowledge institutes, funding, standardization bodies,
Infrastructure				
Hard Institutions				
Soft Institutions				
Weak Networks				
Strong Networks				
Capabilities				

Table 57: Systems Innovation matrix of the implementation phase of an LNG fuelled IWT vessel
Source: own creation, based on Aronietis (2013)
Legend: black shaded cells represent identified failure factors. Grey shaded figures show identified success factors

3.5. Discussion

The chicken-and-egg problem remains in all identified phases 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.

Subsidies are given to the implementation of the LNG but as new research shows the lower performance of emitted GHG by LNG vessels, it could be from a welfare perspective that the social benefits are too low to justify the subsidies. This is further researched during the SCBA. The added external costs related to the truck-to-ship bunkering are also briefly examined.

Smaller medium-sized enterprises with usually one vessel still have not found their way to greening technology such as LNG. The market remains small and limited to the tanker segment of large vessels. Others 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, especially for the mono-fuel vessels, LNG still has a large potential, as many expect an increase of the conventional fuel prices (Prominent, 2018). 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 considered to be too high or when LNG bunkering is not feasible because of infrastructure problems, the vessel is perfectly able to solely run on diesel to continue operations.

3.6. Initial conclusions

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.

The threshold (revenue minus costs or the net benefits) could be regarded by most vessel owners as not high enough to invest without subsidies. Some respondents pointed out that the credibility of

policy actors providing subsidies or proposing masterplans is jeopardized by every election or replacements of key decision makers.
Another uncertainty are the masterplans of several EU MS and ports. 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. Only the number of approved sites to allow truck-to-vessel bunkering has slightly increased.

Large inland shipping companies can take more risks and can digest or compensate more easily different kinds of failure than SME's. This general truth is certainly the case for LNG. The original business case behind the first mono-fuels in Europe hardly survived and the ships were forced to be sold to another company at a significant loss. LNG does not only need sufficient infrastructure to become successful, it also needs frequent active vessel operations. LNG fuel has to be kept under a very low temperature and it digresses or loses performance in a couple of weeks of non-usage (ageing process).

The LNG tankers that are built at the moment are mostly dual fuels with an engine that runs on diesel and LNG. They usually have a long-term contract with major fuel suppliers/customers such as Shell. The positive business case depends on the price spread next to the 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 cultural biases.

Concerning the environmental benefits, it is important to distinguish among two external costs: 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, CO_2 or CH_4 (Methane) by carbon-based fuels still add to the global warming of the planet. In case of the LNG engines, the CH_4 waste is an important issue that invites more research or even some kind of auxiliary innovation in order to fully comply with the Paris declaration.

Another problem of LNG engines on a vessel 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. Crew members have to be trained to treat the fuel in the safest possible manor and increases the crew cost because of additional training. This extra cost is considered to be low because of the already relatively expensive obligated frequent ADN training.

3.7. Detailed analysis

The barriers were briefly identified according to their evolution during the initiation, development and 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 (2015) 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, 2015:17). 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 by Figure 44 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 44: 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 by Figure 44 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 by Figure 45.

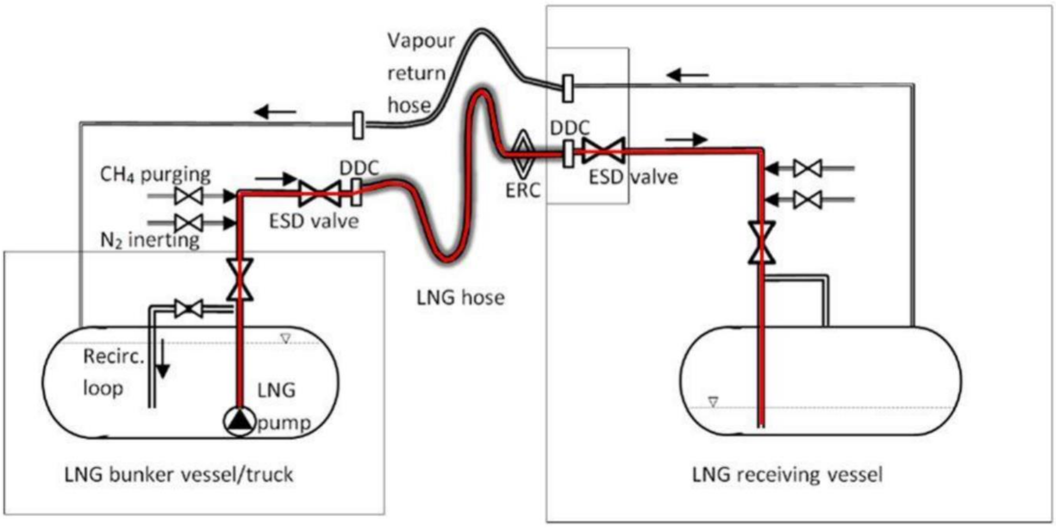


Figure 45:Bunkering process of LNG from tank to tank
Source: LNG Masterplan 2015, DMA, "North European LNG Infrastructure Project – A feasibility study for an LNG filling station infrastructure and test of recommendations", (March 2012) [152]

[152] 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. CH_4 (methane) purging, N_2 (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 have to be precooled to avoid LNG boiling and again be made inert. The connected system can now purged to remove remaining nitrogen. After bunkering, the lines have to 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. But the procedures for conventional bunkering are mostly simple 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)[153], 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.

[153]http://lngbc.eu/system/files/deliverable_attachments/LNG_BC_D%203%208%20Cost%20analysis%20of%20LNG%20refuelling%20stations.pdf

Figure 46 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).

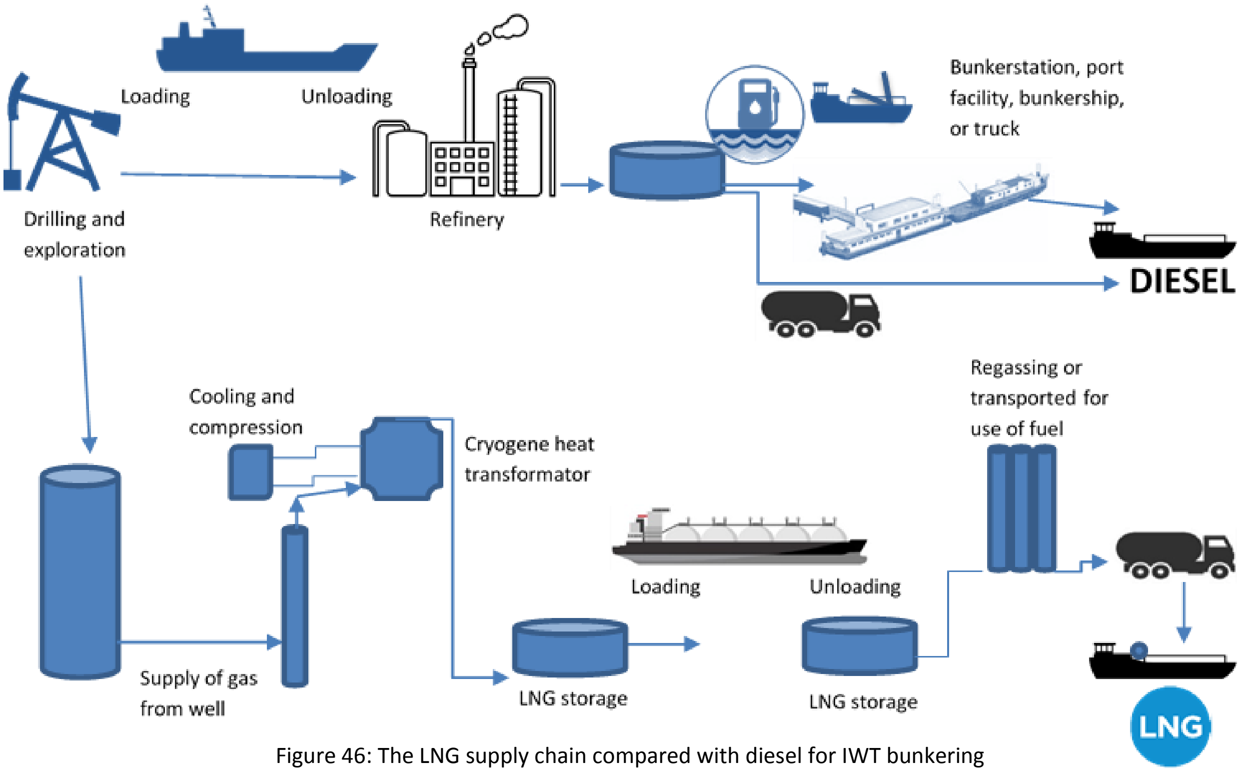


Figure 46: The LNG supply chain compared with diesel for IWT bunkering
Source: based on Oranjewoud (2006) and own creation

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 has to be taken in account by potential investors when discussing the critical mass of consumers needed to make the facility profitable.

Another challenge lays 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. Also, 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).

The LNG Masterplan has carried out pilot deployments in both the Rhine and the Danube region. In Ruse (Bulgaria), the LNG terminal was equipped with a truck fuelling station and a pontoon to fuel inland vessels. The Masterplan also provided European subsidies for the building of the Eiger, Ecoliner and the Sirocco. Figure 47 shows the locations where TTS is currently possible. On-shore facilities are planned in Antwerp, Mannheim and Cologne.

Figure 47: LNG Masterplan Rhine/Meuse-Main-Danube current developments
Source: LNG Platform as shown on the project website. The sun like markings represent locations for TTS.

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 emissions[154]). 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 have to be type-approved in both cases one year in advance. No engine replacement provision is included in the regulation for IWT. Only new engines have to 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.

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). But as the regulatory bottleneck is removed an no more derogation should be demanded by the innovator, mainly the emission policy remains relevant.

It could be expected that policy makers 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. In the meantime, given the reduction of emissions compared with conventional fuels, LNG can still be considered a transition fuel that relatively easily 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 development[155]. Most vessels with LNG that are being built or already are operational, received public funding for at least the half of the additional cost of the investment when compared

[154] 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
[155] https://ec.europa.eu/inea/sites/inea/files/fichenew_2012-eu-18067-s_final_0.pdf

with conventional technology. Several research projects emerged with public funding from the EU, national governments, ports and even provinces. Of all identified LNG related projects for IWT, a total of EUR 66.7 million was contributed by EU funding between 2002 and 2018 (Table 58).

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 environmental friendly and efficient fuel	Pro Danube Manageme nt 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 Developme nt 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 58: Project overview of LNG in IWT and EU-contribution (non-exhaustive)
Source: own compilation, based on INEA 2018, project websites

The total budget of the identified projects since 2002 was more than EUR 127 million. The results are diverse and lay between 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, a number of now operational vessels received subsidies. The impact of the given subsidies is further discussed in the policy analysis in this research.

Several public funding possibilities were identified at national (Dutch case) and European level. The Dutch government provides following funding possibilities and also has a special tax regime for LNG which is lower taxed than diesel:

- Lower tax on labour involved in research and development of innovation[156].
- Tax deduction of expenditures in research equipment.
- Innovation box: companies are allowed to allocate profit from the innovation in a lower tax tariff.
- Special TKI-Gas (*Topsector Kennis en Innovatie*): funding mechanism for energy innovations

[156] Wet Bevordering Speur en Ontwikkelingswerk - WBSO

- 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.

At the European level, public funding is currently possible through the CEF calls (*Connecting European Facility*) and the European Commission Horizon 2020 program. The CEF focuses on innovation that is ready to be implemented on the market and to stimulate enrolment, which explains the market orientation of CEF. The Horizon 2020 focuses on technical innovations, research and development. This approach stimulates research-sided innovation. The time needed to request a subsidy can be divided in two periods[157]:
- Period 1: preparation of the request and agreement or support of national government.
- Period 2: the proposal is sent to the European Commission (CEF calls) for evaluation. This evaluation of all proposals takes minimal two months. Afterwards all MS of the EU are consulted together with the European parliament. An additional four months are required to select individual subsidy contracts.

At least one year is needed from preparation of the request until uncertain clearance of the European Commission. Exact amounts of subsidies for each ship were not given. Most of the emerging existing LNG fleet in Europe are built and subsidized under Dutch and European support.

Also 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)[158].

C. Interaction conditions

The innovation network is an important success factor for the innovation. In case of LNG, a number of 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 of the innovators of the first LNG vessels are considered to be 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/O), several partners are lined up such as:
1. Engine manufacturer: provides reliable engines, specialized installation and service, and gives information concerning training and manuals.
2. Classification societies: these societies support the VO/O to comply with regulatory standards and to get approval for the installed innovation. A classification report is usually mandatory for the authorities.
3. 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

157 https://www.rvo.nl/subsidies-regelingen/cef-transport/faq
158 https://www.eicb.nl/wp-content/uploads/2016/08/Consultatieronde-Subsidies.pdf

4. Charterer or cargo owner: also referred to as shipper which are the customers of the VO/O. 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. But in case of LNG, major customers offer fixed contracts which are a success factor in the business strategy of the customer.
5. Freight brokers: the intermediary role of the freight broker is already analysed in other cases within this research (e.g. e-bargebooking). They often are involved as co-investor within the vessel and have the most benefits if a vessel is successful.

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 of all, 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 has to 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 Quatar. Forecasting gas demand goes with a number of 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 at 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 a number of 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 media exposure for the first vessel or innovator offers other advantages such as more appeal towards customers and potential investors as long the innovation remains a success story.

D. Capabilities

The most important success factor for an innovation is funding. If not enough funding is available to initiate, develop and implement the innovation, the innovation will fail. The innovator has to be able to take into account 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. But funding is not the only capability the innovator should have.

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. VO/O's 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 interesting 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 SME's and one-vessel owner / operator limit the investment capacity at customer side. The bargaining power of these SME's 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 SME's 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/O 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. Not only the prices that are expected to increase of the new engines after making the new emission standards mandatory, also the certification procedures of the engines have a relative high cost, which are included in the vendor price and payed by the customer.

For alternative fuels such as LNG, there is a potential market, but there are limits because of past enforced investment policy where VO/O's were obliged to invest in completely new double-hull vessels with still young engines and more strict financial conditions than before (most banks required more own equity). Furthermore, there are subsidies, but they do not find their way easily to SME's which are still the majority of the fleet. The potential customer base does not seem to follow very soon and awaits until it is proven that the alternative fuel technology is safe, mature, has sufficient infrastructure

4. SCBA

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. This analysis will not be as broad as the cost-benefit analyses of Prominent that took place between 2015 and 2018 within a consortium. As during the SCBA of the automated vessel, the analysis is conducted from a customers' perspective (VO/O) and focuses on one vessel. In practice, it is clear that LNG-dual fuel, is being implemented in IWT, mainly in the market of dangerous goods transportation (DGT).

Although, as mentioned, there is also 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. To be clear, the SCBA in this research focuses on the potential business case of a self-propelled tanker motor barge of an independent VO/O of 110m.

Costs and benefits are mainly given by recent research as mentioned in the literature review and own developed methods as explained further. The main focus is on costs related to fuel usage, emissions and GHG. The main difference with the findings from Prominent and other research is the adjustment of regulation that was needed to remove the legal barrier for LNG to diffuse. But there are still barriers left, as shown by the SIA for market uptake.
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), give 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 in account the energetic value of both fuels.

Price evolution of fuels are volatile and depend on a number of factors such as worldwide economic development, geo-strategical policy and political stability which requires constant monitoring and business analysis but which lays outside the scope of this study.

4.1. Approach

The costs and benefits of the actors will differ. The following table shows the structure of the main costs and benefits grouped by the different actors involved:

Actor / SCBA component	BENEFIT		COST	
Companies (the innovator)				
LNG engine and tank development			X	
LNG installations	X			
Customers (vessel owners)		ΔR_p		ΔC_p
Expected fuel price difference	X			
Bunkering infrastructure			X	
Maintenance, training and repair			X	
Installation of LNG system			X	
Society				
Subsidies			X	
Emission reduction	X	ΔB_s		ΔC_s
Fuel consumption	X			

Table 59: Actors and their direct costs and benefits of LNG-fuelled navigation
Source: based on Aronietis R. (2013)

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 thresholds[159] to achieve a successful innovation are derived from following equations:

$$\begin{cases} \Delta R_p - \Delta C_p + S_p > \times \\ \Delta B_s - \Delta C_s + S_s > \gamma \end{cases}$$

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 considered to be 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 the SCBA a 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.

4.2. Costs and benefits for investors

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 the findings of Prominent (2015-2018) for the conventional vessel which is the baseline scenario. The costs of the combination of LNG and diesel (LNG-D) are based on literature review, interviews, own developed insights and a number of assumptions and uncertainties. In this case, the lifespan of the vessel is expected to be 25 years which could be longer in reality.

The vessel profile and sailing behaviour is derived from the extensive research of Prominent and is shown in Table 60. This part was conducted in the beginning of the project in 2015 and made it possible to identify two tankers of 110m with diesel engines to build the baseline scenario which is used in this research.

[159] 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.

		CTV 1	CTV 2
Selected representative journeys Rhine / ARA	Port A Port B	Rotterdam Kampen/Zwolle	Terneuzen Rotterdam
	Type	Liquid Bulk	Liquid Bulk
	Vessel	MTS	MTS
	type	110m	110m
	Commodity	Oil	Chemicals
	mln tkm	282	166
Vessel dimensions (m)	Length	110	110
	Width	11.4	11.4
	Max Draught	3.7	3.5
Max payload (t)		3257	2908
Operational hours/year		4318	4318
No of Engines Installed		1	1
Total power main engines [kW]		1322	1550
Payload carried (t)		2182	1948
Distance (roundtrip in km)		382	294
Empty return trip to port of origin		No	No
Number of trips per year		97	97
Average speed over ground for roundtrip (km/h)		13.2	10.1

Table 60: Vessel and sailing profiles of MTS of 110m
Source: based on Prominent (2015), D.1.1. Annex A3

The 110m MTS is adjusted with other findings as explained further but does not show significant differences with the vessels in Table 60.

The following paragraphs explain the cost structure of the hypothetical tanker vessel of 110m in a null scenario (conventional tanker vessel, CTV) with a CCNR II engine and a comparable tanker vessel with a dual fuel scenario combining 80% LNG and 20% diesel. To take in account the beginning of the first dual-fuel vessel, prices are adjusted to 2012 where possible. 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.

The problem with this approach as in other studies, is the fact that CCNR II engines do not comply with stage V starting from 2019 for the IWT. To improve the analysis, the baseline scenario should be a conventional vessel but with an engine complying stage V. This invites future research.
The costs are the basis for the further sensitivity 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 the possible revenues in this business 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 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)[160] for the main diesel engine (including the gearbox), assuming an engine power between 1,322 and 1,550 kW (as shown Table 36) and adjusted for prices of 2012.

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

[160] 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

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 main focus of the research lies on the main engine and not on the genset or bow thrusters. They are included in the capital value, but the lifespan of the genset and other systems is not taken in account in the further analysis.

C. Terminal Value

The terminal 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 terminal value. The terminal 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/O 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 terminal 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 terminal 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 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)[161].

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

[161] https://brage.bibsys.no/xmlui/bitstream/handle/11250/2445595/11134_FULLTEXT.pdf?sequence=1

weaken the engine, 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 considered to be 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 is also M&R, as is cleaning of the tanks. The 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/O 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 reduction of port dues 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 dues[162]. The procedure of the Green Award inflicts renewal costs for the VO/O every three years. Next to submission costs of the application, an audit of the enterprise has to be repeated every three years to establish conformity between management procedures and practice[163] 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 no GAC system, but inland vessels can receive a strategic reduction of 15% if certain conditions are met, such as:

- The vessel stays at the port at least three times a week and this during two months;
- The vessel has an engine of class CCNR 2 or better;
- The vessel berths maximum three terminals within each port stay;
- The vessel loads or unloads at the port;
- At least 75% of the double TEU capacity of the vessel has to be loaded (in case of a container ship);
- The vessel stays maximum 7 days at the port and
- The aim of the trip of the inland barge may not result in shifting maritime volumes towards another port[164].

A more accessible measure at Port of Antwerp than the strategical reduction, is a reduced rate based on environmental performance. In this case, vessels have to 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.

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[162] https://www.portofrotterdam.com/nl/scheepvaart/binnenvaart/meldingen-en-ontheffingen/binnenhavengeld

[163] 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

[164] http://www.portofantwerp.com/sites/portofantwerp/files/2018_tariefverordening_op_de_binnenvaart.pdf

It is clear that there is no common policy at 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, lays for the Port of Rotterdam between EUR 0.094 (for 7 days) and EUR 3.253 (for calendar year)[165]. 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 municipalities[166], 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 in account next to a variable part for every tonkilometer 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 lays between EUR 31.57 and EUR 47.36 (night tariff).[167]

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 in 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 during 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 brokers 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 2016[168], 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.

G. Financial cost

A total of 70% of the capital cost is leant 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.

[165] https://www.portofrotterdam.com/sites/default/files/general-terms-conditions-port-tariffs.pdf?token=3_04O8y0

[166] For the municipality of Arnhem passage costs are EUR 0.04 per tonnes tonnes tonnes dwt for a duration of 4 days. https://zoek.officielebekendmakingen.nl/gmb-2017-224570.html

[167] http://www.vnf.fr/vnf/img/cms/Transport_fluvialhidden/avibat_tarif_2018_20180725115202.PDF

[168] https://www.inland-navigation-market.org/wp-content/uploads/2017/09/om16_II_en.pdf

H. Subsidies

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 VO/O's which addressed a maximum of 30-40% of the costs of the new engine[169]. In France a VO/O 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 is 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/O and charterer. The charterers provision is estimated at 7% of the earnings within a fixed long term contract at one freight broker 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 61).

Annual crew costs, taxes incl.	Belgium	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 61: Crew cost (taxes included) in the CCNR MS and Luxembourg
Source: Rebelgroup et al. (2015), n.a. = not available in original study

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.

[169] http://www.itb-info.be/files/cms1/eindrapport-binnenvaart-final.pdf

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 of the fact that the CTV and LNG-D in this model have to comply to the ADN and technical requirements, they have to 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. They 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 days [170]. 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. Also 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 62. 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). 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.[171]

	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 62: 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 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 has to pay to load LNG is 8.67 EUR/mWh (PitPoint b.v., 2018). The logistics cost, to transport the fuel

[170] which could add up to months since 2016 in the Flemish region
[171] 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).

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 63 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
Antwerpen	€ 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 63: Total logistics cost of LNG distribution to IWT
Source: own calculations based on PitPoint BV (2018) and monthly average quotation of TTF (2018)

For this SCBA 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 of 5,312,808 kWh (419 tonnes), an estimated 786 m³ LNG is needed or 356 tonnes. The explained calculation delivers the results as presented in Figure 48.

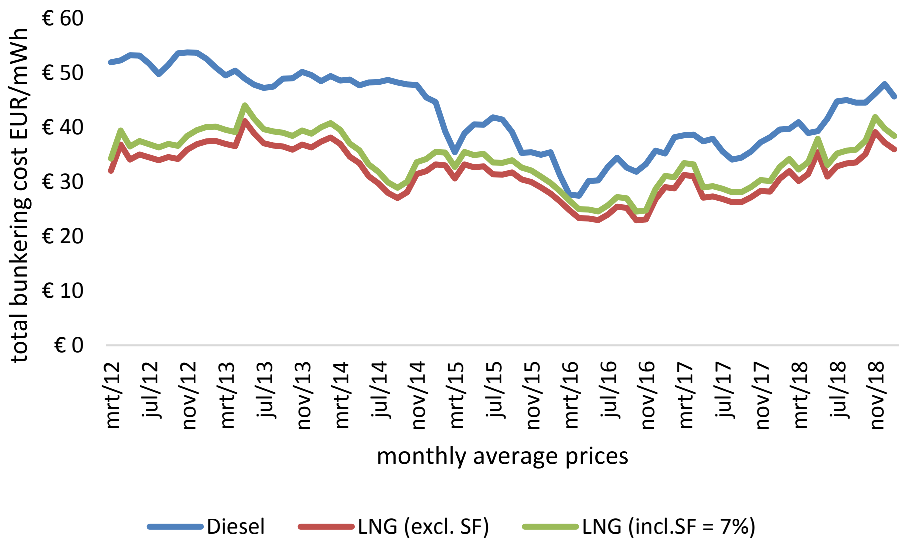

Figure 48: The price difference between LNG and diesel for TTS
Source: own calculations based on PitPoint BV (2018), monthly average quotation TTF (2018), CBRB by Contargo (2018)

To bunker LNG at port of Antwerp, the VO/O has to 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.[172]

[172] 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

The truck has to 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 have to 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.[173]

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 perspective and the increasing emissions (and regulation) from an economic welfare perspective.

The SCBA 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 lays outside the scope of this research, a simplified forecast is applied using trend analysis, with excel as explained in the case concerning automation.

As fuel consumption depends on the sailing profile of the ship, Prominent provides an overview of different ship profiles. Two were mentioned earlier (*Table 60*). For the CTV in this research, annual operational hours of 4,318 hrs are assumed. The engines are not always at full power. Table 64 shows the different consumption profiles for each CTV according to engine use. 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 takes into account the gross heating value of diesel (12.7 kWh/kg) and a density of 837.5 kg/m^3.

CTV 1 diesel

Energy output	kWh	ton	m³	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 64: 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)

The LNG-D engine is assumed to offer the same energy than the conventional engine. It has to be noted that fuel efficiency of the engine and loss of energy because of the methane slip is not accounted for yet. At the end of the calculation and during the sensitivity analysis, this can be adjusted.

[173] https://www.cryogas.pl/en/lng_facilities_-_scheme

With the DF engine of the LNG-D the needed fuel can now be calculated and set according 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. Results are presented in Table 65.

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%	5708396	306	90	227814	260732
93%	5312808	285	84	212027	242663
90%	5137556	275	81	205033	234658
80%	4566717	245	72	182251	208585
70%	3995877	214	63	159470	182512
60%	3425038	184	54	136689	156439
50%	2854198	153	45	113907	130366
40%	2283358	122	36	91126	104293

Table 65: Price of bunkering an LNG-D with one 1,322 kW DF engine
Source: own calculation based on Prominent (2018), UK Government GHG Conversion factors for Company Reporting (2018), CBRB as presented by Contargo (2018), PitPoint (2018), TFF spot market (2018). Price LNG = 38.5 EUR/mWh and diesel = 45.7 EUR/mWh

According to prices of November 2018, the bunkering of the LNG-D vessel was 12.6% less expensive. But to compare on a yearly basis for the SCBA 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 2018[174] concerning an average world price of crude oil[175] and the price of natural gas for the European market[176]. 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)[177] to deflate the nominal prices. This is applied for filling the missing gaps in the dataset. Figure 49 shows the evolution of the considered prices.

[174] 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
[175] Crude oil, average price of Brent, Dubai and West Texas Intermediate, equally weighed.
[176] 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.
[177] 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.

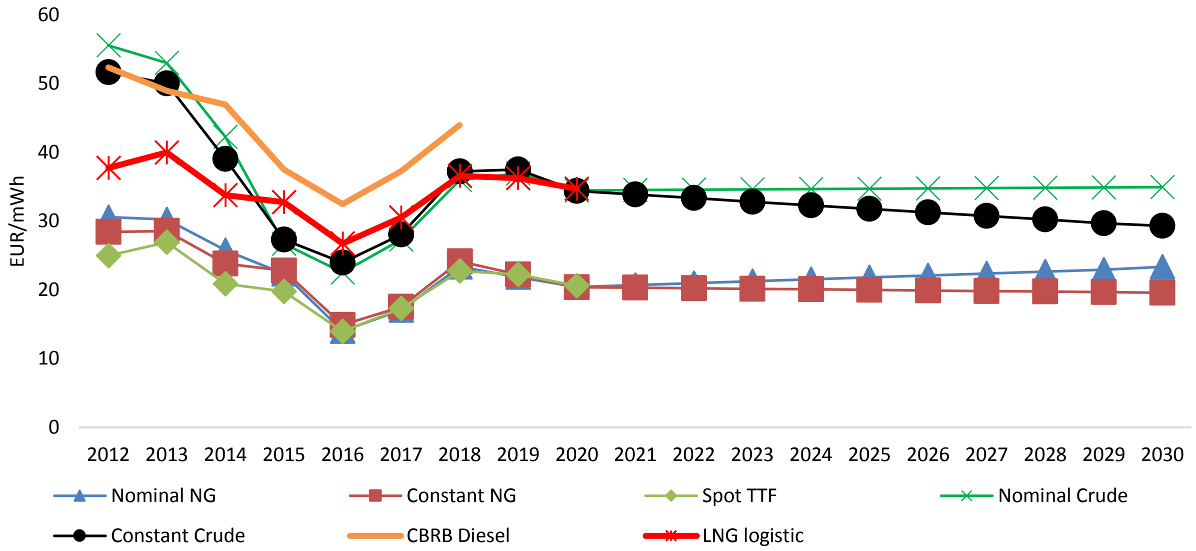

Figure 49: Forecast of fuel prices until 2030
Source: Own calculation based on World Bank for constant and nominal prices of crude oil and natural gas between 2019-2030; Gate TTF (Gasunie, 2018) for LNG between 2012 and 2018; ICE ENDEX TTF Futures for 2019 and 2020; Contargo for CBRB diesel price; MUV index of the World Bank; average exchange rate (Statista Ltd., 2018); UK Government GHG Conversion factors for Company Reporting (2018); PitPoint BV (2018)

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 compiled forecast for the bunker fuel in the SCBA is shown by Figure 50.

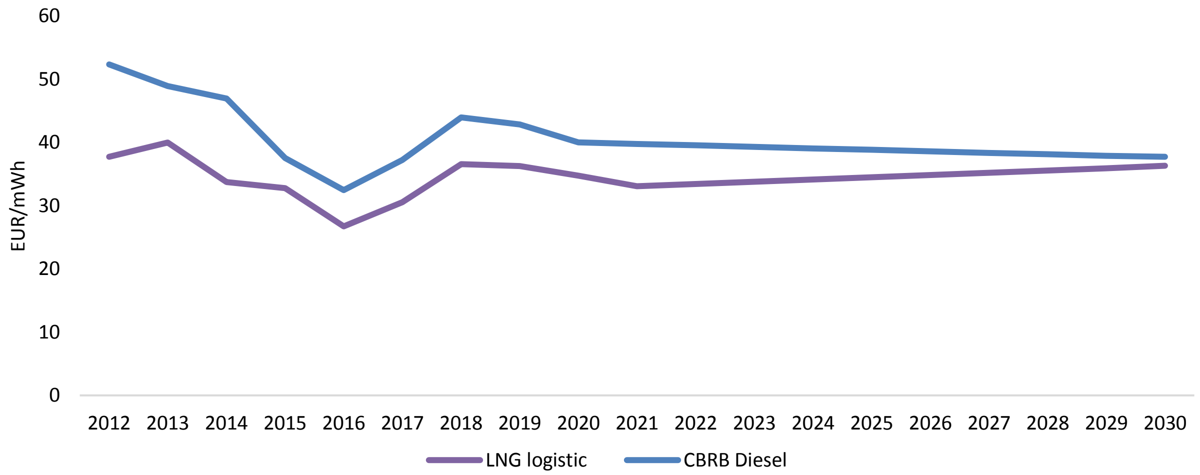

Figure 50: Forecast of bunkering price LNG and diesel
Source: own calculations derived from Figure 49

M. Taxation

Amongst the CCNR countries and Luxembourg, taxes tend to differ (Rebelgroup et al., 2015) with Belgium having the highest corporation tax (*Table 66*) without taking in account the Notional Interest Deduction[178].

%	Belgium	Netherlands	Germany	Switzerland	Luxembourg	France
Personal income tax	50	52	45	40	44	45
Corporation tax	34	25	30	18	29	33

Table 66: 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 VO/O's 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 of the fact that the majority of the tanker barges of >110m are registered in the Netherlands[179]. Furthermore, IWT fuel costs are exempted from taxes.

N. Freight rate and revenue

During this research, it was easier to find freight rate data for the tanker IWT market then 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 stabile 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 in 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 51*). 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.

[178] The possibility for corporate tax payers to deduct from their taxable income a fictitious interest calculated on the basis of their shareholder's equity
[179] 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.

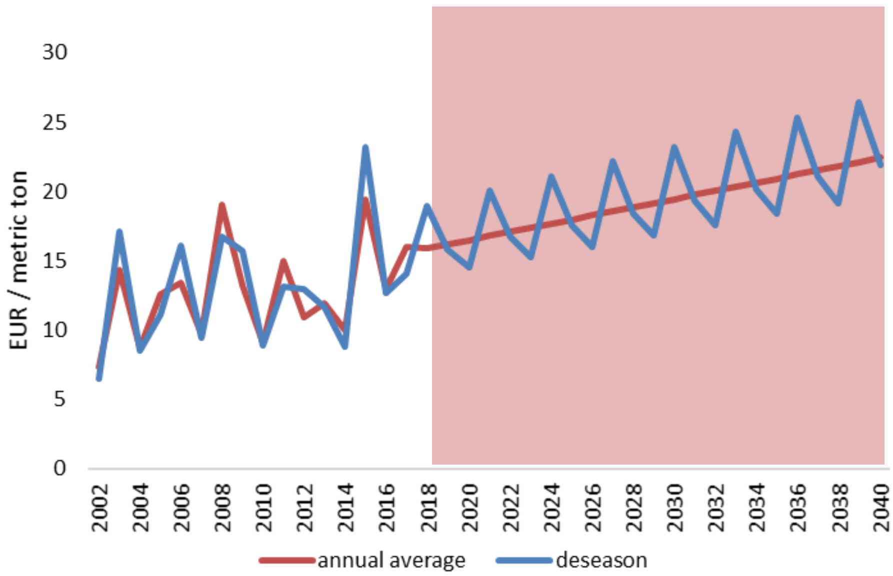

Figure 51: Evolution of tanker freight rate for the traditional Rhine including seasonal variation
Source: based on PJK International (Jan. 2002 – Sept 2017) as reported by Market observation (CCNR, 2016 and 2018). Own forecast from 2018. Seasonal variation of monthly data is converted in annual averages, including seasonal factors.

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 of the fact that the innovation is not assumed to have an impact on the earnings. Alternative fuels are entirely focused on fuel cost reduction, which is the main private benefit and objective of the innovator.

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 have to be in order to reach their destination. This results in less available vessel capacity at the IWT supply side. Demand has to address additional suppliers with higher freight rates as a consequence. 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 Loreley In the state Rhineland-Palatinate in Germany (Figure 52).

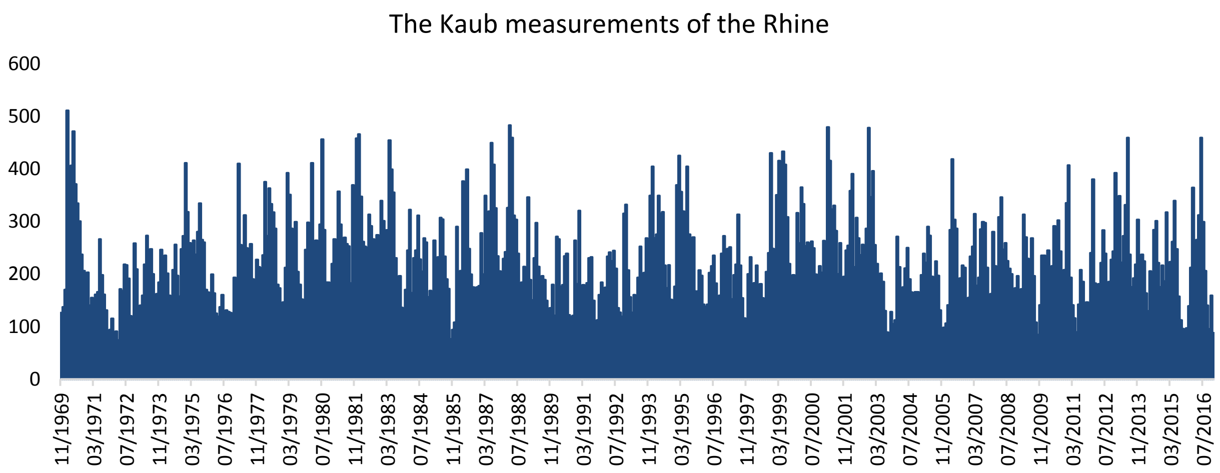

Figure 52: Water depth at Kaub between 1969 and December 2016
Source: elwis.de (2017), Kriedel N., Market Observation (CCNR, 2018)/ monthly values are averages of total days

The relationship between water depth and freight rates is shown by the following parameters:

Regression Statistics	
Multiple R	0,676333
R Square	0,457426
Adjusted R Square	0,454429
Standard Error	0,141973
Observations	183

The multiple correlation coefficient shows that there is significant association between both variables. The R Square shows that 46% of the freight rate is explained by the water depth. One of the emerging questions after the analysis of the earnings and the relationship between freight rate and water depth (as shown in Figure 53), is then if the weight of the LNG tank on board, has an influence on the minimum depth of the vessel. Is there a difference between a CTV and an LNG-D in this regard?

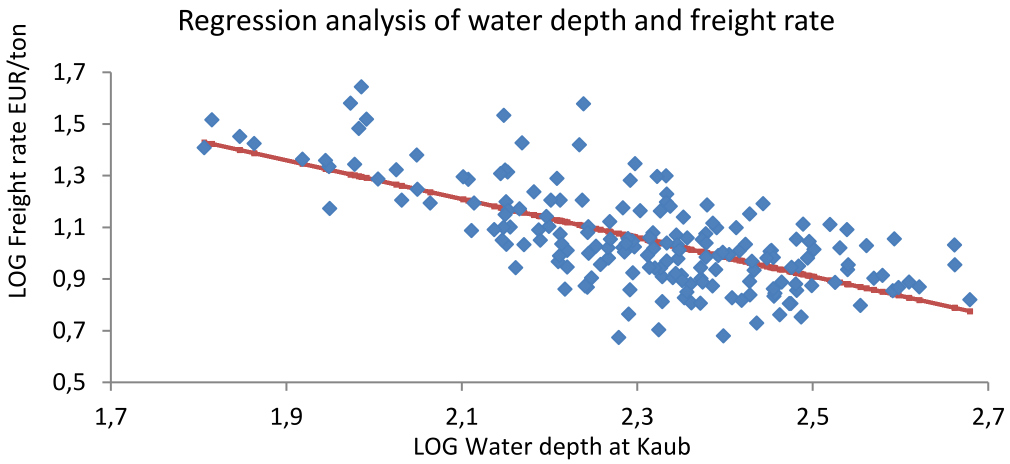

Figure 53: Regression analysis of water depth and freight rate
Source: own creation and calculations, based on PJK International, Kriedel N CCNR 2017, elwis.de (2017)

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 lays 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 times[180] 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). In reality 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.

[180] If parallel bunkering of diesel and LNG is allowed, the number of operations is still 17 compared to 13.

4.3. Costs for society

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 infrastructure (RICARDO-AEA, 2014:11). During the past decades; researchers have tried to valorise these costs which led to more acceptance as an element in modern social cost-benefit-analyses.

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 at 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.

A. 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 transport. During the first year of operation, the former known TMS Green Stream 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 since 2013.

The European Commission proposed to install onshore LNG bunker facilities at inland ports within the core network of the trans-European transport before 2025[181] and subsidized the LNG Masterplan for the Rhine-Main-Danube with EUR 40 million. Together with the ports of Basel, Rotterdam, Antwerp, Vienna and Strasbourg, the Port of Mannheim looked for possibilities to install an onshore facility to reduce the external and internal cost of the distribution of LNG by truck, but at this date none of them are implemented and were postponed. One onshore facility is planned to be operational by the second quarter of 2019 in Cologne. The launching customer is Shell Western LNG B.V. and the facility will bunker Shell chartered vessels of Plouvier transport and its Swiss unit Intertrans Tankschiffahrt. The LNG facility (as conceptually shown in Figure 54) will be constructed by PitPoint B.V. of the Total-Fina group with the support of CEF and within the project Breakthrough LNG Deployment in Inland Waterway Transport (Grendel, 2018).

The port authority of Port of Antwerp (PoA) launched a tender to build an LNG-bunker facility in Antwerp in 2014, which is partially subsidized by the LNG Masterplan for Rhine-Main-Danube within TEN-T, but until now, there is no bunkering station yet. The tender includes a concession of five years for a usage fee based on 450m³ storage capacity and two tariffs concerning the tanking area of trucks (annual EUR 10,516 for 1656m²) and for the rest of the concession area (7207 m² or EUR 34,233)[182]. The initial investment cost can be paid by the port authority against payment during five years, but this cost depends on what the subscriber of the tender proposes (Vandermeeren, 2014). In the meantime, since 2012, truck-to-ship bunkering is allowed with trucks that deliver the LNG from the main hub in Zeebrugge (more than 100 km from the coast of Belgium to port of Antwerp).

[181] http://lngmasterplan.eu/images/D_121_Supply_study_-_Rhine_v1.0_FINAL_2015-6-30.pdf
[182] Mentioned prices are prices of 2013 as decided by the board of directors of PoA on November 4th, 2013.

In the Seineport of Rotterdam, inland vessels can bunker LNG since 2013 by truck. The port management regulation was adjusted by the city of Rotterdam to allow the usage of LNG as fuel for inland navigation vessels. Furthermore, the presence of LNG hub terminal at the Maasvlakte, lowers the distance for the truck-to-ship delivery.

Figure 54: Conceptual presentation of an on-shore LNG bunkering station
Source: PitPoint.LNG (2018)

As on-shore bunker facilities are being planned together with private partners, the social infrastructure cost is not expected to change yet. The investments in inland navigation infrastructure comprises bunkering facilities that are assumed to be dedicated for inland navigation vessels to avoid or complement truck-to-ship bunkering. This assumption is unrealistic because of the fact that the bunkering facility will probably aim at more vehicles or vessels than only IWT. Internalizing the external cost for LNG bunkering infrastructure in IWT LNG-D cost structure, would not be correct because more users are taken in account than only IWT. Investments in LNG bunkering terminals can vary from EUR 15 to 137 million and operational costs can vary from EUR 3 to 17 million a year (Faber et al., 2015). These costs depend on the chosen configuration of the bunkering station. If chosen for a distribution model with a pipeline system between LNG terminals and bunker stations, costs are estimated for one small sized bunker station at more than EUR 40 million without the pipeline (EUR 31/meter).
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. Far more relevant are the emissions costs from a welfare perspective. The next part gives insight how much a truck-to-vessel bunkering operation costs in emissions and greenhouse gases for society. In further research concerning the social costs of an onshore LNG bunker station, these costs can be used. Now the difference between emissions and GHG are discussed for the CTV and LNG-D.

B. 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 as specified further in this case analysis. Although a transition fuel, the fuel usage should contribute to the objectives of the Climate Agreement of Paris (UNFCCC, 2015). The European Commission has therefore shown a significant interest in the usage of LNG as fuel for IWT and the maritime. Through the Connecting Europe Facility (CEF) and other European funding, a number of projects, research and ship building were co-financed by the European Union.

According to the standard EN 16258 “Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services”, indirect energy consumption and emissions from the entire energy process must be considered , thus including well-to-wheel (in this case propeller) and well-to-tank emissions. In calculating emissions for IWT, not only loaded and empty trips have an influence, also upstream, canal or downstream navigation have an impact on fuel consumption as thus emissions.

The methane slip lays according to van Beek et al. (2017) between 1 and 9 % of the total produced natural gas. 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 CO_2 over a given timeframe. For all GHG's, an CO_2 equivalent is calculated by using this Global Warming Potential (GWP).

The annual emission values are recalculated from Verbeek et al. and converted from MJ to kWh where needed and fitted to the model as developed in this research. *Table 67* shows the annual energy use, the GHG's and emissions such as NOx, SO_2 and PM. The values are based on a maximum engine performance. During the further SCBA, the assumption is made that the engine performs annually at 40%. The table shows that according to Verbeek et al. (2011) the engine efficiency is 1% lower for the LNG engine. This is an assumption that is not taken in account in the further analysis within this research.

To calculate the GHG's and the SO_x, the specific emitted values are expressed by g/kWh and multiplied by the annual fuel energy (Verbeek et al., 2011). All other emissions are calculated by multiplying the specific emitted values by the annual power output of the engine. Emissions during the WTT were not given.

Vessel		CTV	100% LNG	Difference CTV – LNG (kg/kWh/y)
Fuel		diesel (EN590)	LNG	
Injection		conventional	monofuel	
Pmax (kW)		1,322		
Energy output (kWh/y)		5,708,396		
Fuel Energy (kWh/y)		14,484,484	14,696,147	211,663
Well-to-tank (WTT)				
CO_2	kg/kWh	716,982	476,155	240,827
CO_2 - equivalent of CH_4 (factor 25)		36,501	92,586	-56,085
CO_2 - equivalent of N_2O (factor 298)		0	0	0
Tank-to-propeller (TTP)				
CO_2	kg/kWh/y	3,858,667	2,968,034	890,633
CO_2 - equivalent of CH_4 (factor 25)		0	701,816	-701,816
CO_2 - equivalent of N_2O (factor 298)		20858	21162	-305
NOx		50,233.9	17,072.2	33,161.7
PM		513	186	328
SO_2		20	8	12

Table 67: Annual emissions of LNG monofuel and CTV from well-to-propeller at maximum engine power
Source= based on Verbeek et al.(2011), emissions converted from g/MJ to g/kWh and to kg/kWh and fitted on the SCBA model. The engine efficiency differs 0,6% in this table. In further analysis not taken in account for reasons of simplicity.

According to the calculations in Table 67, the overall performance between the CTV and the LNG-D is 6% better for greenhouse gases whereas the LNG-D emits annually 25% less CO_2 than the CTV. The emission of air pollutants such as PM, SO_x and NOx is more than 65% better for the LNG-D. The direct and indirect emission of CH_4 of the LNG-D (methane slip included) is significant with an estimated 702 tonnes in one year at maximum power.

According to van Liere, Quispel, Tachi and Karaarslan (2016) LNG contributes roughly 20% to the reduction of CO_2 emissions, but under the precondition that the emission of methane slip will extensively reduce. It was stated by the engine manufacturers during the conducted interviews that the problem of methane slip would be solved by 2025, due to improved engine techniques. The precise estimate on emission reduction depends on the engine type, the used percentage of diesel and LNG for a dual fuel, the sailing and speed profile of the ship and the fuel consumption in general. The reduction is therefore difficult to predict precisely and there is no unanimity in literature.

With the method of Verbeek et al. (2011) together with the monetary values from Ricardo – AEA (2014), it is now possible to monetize the emissions and greenhouse gases and express them in external costs. For the dual-fuel engine, the engine efficiency is considered equal with the diesel engine. The external costs are calculated for LNG from Quatar and are multiplied by 80%. Diesel is 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 based on Delhaye et al. (2017). For the model, they have to 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 CO_2 equivalent tonnes (prices of 2015). Ricardo-AEA uses other conversion factors for N_2O (290) and CH_4 (24) than Verbeek et al. To stay consistent with former calculations, the factors remain the same as used earlier to convert all greenhouse gases to CO_2 equivalent values (25 for CH_4 and 289 for N_2O). The following table shows the annual external costs for the CTV and LNG-D.

External costs WTT (prices in 2015)	EUR/kg	100% engine power (y)		40% engine power (y)	
		diesel EN590	**LNG-D**	**diesel EN590**	**LNG-D**
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_2equivalent of N_2O	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_2O	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		1089840	724787	429510	285642
GHG WTP		463301	428532	182589	168886
Emissions WTP		626539	296255	246922	116755

Table 68: External costs for CTV and LNG-D
Source: Own calculations based on Verbeek et al. (2011), Delhaye et al. (2017), Ricardo – AEA (2014)

The annual difference between the CTV and the LNG-D vessels are shown by Table 69. The external costs are almost 42% lower for an monofuel LNG vessel and 33% for the dual fuel in comparison with the CTV on diesel. There is only a small difference between the values when engine efficiency is not equal, when LNG combusts only for 38.8% and diesel for 39.4%.

	Equal engine efficiency	1% different engine efficiency (38% vs 39%)

	Reduction LNG (mono)	Reduction LNG-D (DF)	Reduction LNG (mono)	Reduction LNG-D (DF)
Total external costs WTP	41.9%	33.5%	-0.6%	-0.4%
GHG WTP	9.4%	7.5%	-1.3%	-1.1%
Emissions WTP	65.9%	52.7%	0.0%	0.0%
GHG TTP	6.2%	5%	-1.4%	-1.1%
Emissions TTP	65.9%	52.7%	0.0%	0.0%
GHG WTT	25.6%	20.5%	-1.1%	-0.9%

Table 69: Difference of external costs between LNG and LNG-D for equal and non-equal engine efficiency
Source: Own calculations based on Verbeek et al. (2011), Delhaye et al. (2017), Ricardo – AEA (2014)

Other external costs such as noise, accidents and congestion are not analysed, because of the assumption that no change will occur on these costs after implementing the innovation. Although it is claimed that an LNG engine produces less noise, the external cost values for noise of the CTV are relatively marginal and are assumed not to impact on the main findings.

4.4. Net present values

The net present values (NPV) and the internal rate on return give insight in the business case. If the NPV is higher than in a scenario without the innovation, than the investment is worth to proceed. In this research the NPVs are calculated for 8 scenarios based on the developed model and compared with the null scenario without the innovation (CTV). The first part includes only the private costs to answer the question if it is a positive business case from an industrial perspective and the second part internalizes the externals costs, to answer if the business case is positive from a welfare-economic perspective.

A. Industrial-Economic perspective

For the private business case the net values for both equity and enterprise perspective are given in Table 70 together with the internal rate of return ratios for both perspectives. These values are without external costs. The null scenario has an NPV of 2,662,707 and has to be compared with all other NPV's.

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 70: Net present values of LNG-D scenarios and baseline
Source: own calculations, based on van Hassel (2011)

The best 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 SCBA 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.

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 given subsidy as explained and shows the impact of a subsidy on the business case from an equity perspective. Especially the cash flow of the first year of operation increases if the subsidy is given at the beginning of the operation.

Scenario 3 assumes that the price of LNG rises with one percent. This has no significant influence on the business case and also covers a possible loss of LNG because of a potential methane slip of 1% which has a similar effect than an increased price for LNG of 1%.

Scenario 4 shows the impact of a price increase of 8% of LNG or in other words a 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. The same 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.

B. Welfare-economic perspective

Because of the internalization of the external costs in the business case, all NPV's show a lower value than without internalization but are all higher than the null scenario. The best options are still the LNG-D with and without subsidies. The price of LNG can even go up with 10%. Scenario three not only covers a price difference of one percent, it also gives a comparable value if the engine efficiency would be 1% worse for the dual fuel engine. If the LNG-D would receive the same port and fairway discount than the CTV, the business case is still better. Although a negative NPV for equity, the LNG price may become 5% more expensive than diesel as scenario 7 shows and still offers a better alternative than the CTV (Table 71).

Scenarios	Short description	NPV eq (EUR)	NPV ent (EUR)	IRR eq	IRR ent
0	CTV	-1,222,536	265,798	5.7%	7.8%
1	LNG-D (80-20)	182,595	335,240	10.6%	10.4%
2	LNG-D (subsidy)	715,862	335,240	12.7%	10.4%
3	LNG + 1%	169,015	334,914	10.5%	10.4%
4	LNG + 8%	73,951	332,629	10.2%	10.3%
5	LNG + 10%	46,789	331,976	10.1%	10.2%
6	LNG = D	-91,250	336,692	9.7%	10.0%
7	LNG > diesel, 5%	-172,845	335,133	9.5%	9.9%
8	LNG-D P&F CTV	166,144	334,530	10.5%	10.4%

Table 71: NPV analysis after internalization of annual external costs (40% of maximum power)
Source: own calculations

The NPV difference with the null scenario gives the social benefit of the innovation within this project or model. In six cases there is a social benefit compared with the null scenario. In all scenarios the total external costs of the LNG-D are lower than the CTV.

C. Summary

The difference between the null scenario and the scenarios with the implementation of the innovation are shown by Figure 55. Scenario 1, 2, 3 and 8 show the most interesting scenarios from both perspectives. When removing the subsidies, the innovation still offers sufficient incentives to continue the implementation.

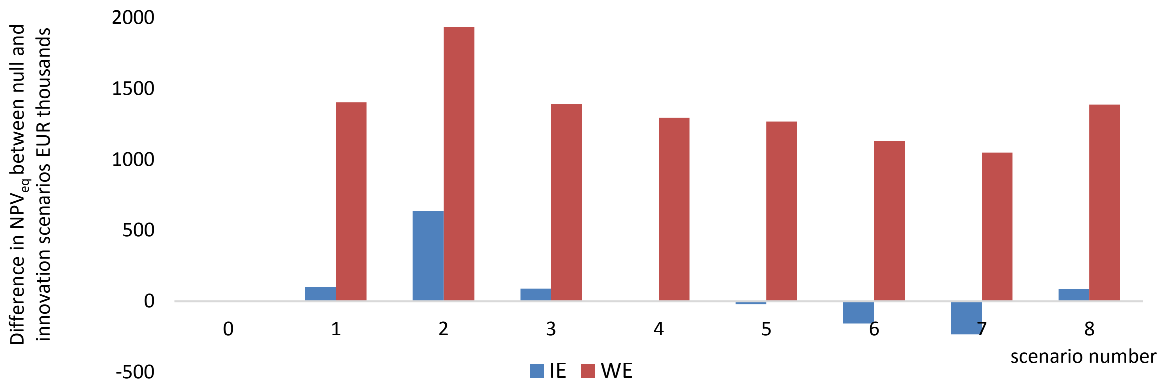

Figure 55: Difference of NPVs from welfare economics (WE) and industrial economic perspective (IE)
Source: own calculations

The sensitivity analysis keeps the welfare- and industrial-economics perspective separated to test both private costs and social costs within the business case to reduce uncertainty.

4.5. Sensitivity analysis

The sensitivity analysis improves the SCBA by adjusting values with the objective of reducing uncertainty in the modelled calculations. The sensitivity analysis has been conducted here to measure the impact of changes on the NPV and IRR of following variables:

1) Revenue (less cargo because of fuel tank)
2) Discount rate
3) Methane factor

A. Revenue

The weight and volume that the cryogenic tank needs, will reduce another area in size. As explained in case of the MTS Sirocco, it was chosen to decrease the living area to put the two tanks at the back of the ship. When the above deck tank is not allowed to be placed directly on top of the loading area on a tanker, this will reduce the payload and thus the revenue when compared with a CTV. As inland navigation transport receives revenue from freight rates according the payload and distance, this part of the analysis tests how the business case could change if less payload can be loaded in comparison to the null scenario with the developed freight rate. The next figures show what happens to the 8 scenarios when the payload is smaller after the implementation of the innovation. The P&F use the payload as a variable to calculate the port due that has to be paid. Changes in payload also influence the P&F with the same percentage. Next to P&F also charterers provision changes as it is a percentage of the revenue.
The weight of the LNG installation and tank are then assumed to be the same weight as the cargo that is reduced. With this assumption the fuel consumption will not change. In reality, it could be the case that the LNG installation is heavier than the cargo reduction which would increase fuel consumption.

By reducing the payload without impacting on the fuel cost, the business case changes significantly as shown by Figure 56. Although all scenarios still show positive NPV's from an equity perspective, only scenario 2 (with subsidy) has a better business case than the null scenario. It could be the case that a vessel with a higher payload than used in this model, could easier deal with the possible cargo reduction. But then, the fuel cost increases because of an increased C_T, next to an increase of P&F. Figure 56 shows the difference in NPV's of all scenarios with the null scenario if the transported average payload is reduced by 1% until 10% because of the installation of the LNG installation. It also shows what happens if the average transported payload is increased in all scenarios (including the null scenario) with 1 percent without an increase of fuel consumption. In reality, there will be a small increase in fuel consumption because of the increase of payload, but knowing that the average payload in this model at 0% change is only 1,948 tonnes per trip at a maximum capacity of 2,908 tonnes, an increase of 1% is considered to be relatively insignificant to influence the fuel cost.

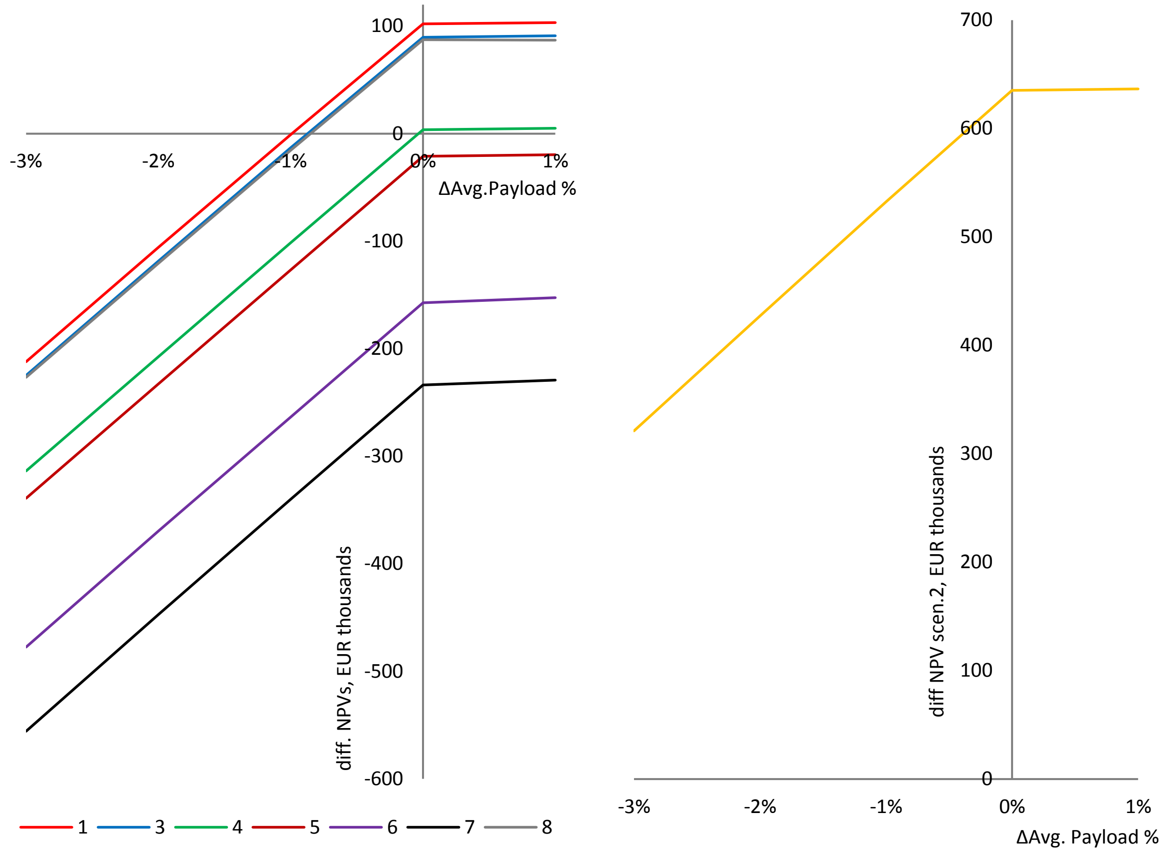

Figure 56: Impact of average payload reduction on the business case
Source: own calculations; because of visual reasons the figure on the left shows scenario 1 until 7, the figure at the right shows scenario 2 with subsidy

An increase in maximum payload entails another ship with other dimensions and with perhaps the necessity of a more powerful engine or more cryogenic tanks. The capital value would also change then and would be outside this model.

B. Discount rate

The third important aspect of the SCBA to consider is the impact of the discount rate on the valuation of the innovation. Figure 57 shows the impact on the NPV from equity perspective for all scenarios. As the discount rate increases, the NPV decreases. If the discount rate increases to approximately 15%, all non-subsidized scenarios are negative. For all discount rates under 15%, scenario 1 and 2 are always more interesting than scenario 0.

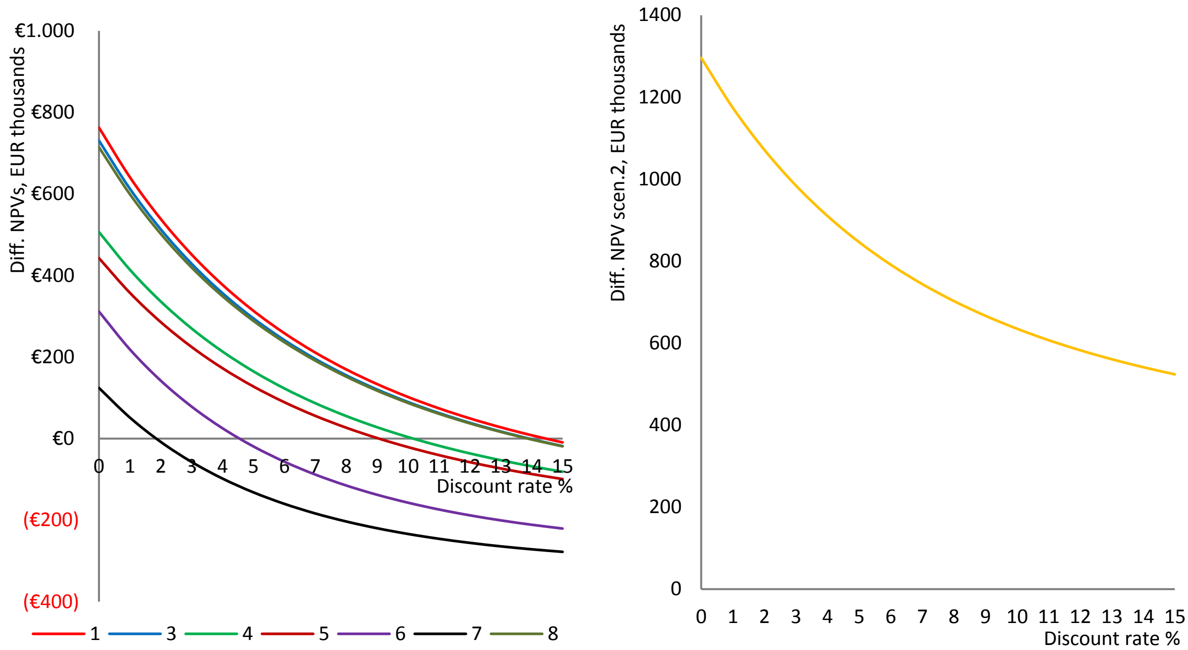

Figure 57: Impact of the discount rate on the differences between NPV's of all scenarios with the null scenario
Source: own calculations; because of visual reasons the figure on the left shows scenario 1 until 7, the figure at the right shows scenario 2 with subsidy

C. Methane factor

In this test, the methane factor is increased, to see the effect on the business case. In most recent research (van Liere, Quispel, Tachi and Karaarslan, 2016; Delhaye et al., 2017) the methane factor is estimated at 22 or 25. This value expresses the impact on global warming compared with CO_2 which actually means that methane is considered between 22 and 25 times worse than CO_2. According to van Beek (2018), this factor is at least 34. To reduce uncertainty, the factors are adjusted and the impact on the business case is analysed after internalization of the external costs.

The adjustment of the factor of methane shows only a relative impact on the business case after internalization of the external costs as shown in Figure 58.

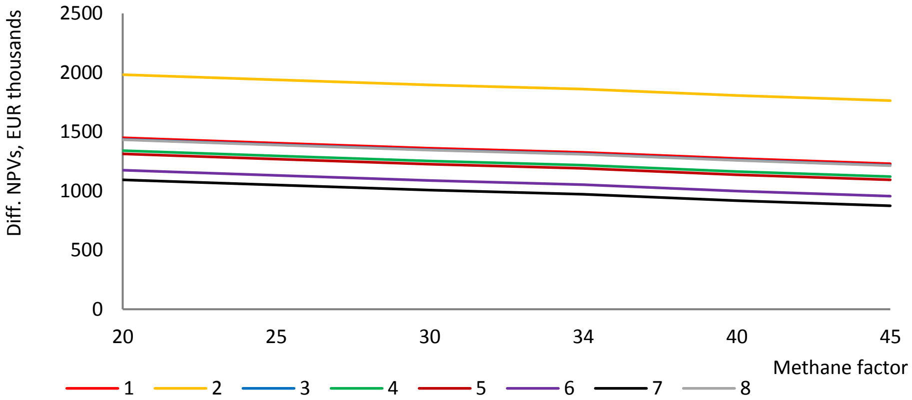

Figure 58: Effect of the methane factor on the business case
Source: Own calculations based on Verbeek et al. (2011), Delhaye et al. (2017), Ricardo – AEA (2014)

Even if the methane factor is doubled, the impact is still relative low. The external costs are mainly driven by the emissions which are valued higher than the CO_2 or other greenhouse gases. But when zooming in on the reduction of external costs for methane as an important GHG, compared to the CTV during the TTP, the performance is worse at a factor 34. This means that, when the emitted methane is considered not 25 but 34 times worse than CO_2 for climate change, the dual fuel in this model emits 0.2% more GHG in the atmosphere than a conventional vessel.

4.6. Conclusion

Despite the relatively expensive bunkering cost, because of the lacking LNG infrastructure, the dual fuel engine still provides a positive business case from industrial perspective in this model. The added logistics costs do not show a significant impact on the business case. Another interesting fact is the long run convergence of crude oil and natural gas prices as predicted by the World Bank. If the calculated forecast of the diesel price remains stable and LNG prices would increase with 8%, the business case shows a lower NPV than investing in a conventional tanker vessel. Caution is needed in interpreting the results within the limits of the cost–benefit model, because for instance, it was not yet possible to compare the LNG-D dual fuel engine with a stage V engine. As more type approved stage V engines come on the market, this analysis and other literature can be improved.

Also the forecast of the freight rate and the expected earnings do not take in account the possible changes on 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 as described such as lack of bankruptcies, building time, and other aspects. The forecast of the freight rate took changes of water depth in account. This seasonal phenomenon can change in the future by canalizing the Rhine of because of modal shift towards railways and trucks, but these scenarios lay outside the scope of this research.

The threshold from an industrial-economic perspective, lays between EUR 2.4 and 3.3 Million, but is after the lifespan of the vessel which is 25 years in this model. It could be the case, that investors find these values too low as many uncertainties remain (e.g. the added complexity of bunkering).

The scenario with subsidy has an impact on the business case from an equity perspective. When viewed from a welfare economics perspective, all the developed scenarios offer better options than the null scenario. The methane slip and the CO_2 equivalent factor are adjusted in the sensitivity test, but the innovation still performs better than the conventional vessel. The subsidy can be considered justified from an welfare economic point of view if also the pollutants are taken in account. The subsidy is not justified if GHG reduction is the main policy objective. The threshold or the height of the social benefit, should be considered sufficient for policy makers in order to subsidize an LNG vessel. From emission perspective, the LNG dual fuel vessel shows already a reduction of 52% of emissions during the TTP compared to a conventional vessel, but the greenhouse gases only show a five percent reduction. If the methane factor is put at 34 as some sources suggest, the greenhouse gases from tank-to-propeller are even worse than a vessel running at 100% diesel (-0.2%). More research is needed to measure emissions in real-life from different places on board of a vessel and during different situations.

As technology evolves rapidly, other alternative fuels or after-treatment systems could offer better business cases. The method as developed in this research could also be applied on other fuels such as Hydrogen or on electrical propulsion.

The zero emission fuel does not exist in WTP. Even if a vessel would be electrical, the electricity is generated according to the energy mix of a country's transformation sector. Also the case of hydrogen, which is generally made from methane, entails external costs, but these (an others) invite further research as IWT and transport in general, looks for sustainable innovation to reduce its impact on climate, health and the environment.

5. Policy Analysis

As described in the deliverable concerning the institutional setting, the European IWT policy is situated within a multi-layered and multileveled governance model with competences on port, regional, national, multilateral (e.g. river commissions), European (European Union) 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 being reformed towards one level playing field for the entire IWT on the continent.

The policy situation concerning alternative fuels, offers a window of opportunity 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 the policy analysis included a quantitative approach from a SCBA perspective, as in the case of the automated vessel, here there was not enough material found to quantify all policy costs. Hence, the resulting analysis is more descriptive and qualitative with some exceptions. Nevertheless, the policy analysis delivers final insights after the SCBA and the SIA on the innovation and supports the conversion of the research findings into more readable policy recommendations towards policy makers and makes it possible to answer the question what policy should do.

First, the subsidiarity test is applied on the regulatory incentives behind the shift to alternative fuels or propulsion. Then the externalities are closer examined, followed by an identification of policy options. The next part considers the compliance costs from a policy consumer perspective (in this case the VO/O). The final part of the analysis includes different potential options for the IWT policy on LNG.

5.1. Subsidiarity test

The subsidiarity test as explained in the methodology, is used for the NRMM through following steps:

1. Is the proposed action within the scope of the competences?

Within limits the European Commission can make standards together with the river commissions and urge the MS to transpose a directive but not without avoiding different timings of transposition and with the possibility of the implementation of different approaches to reach the objectives. A European directive is from this perspective less enforcing than an EU regulation that bypasses state law because of supranational primacy. A directive still allows differences between states which is often because of undisclosed political reasons.

2. Is EU action necessary? Are there externalities or advantages (economies of scale)?

If MS would make standards, cherry picking could happen. Vessel owners would shop their engines in those MS that have less severe emission standards and can therefore offer relatively cheaper engines. 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. The benefit of emission reduction will otherwise probably not or less be reached.

The market of IWT is already considered to be relatively small on a European level. Implementing emission standards on the national level would narrow down the market and would decrease incentives to invest in research and development of better engines. New entrances on the market will probably face relatively higher costs.

3. Is cooperation between MS possible and credible outside the European institutions?

At the level of the CCNR, there is a strong institutionalized network of expertise and collaboration between Rhine riparian states and Belgium. But when comparing the emission reduction ambitions of the CCNR II and EU stage IIIA, there is a significant gap. One could state that the emission ambitions of the CCNR are lower than the objectives of the EU. During the last discussion in establishing the last NRMM for stage V, the industry and the sector organizations opposed the stringent ambitions of the

European Commission for stage V implementation and asked a level of emissions that was comparable with Tier 4 of the US standards. The policy outcome was that the EC decided to maintain the aimed target of the stage V engine which was claimed not to exist on the market yet.

The NRMM directive originated from the environmental policy of the European Commission. Also, the scope of the directive includes all non-road machinery which is broader than the scope of the river commissions. Next to non-road, the EC also has standards for road haulage. In order to avoid a possible modal shift, the European Commission is in theory provided with the competence and overview of developments in other modes and could maintain a more balanced approach than only a one-sector dedicated policy maker[183], but without the same in-depth knowledge as the river commissions. Furthermore, the externalities of emissions and GHG are cross-border and have a larger impact than only the Rhine or the Danube regions.

MS or lower policy levels are able to initiate multilateral or bilateral cooperation, especially when more ambitious objectives (even lower emissions) are envisaged and new policies could be designed parallel to higher level policies. This could result in the design of new policies and the identification of better practices that could eventually be debated on higher levels. But again, this would not contribute to less complexity and differentiation or lower the transaction costs of IWT users (e.g. compliance cost).

Also, the political reality in MS is differentiated amongst the European continent. While some MS (or lower levels such as a port) have more means, ambitions or possibilities to develop a more stringent policy, others could show less interest in implementing emission reduction policy. This differentiation is for IWT a common accepted fact: only a few MS show interest in developing an IWT policy.

Another aspect refers to the implemented policy tool. Tax incentives for alternative fuels belong to the genuine competence of a Member State. In this case there are noticeable differences between countries which leads to differentiation on the market and even possible "unfair" competition (e.g. tax levels, exploitation permit, different rules for LNG trucks with 18 tonnes in Germany and 20 tonnes in the Netherlands). Here, the importance of multilateral cooperation is expressed by the necessity to establish common rules amongst the different regulators, in order to keep the playing field levelled within the internal market.

4. **Should implementation, monitoring, enforcement of the policy should be done by the higher level or can it also be done by the lower levels?**

Concerning emissions regulation and GHG ambitions, the monitoring, enforcement and implementation of the supranational directive or the CCNR regulation is now done by the MS. The approach is differentiated and depends on the means of the lower authorities. Where some countries have more means to monitor emissions (f.ex. sniffers, more inspectors, …etc), others might have a more tolerant 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 by the European Commission. 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 needed technological innovation and can be considered as a regulatory bottleneck.

The lower authorities are supposed to have enough inspectors and police officers to inspect the fleet on environmental and other compliance. However, this also differentiates between MS, both in quantity as quality of personnel. 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

[183] In reality, when dealing with multimodal policy, the experience is that road haulage determines the agenda followed by railways.

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 European Hull database or the administrative actions taken under the CDNI agreement (European treaty concerning vessel waste). But for now, it could be easily the case that skippers receive several fines on one trip if there are irregularities or signs of non-compliance.

5.2. Proportionality

The principle of proportionality in case of inspections for environmental regulation compliance, indicates that any enforcement or implementation action would be less effective and lead to disproportional use or policy means. Appointing an agency with EU bureaucrats and use EU budget to send EU inspectors in all MS, can be an exaggeration and not necessarily mean that enforcement policy would be more effective or even feasible than a national one or on a lower level. It could then be a disproportional method to address the challenges this way.

5.3. Current policy

In SORT-IT (Strategic Organisation and Regulation in Transport, 1999) [184] regulatory and organizational structures were studied according to their cost-efficiency and external benefits. Efficiency in this case was defined as production and consumption efficiency. Production efficiency is defined as production of policy with the lowest cost, while consumption efficiency refers to the level of consumption that equals the welfare maximization of the consumer. This maximization is defined as the sum of the production surplus, consumer surplus and the external benefits of the policy.

In case of alternative fuels, it is not only from an organizational perspective challenging to define an optimal policy. Also, the objective is challenging to define. The European Commission and other policy levels have subsidized LNG, hydrogen and the building of the first electrical vessel (e.g. Port-Liner, ongoing) and during this research it became clear that the social benefits of LNG are mostly related to emission reduction, but not for GHG reduction. From a social welfare perspective, the most efficient policy aims at the highest social benefit with the lowest cost.

If the subsidies as assumed in the model are reviewed from the perspective of policy efficiency, it could be the case that after internalization of the external cost the social benefit (the reduction of emissions and GHG) is lower than the given subsidy. To analyse this, the same method is applied as used in the cash flow analysis of the SCBA and as applied by van Hassel (2011). The subsidies are in this case regarded as the investment and the annual reduction in emissions and GHG are considered to be the generated cash flow during the life-span of the investment (25 years). The NPV is then the value of the investment at the end of the life-span expressed by the cumulative cash flow. The alternative is not to invest and to keep the money where it hypothetically grows according to the indexation of an assumed 1,8% from EUR 533,266 to EUR 818,259.

If the policy target is to reduce emissions and GHG, the net present value of the public investment in form of a given subsidy would be positive and better than the null option of doing nothing (Figure *59*). If it is the policy objective to reduce air pollutants, then a subsidy for LNG vessels is successful and efficient. *Figure 59* shows the cash flow analysis when the subsidy is granted as described in scenario 2 of the SCBA. The NPV of the investment is higher in case the CO_2 equivalent factor for CH_4 is 25 and not 34.

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[184] EC (1999), Strategic Organisation and Regulation in Transport, SORT-IT, research for sustainable mobility, consortium of universities, Luxemburg, 106p. Also read Dullaert, W., Meersman, H., Moglia, F. and Van De Voorde, E. (1998), Regulation and deregulation in inland navigation, 8th WCTR proceedings, volume 1, Antwerp, pp.: 324 en Meersman, H. and Van de Voorde, E. (1997), Modal Choice models for Belgian Freight Transport, Report for the Scientific Offices of the Services of the Prime Minister, Belgium, in EC (1999), Strategic Organisation and Regulation in Transport, SORT-IT, research for sustainable mobility, consortium of universities, Luxemburg, pp:106

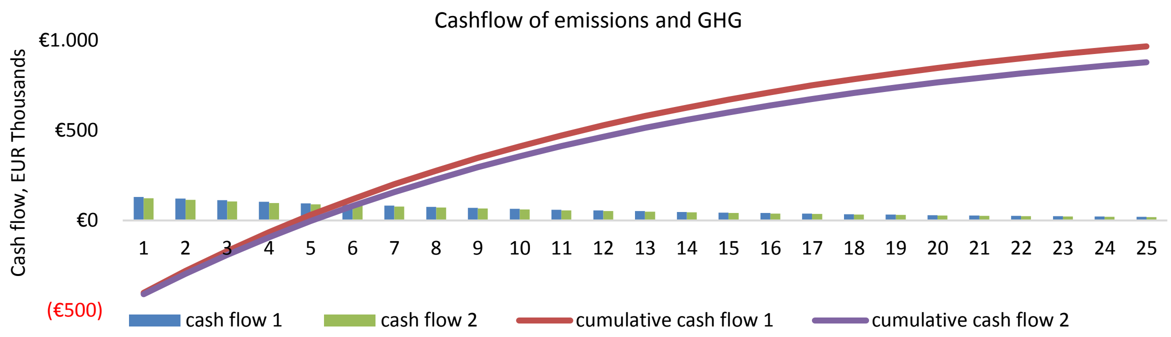

Figure 59: Cash flow analysis of social benefits according to subsidy
Source: own calculations. Cash flow 1 includes CH_4 factor = 25; Cash flow 2 includes a CH_4 factor = 34

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. Figure 60 shows the net result of the subsidy for methane factor 25 and 34 for only the GHG reduction. In both cases, the result is negative.

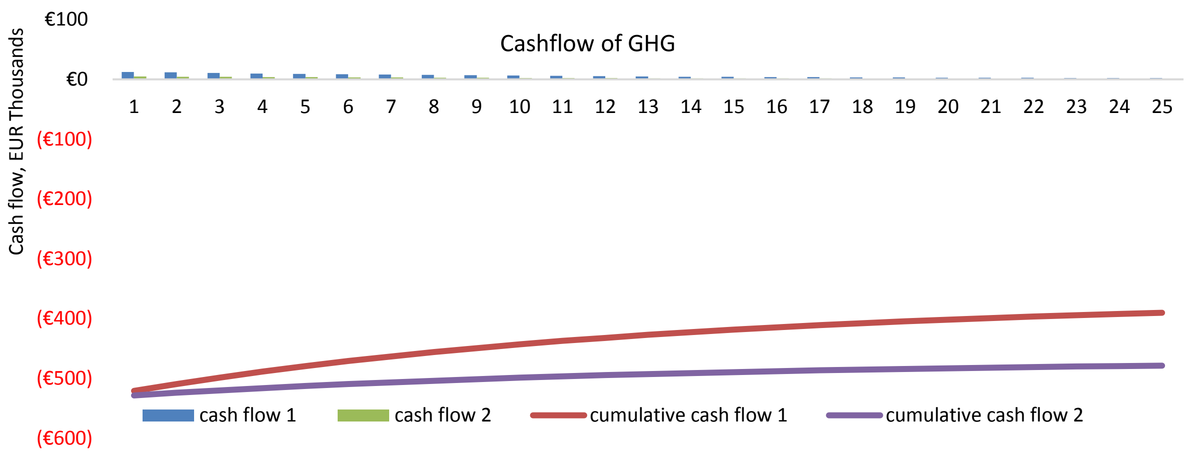

Figure 60: Cash flow analysis of subsidy targeting GHG reduction
Source: own calculations. Cash flow 1 includes CH_4 factor = 25; Cash flow 2 includes a CH_4 factor = 34

Comparing the calculated cash flow results with a scenario of doing nothing (not giving the subsidy), would give the highest and most favourable NPV to a policy scenario where the reduction of GHG and emissions together are targeted (Table 72). All other scenarios give only low values or even negative ones in case where only GHG is targeted. Policy has other premises than a private company or investor. Even a small benefit which would be of no interest to a private investor can be of higher value for a public investor.

Difference with null scenario	Cash flow (CH_4 factor=25)	Difference with null scenario	Cash flow (CH_4 factor = 34)	Difference with null scenario
Reduction of emissions	825,272	7,013	825,272	7,013
Reduction of GHG	- 390,255	-1,208,515	- 478,682	-1,296,941
Reduction of emissions and GHG	968,283	150,024	879,856	61,597
Doing nothing	818,259		818,259	

Table 72: Results of subsidy targeting GHG and emissions compared to null scenario
Source: own calculations

This analysis excludes the rest of the market outside of the model. If IWT would not change rapidly and therefore would lose its image of sustainability, it could lose market share towards modes with higher external costs which could lead to even lower net present values of the investment. From this perspective, a relative low NPV after 25 years can still be more interesting from a societal point of view in the case where a scenario of doing nothing would lead to loss of modal share of IWT and a share increase of transport modes with higher external costs.

5.4. Initial conclusions

When viewing the IWT environmental policy, it becomes clear that many good-intended initiatives are hardly coordinated and lay fragmented on different policy levels. Standards are drawn by the European Commission and by the CCNR, subsidies come from EU funding, MS, ports, fairway managers without or with hardly any cross-border or even national coordination between the involved institutional actors. The EU and the CCNR are limited in their policy arsenal since enforcement, monitoring and tax (charging) policy are not within their competences and depend on the political good will of the MS or lower levels of policy. The institutional framework requires a level of expertise to have an overview of all possibilities within the network and entrance to this network comes with a relative high transaction cost from consumer or citizens' perspective. The latter argument can already be a strong argument to advocate for supranational or community initiatives or policy actions.

The answers on the questions related to the subsidiarity test of Pelkmans (2006)[185], are not that clear-cut. The subsidiarity test still could invite political bias which weakens the economic rationale behind it. Nevertheless, the test supports policy choices within a multilevel governance model by reducing complexity, policy entrance and other transaction costs for users and policy makers. It could even reveal possible innovation bottlenecks in stimulating market uptake. Even if not all answers are given, this test could still support the making of a more effective and efficient innovation policy for the IWT.

5.5. Costs of Policy

From the perspective of the consumer, which is in this case the vessel owner/operator and the society, 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 in account. Then the enforcement costs are analysed.

A. Compliance costs

Compliance costs can refer to the dry docking, inspections and surveys with respect to vessel and crew. Within countries these required costs could differ which allows cherry picking of vessel owners/operators and lead to unfair competition. There are different prices of certificates, the time between dry docks differs and the needed time for inspectors to perform their inspections can also be different. According to the study of Rebel Group (2015), these costs differ between the MS significantly. The example of Belgium illustrates administrative differences between MS. Since the state reform in Belgium, waiting time for inspections has increased by months because of a lack of expertise, sufficient personnel and means. Also, crew certificates have a longer waiting time for renewal. Prices differ between the Netherlands and Belgium, and the difference is significant enough to make Dutch VO/O's to buy their needed certificates in Belgium despite the tardiness in delivering them. Whereas in the Netherlands, a criminal record is demanded from VO/O's when renewing their certificate, Flemish civil servants do not ask for this and the records are kept on a federal level without open access for regional services.

For the ADN treaty it is necessary to frequently follow trainings in order to keep the basic or expanded certificate up to date. For LNG an extra training is also required. These additional training costs are compliance costs in relation with the crew.

The technical compliance costs of the vessel depend on the technical regulation and new provisions. If the CCNR or the European Commission and now the CESNI ES-TRIN standards would require new rules

[185]Comparable tests have found its way into the European Impact Assessments of new regulatory actions (RIA)

of compliance such as, for example, new noise limits on-board or a standardized dinghy, this would result in increased technical compliance costs.

With the new NRMM stage V, all VO/O's 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 higher entrance price to the market through compliance costs for potential new starters. Starters with a new vessel complying to all regulation, could 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.

The effect of compliance cost can be retrieved from the SCBA model. What would have happened if the derogation procedure (explained earlier) of the MTS Argonon would ended in a rejection of the innovation by policy makers? Would a number of vessels have to be dismantled or sold to countries outside the legal scope and with less stringent safety rules? In case of the Argonon, it is not possible to quantify the efforts of the early innovator to convince the different policy makers. Not only the CCNR in Strasbourg was addressed, but also the European Commission and the UNECE 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 and probably exceed the assumed capital value in the SCBA of the LNG-D.

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 this market. As seen in the SIA of the e-bargebooking, EBIS can have an impact on the business structure with an indirect lock-in-effect towards the freight broker.

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 61). When the compliance costs are multiplied by a factor 11, the NPV becomes negative. The analysis is based on scenario 1 from the SCBA. Also, the moment when the business case has a first positive cumulative cash flow, is delayed by every increase of the factor. An increase of the compliance costs can cause a potential barrier for the innovation.

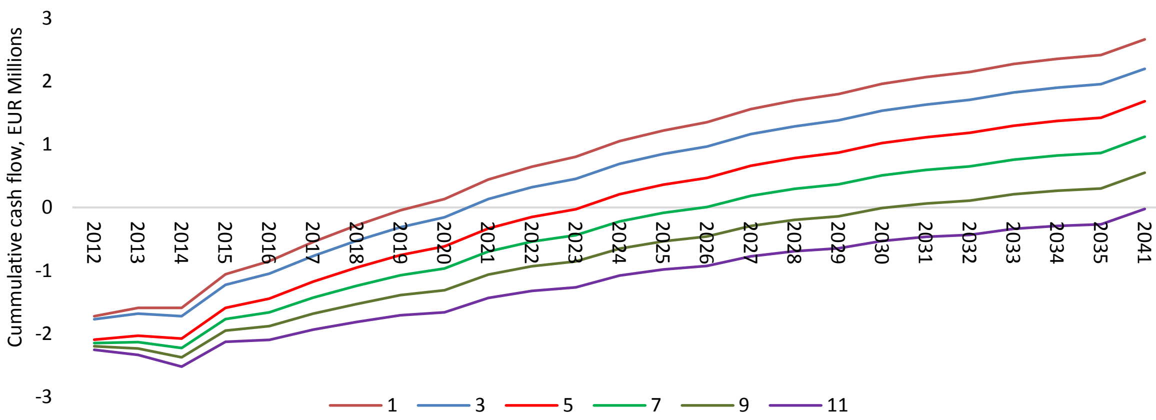

Figure 61: Cumulative cash flow analysis and the impact of compliance costs in scenario *1*
Source: own calculation. The uneven numbers represent the compliance cost factor.

Introducing new rules where a vessel has to comply to, has an impact on the business case, which illustrates the importance of regulatory certainty.

Vessel owners may not be that fond to comply to additional rules, but in some cases, these rules could have a significant side effect. 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.

B. Enforcement costs

Investing in enforcement of emission reduction, could demand MS without IWT to pay relatively higher costs without clear benefit while opportunity costs emerge if other alternative policies could achieve more national benefits (investing in road haulage reduction of emissions or railways). There seems to be hardly any incentive to tackle this at European level. Ports and MS with IWT have developed policy on this topic on a differentiated way, but to coordinate these approaches to be more effective, cross-border cooperation could become more necessary. 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.

From a SCBA perspective, these costs can be included in the category of compliance costs. Paying a fine or penalty, adds then to the compliance costs. But also, the port dues and fairway dues can be considered as a way to gentle enforce policy by giving discounts or penalties.

When using the similar approach as for the compliance costs, the impact of the P&F can be shown by applying factors to the cumulative cash flow analysis as in Figure 62.

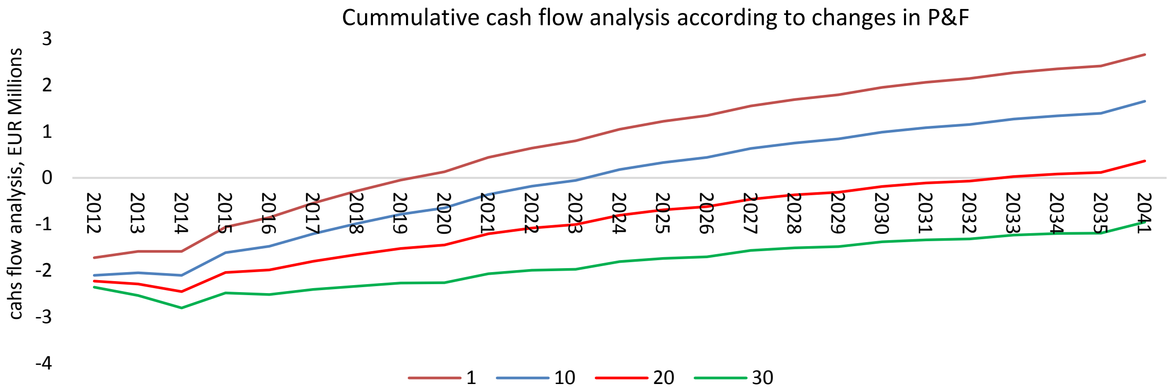

Figure 62: Cumulative cash flow analysis and the impact of P&F in scenario 1
Source: own calculation

The impact of the P&F costs is relatively small as established in the SCBA. When multiplied by a factor 10, the first year of positive cumulative cash flow delays with almost five years. When multiplied by 20 the first year becomes 2033, but the NPV is still positive. Enforcement is feasible through port dues and fairway fees, but the reduction has to be increased in order to have more impact to become an incentive tool to support a desired policy. Nevertheless, the impact of P&F is relatively small on the business structure of the examined vessel models.

5.6. Policy options

To stimulate emission reduction in IWT, several options may be considered. According to van Essen et al. (2004) it is possible to design economic incentives for VO/O's to invest in emission reducing technology. The study studied potential pricing policies with a focus on NOx emissions. Price policies in the study included a differentiated fuel charge, a differentiated waterway charge and differentiated port dues to charge users with higher emissions and benefit those with lower emissions.

A fuel charge (FC) is legally not possible for the IWT, the Mannheim Convention prohibits this.[186] However, as shown by the CDNI treaty, it might still be possible, if there is enough political will. The institutional setting of the European IWT is a disadvantage to successful 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. But again, within the institutional framework, this could provoke the same behaviour of cherry picking between MS. Vessel owners could still tank in those MS with lower or no taxes of conventional fuels. If IWT charges would be invested back in the sector, the negative effect might be decreased.

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 an amendment of the Mannheim Convention may be needed.

The differentiated port dues (DPD) are legally possible and vessel owners in IWT are not in a position to avoid a port because they don't agree with the ports policy which could be the case in maritime where big ocean liners have more negotiation power over a number of ports. 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 VO/O's to comply (higher compliance cost for VO/O), the threshold of the charge, as in other policy options, determines the success. 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/O would experience it as nuisance and policy would fail. The level of the charge is challenging to determine, but the policy maker should be clear in the objective, credible and consistent. The identified port charging rules still support CCNR II engines, but this could change in a nearby future when also CCNR II engines could be charged. The usage of LNG is now supported but in a few years it could be possible that policy makers decide to charge GHG's. LNG has a much better performance for air pollutants but its performance in GHG's is only relatively less than conventional fuel and according to recent sources, even this advantage concerning GHG's is under debate and needs further scrutiny. If the chosen threshold is too high, shippers could choose to shift to other transport modes as lower capacity can be offered by the IWT to the port.

Stimulating market uptake of emission reducing technology or fuels can also be reached by new regulation such as the NRMM. But also this approach has disadvantages. The investment of VO/O envisages a long-life span and complies with the regulation of today. This is the main reason why policy makers chose to let new emission standards only be mandatory for new engines. If a VO/O would choose to make an investment in a CCNR II engine before 2020, it would not meet the requirements of the stage V engines as described in the NRMM and mentioned in the Annexes of this research. But the VO/O will not be punished this way to choose today for a cleaner engine than he or she might had before. 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 (*cubanisation*), it could be the case that the majority of the fleet will be between CCNR II and III engines instead of the target of upgrading the fleet in 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

[186] 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 where not similar but choose to recognize each 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. The main problem here is the size of the market. IWT in Europe is considered to be a niche market which slows down developments of new technology. When expected profit margins are too low, the opportunity cost is too high when money and means could be allocated for more profitable innovations in other transport modes such as road or maritime from the perspective of the innovator or in this case engine manufacturers. The LNG engines for the IWT on the market are mainly modified maritime engines and thus depending on technology that was originally created for the maritime. As transport as a whole grows, the emissions would probably increase if nothing is changed and markets do not find incentives to implement change. The IWT could lose its perceived environmental benefits because of its own growth and because of the emission reduction policy in other modes.

Policy also has to bear in mind that charging the IWT, could provoke a modal shift towards other transport modes. If this is the case, the total societal costs would increase. But this needs to be examined more closely. Because implementation of emission charges is finding its way in road haulage and external costs concerning rail infrastructure are also being charged in an increasing number of European MS.

Charging VO/O's would also force them to save on less essential business costs. In worst case scenario, they could save money on M&R with a lower safety level as a consequence or look for cheaper labour. The latter lays outside of the scope of this research but the last decade it has become common practice to outsource crew members to small independent firms. However this lays outside the scope of this research. A boatman that works outside the normal employee relationship for the VO/O as an independent firm, could lower the crew cost with half. The result is that the boatman is very vulnerable and dependent on one customer. The VO/O does not have to pay for insurances, social taxes or holidays and can easily terminate the contract. The boatmen carries these costs within the regulation of the country where the enterprise of the boatman is located. This kind of cheap labour, has an impact on the quality of labour and perhaps also on safety, but lays outside the scope of this research. Higher costs provoked by policy or by price evolutions on the market, tend to stimulate the search to work more efficiently on-board of the vessel. Cost reduction is for most VO/O's the only way to pay off their investment. As discussed in this research, the negotiation power of the VO/O is limited to ask for premiums on the freight rate. Only when supply of capacity in IWT is lower than the demand, this negotiation power could increase.

Capacity policy (CP) as during the nineties, could modernize the complete fleet according to new regulation. But, at the moment, 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 be large incentive in modernizing the Danube fleet and their engines.

Furthermore, the rules for road haulage since the early nineties, are much stricter, together with shorter truck lifespan, the emissions of road haulage changed dramatically and more rapid when comparing with IWT and are still improving. The absolute emission of the engine is one perspective to view to this challenge. And from this perspective, the environmental performance of vessels are worse than road haulage. Another way is to compare these modes together with volume and performance. For shipping a total payload of 2,500 tonnes from Antwerp to Basel, 100 trucks of 25 tonnes are needed to do the transport at once, or 200 trips with one truck (including empty trips), while only one IWT vessel can provide the same performance without congestion or high accident costs. If trip – distance and payload are smaller, the environmental performance of IWT will also become smaller when comparing with road haulage.

6. Conclusion

At the beginning of the analysis in this chapter, it was the ambition to analyse several alternative fuels and propulsions, but during the research it was decided to go more in-depth in one specific case. The LNG case receives significant public funding and has already a number of vessels in the market. There is also a regulatory framework provided. Despite a number of projects, pilots and research, there are still questions that remain. The LNG innovation offered a subject in this research that could be analysed partially ex post and ex ante which could provide added value to existing research. The research and the applied methodology tried to answer two questions: Is there a positive business case? And what should policy do? The SIA approach has delivered in-depth insight of the introduction of LNG as a fuel in IWT and gives a strong foundation for the SCBA. The following views emerged:

- There is variety of alternative fuels and propulsion systems, but LNG has received the most attention the past years by stakeholders and regulators
- The bunkering facilities are critical to stimulate market uptake but seem to have barriers of their own.
- Further dissemination of best practices of the pilots is necessary.
- Subsidies for smaller companies (majority of the fleet) should be feasible and accessible to have more market potential.
- The main focus lays on the tanker market which is a niche in IWT (engine builders consider IWT already as a niche).
- 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 relative long lifespan.
- Cultural barriers include cubanization and perception of LNG as dangerous
- Lock-in effects remain during all periods and could pose a threat or even lead to the end of the innovation if major players change their strategy (e.g. Shell).
- There is a need for further research into methane slip and solutions to improve the valve system to avoid slips. Ways to recover the methane and to reuse it (e.g. heating), are also an option.

These views were developed during the system of innovation approach (SIA), the social cost benefit analysis (SCBA) and the policy analysis (PA). The SIA revealed a number of remaining bottlenecks concerning bunker facilities. The delays in the implementation of the masterplan for LNG, do not support the further implementation of the innovation. The bunker possibilities, routine, and less sever safety procedures of conventional fuels are still more appealing. Also, the differences between MS regulation regarding bunkering trucks loaded with LNG . These trucks are not allowed to go in a tunnel and have different loading limits between MS. Also not everywhere, it is allowed to simultaneously bunker with diesel and LNG at the same location. To support the innovation, the infrastructure should be implemented to avoid the additional logistics costs of bunkering. Nevertheless, 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. The TTS bunkering cost still allows a significant distance between the diesel and the LNG price.

Another conclusion is that public funding does not seem to reach the bulk of the market (yet) which are small and medium sized enterprises. Mostly relatively larger players in IWT received subsidies as shown by the SIA. The main focus of the LNG implementation lays on bigger vessels (starting from 110m length) and especially the tanker market. For engine manufacturers this means that the engine is sold in a niche market within a niche market. This could lead to slower development of IWT-fitted technology, because of the lower profit margins. Another aspect of the tanker market, which could lead to a slower implementation of new engines, is the fact that the last decade there has been an enforced new building in the sector because of the double-hull requirements which happened without public funding. Most of the newly-built tanker vessels have a significant financial leverage and already a relatively young engine that complies with CCNR II regulation. Chances are that these vessels will choose to repair and maintain their engines as long as possible to avoid the requirements of Stage V. Another possible scenario is that VO/O's will shorten the lifespan of their engine and install a CCNR II engine before the implementation of the NRMM stage V.

The SCBA gave 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 business case is mainly developed on the spread between diesel and LNG which makes it vulnerable. In the case analysis, it was shown that if the spread was smaller than 8%, the innovation offers a lower NPV than the null scenario (without innovation).

The threshold or the height of the total social benefits seem sufficient for policy makers to subsidize an LNG vessel and offers no reasons for social resistance against implementation. But when zooming into the benefits while making a distinction between greenhouse gases and air pollutants, the positive effect is mainly because of the latter and not because of the GHG performance. After adjusting the methane slip and the CO_2 equivalent factor, from 25 to 34 as some authors suggest, LNG performs worse than diesel and even adds 0.2% of Greenhouse gases compared with diesel. It could be questioned if the subsidy is therefore justified from a welfare-economic point of view in order to achieve the targets from the Paris Agreement concerning climate change. It is claimed by manufacturers that the problem of methane slip will be addressed in the upcoming years. This claim is already more than ten years old and there is a need for real life measurements in several situations of the environmental performance of an LNG vessel. LNG is therefore important to understand as a transition fuel that in the first place will address challenges concerning public health.

The policy analysis showed that within the complicated multilevel governance model, every level has its own costs and benefits. Ports could offer discounts but as the SCBA showed, these have hardly an impact on the business case. 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.
The implementation of one stage V, together with the ES-TRIN standards, leaves the rather ambiguous situation of different possible certifications within the European Union and Switzerland and will probably lower the private compliance costs, than when an VO/O has to deal with different legal regimes despite the mutual recognition.

Supranational policy is however limited in its policy means. The European Commission is not able to use a tax policy and charge external costs. It would also not be allowed by the Mannheim Convention, but knowing the CDNI (shipping waste convention), there are ways to amend the Convention.

The IWT is an international sector which could allow cherry-picking between MS because of cross-border differences. VO/O's can choose to buy cheaper certificates in Belgium (despite waiting time) than in the Netherlands, but be flagged as a Dutch vessel to attract more national public funding and financial incentives. Crew members can come from relatively cheaper countries to avoid the different national crew taxes. Bunkering prices can also differ between MS. These differences between MS could offer more best practices because of the competition between MS, but support less the integration of one internal market with one levelled playing field.

IX. General conclusion

During this research, the approach of combining SIA, SCBA and policy analysis allowed answering the two research questions.

First of all, positive business cases seem to be possible in IWT, but innovation cases without public funding at one or more stages of the innovation, were not identified. Even in the case of e-Bargebooking, public actors funded a series of failed attempts and funded research during the initiation phase of the innovation.

Purely private innovation, whereby private investors operate without public funding, was not found. Nevertheless, the identified and examined innovation initiatives can offer higher NPV's than in a business-as-usual scenario. However, even when the NPV and rate of investment are interesting from an industrial-economic perspective, innovators do not tend to invest further without public support.

As elaborated, IWT is a niche market with most potential customers active on the Rhine. The relatively small size of the market emerged in several cases as a possible reason why investing in IWT innovation could be not that attractive. Especially, the innovation in the first three considered cases is made tailor-fit for IWT which puts upward pressure on the innovation prices and could slow down market uptake by consumers in absence of mass production. In the case of automation and LNG the market is in reality larger. The technology of the LNG dual fuel engine comes originally from the maritime sector. Although there are significant differences between IWT and the maritime sector, the design of an SCC or a dual fuel engine, can be used for both IWT as for maritime transport, which targets a larger market and can reduce risk. Another aspect is the regulatory framework. When a set of technical IWT standards or other rules differ between the Rhine and the rest of Europe, the potential market becomes limited. The relatively young introduction of ESTRIN from CESNI, can be regarded as a positive influence for potential innovators as long as the set of rules is technologically as neutral as possible. Especially in regard of the globally emerging automation industry, a too rigid regulation could lead to failure of the innovation. The possibility for derogations can facilitate innovations to develop, if provided on time. The procedure of derogations is hardly known by the consumers or innovators. The role of innovation facilitators such as branch organisations, is needed to support innovators in reaching out to relevant stakeholders and actors in the rather complex institutional IWT policy network. It also helps to support potential customers in finding their way in also complex and fragmented public funding possibilities.

From a customer perspective (VO/O's), there are a number of barriers that prevent market uptake of the innovation. The lack of sufficient infrastructure (for instance, LNG facilities) and naturally enough financial means, can restrain potential customers from buying the innovation. Public funding can support the removal of those barriers, but hardly finds its way to the numerous SME's in IWT. In the case of LNG, mostly large firms with more than 20 vessels in propriety, received engine subsidies, but no SME or single-vessel owner was identified so far that invested in LNG or received subsidies related to LNG.

Essential for IWT is the freight rate which has not shown significant increases to cover increased costs which could give the entrepreneur relatively more difficulties to invest in innovation. One of the increasing cost types is the compliance cost, whereby new technical regulation and requirements increase the costs for the vessel owner and decrease the opportunity to invest in other opportunities such as innovation.

The second research question concerns the role of the government. As seen in the relatively detailed institutional analysis, IWT policy is still fragmented and rather complex. To foster innovation, the role of policy should be internally coordinated to avoid extra compliance costs and offer a more transparent public funding mechanism. To tackle the fragmentation of European and even pan-European IWT policy which could generate inefficiencies, a centralization and thorough coordination between remaining fragmented competences within the policy cycle, are needed. Furthermore, policy should also be innovative. To support innovation in the automation of IWT and of transport in general, the administrative requirements should modernize. To allow for e-documents, automated communication with officials, etc., government still has a way to go. The role of government is therefore also to redesign itself. Regulation is often a bottleneck. The system of derogation can offer possibilities to solve this, but the speed of regulators in adjusting the regulation has a direct impact on the business case of the innovation. A delay of adjusted regulation will cost the innovator money. The same goes for delayed infrastructure masterplan implementations. Infrastructure is vital for most identified innovation and is mostly a national or regional competence. The examples from Norway as described in the case of the automated vessel of combined induced power charge mooring devices, are promising but are still relatively expensive. The LNG masterplan also entails a vital role for the infrastructure manager, such as the port authorities of Rotterdam and Antwerp, to finally provide on-shore bunker facilities for LNG vessels. Although, the objectives of the Paris Agreement are hardly met with LNG because of the exhaust of methane, the reduction of emitted pollutants reduces dramatically. As a transition fuel, LNG is still promising to help IWT to a higher stage of environmental performance. Next, as mentioned, public funding and research seems to be crucial for innovations to succeed, but do not guarantee market uptake. Subsidies could be the needed additional incentive to take the risk in investing in IWT innovation next to a positive business plan.

IWT differs between market segments. Tanker barges are used to sail with dangerous goods, which could be one of the reasons why they show more interest in alternative fuels such as LNG than other segments (so far). Small waterways present a market segment where supply of fleet capacity is still decreasing and where annual revenue is perceived to be lower than on larger vessels. The cases concerning the small barge convoy and the PSB suggest 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 offer a potential positive business case, but the IWT market hardly shows any interest and prefers investing in larger ships. Innovation initiatives such as the PSB and the small barge convoy try to reactivate these small waterways, but find it difficult to experience market uptake. In the case of the small barge convoy, EU and MS funding is invested in research, development and building since 2006, but the innovation is still not operational. Private investors are still to be found. Furthermore, as in the case of AGORA (cfr. e-bargebooking), the possibility of market disturbance of a public innovation could result in pushing out private innovators such as 4 Shipping instead of appealing more VO/O's to join an electronic bargebooking platform, which could reduce cost (charterers provision).
Also for Watertruck+, although aimed at attracting new cargo flows that do not exist yet on the current IWT market, the risk of market disturbance in pushing out remaining vessels in this segment can be significant. Nevertheless, except for the PSB, there is hardly any private-driven innovation to target the small waterways. Without public intervention, it seems that the small waterway fleet would further reduce while shifting volumes to mainly road haulage. The relatively high crew cost is significant, especially on the small waterways. It is questionable, if the current crew requirements are still aligned with the technological developments and the relatively low external costs related to accidents. Certainly, when in all transport modes, innovators are developing automated vehicles and vessels that eventually could become unmanned in a nearby future. In all cases, there is a strong safety culture in IWT, whereby the innovator has to prove if the innovation guarantees at least the same safety level as described by the regulation and which is also one of the reasons why IWT is considered to be one of the safest modes of transport.

In the case of the automated vessel, the main cost reduction is the crew cost if regulation would allow it. But not only regulation is an import factor for the business case, also infrastructure adjustments, such as automated mooring devices in locks, can support the market uptake. In case of alternative fuels, the lack of fuelling infrastructure, especially in comparison with conventional fuels, has a negative impact on market uptake.

Large inland shipping companies can take more risks and can digest or compensate more easily different kinds of failure than SME’s. They also find it easier to attract public funding, are represented in the branch organisations, are strongly integrated in policy and innovation networks and can be more resilient in shocks on the market. It can be questionable if the current IWT business structure of one vessel owner/operator is still efficient to support innovations.

Nevertheless, IWT in general, needs more innovation that reduces costs (both private as external) and that could attract more volumes from congested road haulage.

X. Policy recommendations

Throughout the research, it became clear that policy had a significant impact on innovation. Policy can support an innovation or jeopardize further innovation implementation.

What should policy do or not do?

There is no clear-cut answer on this question because the underlying rationale behind this question is first of all political from nature. It belongs to the primacy of politics. 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.

The research, identified a number of options to tackle cross-border internalities such as:

- air pollution by transport by stimulating alternatives (e.g. LNG)
- the decreasing traffic on the small waterways,
- lack of digital applications and automation in the inland navigation.

For policy makers, the social benefits of the reduction of external costs by a possible modal shift from road (less congestion, accidents, emissions) to inland navigation is the decisive argument in general to legitimize public investments.

Public funding such as subsidies, tax cuts or reduction in port dues, can stimulate an innovation, but these instruments are differentiated mainly on Member State level and are difficult to be reached by SME's which comprises the main part of the European fleet. The institutional complexity requires a sufficient level of expertise and has an impact on the innovation phases. Policy makers could support further dissemination of procedures for subsidies and derogation procedures. Too much differentiation at the Member State level also allows cherry-picking whereby vessel owners can choose to comply to the least expensive policy.

The introduction of e-documents and automated processes within policy administrations with well-established legal value at European level, can facilitate the implementation of the automated vessel, the case of e-bargebooking, and can lower the administration costs for the vessel owner and the monitoring costs for the traffic manager in general. A sufficient level of cyber-safety in balance with user friendliness is needed. Specifically, the Budapest Convention on the carriage of goods by inland waterways (CMNI) is one of the European treaties that can be used to give a legal definition to e-documents in European inland navigation within contracts for international transport.

Next to public funding, European policy makers can decide to allow derogations, which means that an innovator is allowed to temporarily 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 the 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). Derogations allow innovations, but the procedure is not disseminated enough amongst vessel owners. Derogations also offer a temporary regime with a clear end date, however, they come with regulatory uncertainty, for instance when the policy makers change the regulation in the meantime, and if so, this raises questions regarding timing. 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).

Innovation needs a transparent and clear legal certainty in (inter-)national courts to protect the contractual binding between the actors during the chartering of a barge and to experience market uptake. Furthermore, to have sufficient critical mass in the relatively small market of inland navigation (enough customers), a high-level playing field is advisable. Too many complexities between different national regulations can jeopardize the innovation. Also the regulations from river commissions and the treaties at the UNECE level should be consistent with the policy of the European Commission. The further development of CESNI can contribute to achieve this objective, next to close cooperation and coordination between institutions. The river commissions and only a relatively small number of EU-MS provide expertise and real policy concerning inland navigation which needs to be taken in account in the development of further European policy within the multilevel governance model of the inland navigation.

According to Vanelslander et al. (2011) innovation needs the development of a vision concerning possible technical innovations in the IWT with high level input and practical feasibility tests of scenarios concerning market, ship technology, regulation, infrastructure and funding. Governments need to give correct market conform incentives without disturbing subsidies. Furthermore, subsidies can lower the market freight rate, giving a disadvantage to existing market players and possibly disrupt the competition. This is perhaps not the case for all subsidies. In this regard, it is questionable whether the regulatory ceiling of subsidies (de-minimis, European Commission 1407/2019), which is EUR 200,000 for a firm over a period of three years, could disturb significantly the market.

After the more generic recommendations, the specific case related policy recommendations are mentioned in the following paragraphs.

1. Institutional framework

Considering that IWT is rather a relatively small market with a lack of standardization in vessel design, the scope of technical standards should be as big as possible to ensure a sufficiently large playing field or market. The regulatory approach could follow the schematic as shown by following figure.

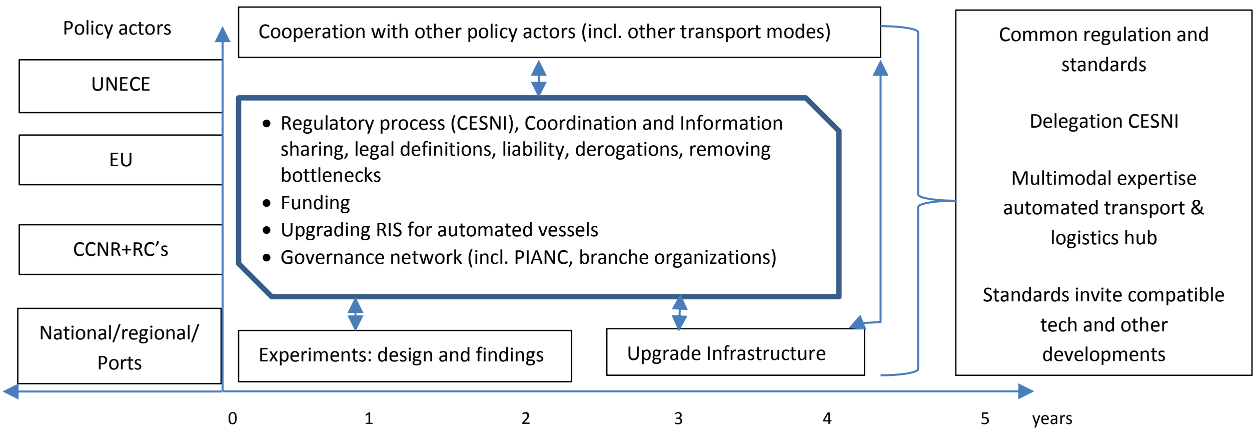

Figure 63: Policy recommendation to proceed for one legal regime
Own creation; RC's= other river commissions

The policy recommendations that can be deduced from the above-mentioned scheme and research concerning the institutional framework are the following:

- **Cooperation:** As long as the institutional setting of European inland navigation is not changed, the recommended approach to tackle the infrastructural and institutional (potential) failure factors or bottlenecks concerning legal definition, monitoring, evaluating, enforcing, infrastructure, standardization and other identified issues such as asymmetrical information, has to follow an institutional cooperation schematic closely linked with all institutional actors on all policy levels to achieve a sufficient level playing field and to maintain a common level of safety for all of Europe.
- **Multimodal approach:** To avoid lock-in effects, the regulatory approaches in other modes, should be taken in account because there are similar challenges to be observed (e.g. liability).

- **Neutrality:** The standards and regulation in IWT should be technology neutral or universal as much as possible to avoid blocking the implementation of other rapidly developing improvements and devices from other sectors instead of focusing on one specific technology, while maintaining the focus on safety.
- **Improved procedures:** the homologation procedures of engines comprise long and relative expensive procedures to achieve the required certificates in order to comply with ruling standards (e.g. regulation on non-road mobile machinery); authorities are supposed to have sufficient inspectors and police officers to inspect the fleet on environmental and other compliance. In reality there is a difference, both in quantity and in quality of personnel between the MS. The supranational levels such as the European Commission and the CCNR should actively monitor and address the procedures on national and regional level. If one Member State fails to implement supranational directives, regulation or other agreements, vessel owners could cherry-pick or apply for certificates/inspections in the most interesting country (forum shopping).
- **Data exchange:** the exchange of data related to the vessel, operations, inspections and on-board crew, should be improved between member states.

  Dissemination: Further dissemination of research results and best practices is needed, especially amongst SME's. More promotion of existing intermediaries between sector and public funding such as innovation platforms and greening consultants, could invite more companies to invest in innovation. Policy and sectoral organisations play an important role and already undertake initiatives.

The following recommendations are case specific.

2. e-Bargebooking

Challenges that have to be dealt with to modernize the business of IWT by introducing *e-bargebooking* and where policy makers could play a role of importance are the following:

- **Infrastructure:** internet coverage should become available on all waterways. The future implementation of the 5G network and further investment in RIS infrastructure can support the innovation by establishing better networks with more speed and internet coverage.
- **e-Government**: strengthen the legal basis of e-documents at an international level (as explained supra). The CMNI could provide a starting point by adding definitions.
- **Freight broker legal status:** Define the legal status of a freight broker, with a description of required skills, training and provide professional certificates. This could be taken up by the European Commission and the MS.
- **No intervention:** Policy should not introduce public competition (e.g. Agora as explained in the analysis) by implementing or enforcing similar innovation.

3. Small barge convoy and pallet shuttle barge

Because of a number of similarities between the analyses of the small barge convoy and the pallet shuttle barge, the policy recommendations are shown together.

- **Compensation:** Subsidies for the innovation can be relatively high and could lead to the unintended loss of the remaining market players on the small waterways instead of the main objective of modal shift from road. Losers of this public innovation are then the remaining owners of small vessels. Policy could decide to compensate them by actively supporting them in investing in innovation or to attract also new cargo flows from road.
- **Transparency:** It is not always clear what the differences or improvements are between the different projects and where each follow-up project improves the findings and design such as in the case of Watertruck+ and its proceeding projects. It could be recommended (in general) for the public innovator to prove in a transparent way the added value of each follow-up project.

- **Research Data collection:** Sufficient data for small waterways is relatively difficult to find. Some online sources, usually public, stopped or decreased publishing because of governments cut-backs or renewal of websites (ITB, PBV, RWS, Vlaamse Waterweg). In times of RIS monitor centres, AIS transponders and the beginning of the debate concerning the development of block chain technology, one could suppose that data-collection can be easier than before. This evolution at the national and regional level of digressing availability or measuring capacity, could lead in a worst case scenario to a policy without numbers or market insight. Knowledge in measuring and the decreasing interest in data-driven policy on a Member State level, can also decrease the quality of data that is delivered to European or international institutions or observation systems. This is certainly the case on the small waterways where official sources provided information online until a couple of years ago. Next to sufficient available market statistics, the data concerning safety (e.g. accidents) is also very scarce. At the level of Eurostat and ITF more data can be demanded from the MS or regions and published freely to aid further research. This could support an empirically proven safety policy as in other modes where more reliable data is used to study accidents and the risk for accidents[187].
- **Debate of single crew:** In times of further automation and the implementation of advanced river information systems, the regulatory distinction between 55m vessels seems to be an arbitrary rule of thumb[188]. The relatively heavy traffic on the Seine and Western Scheldt would make a ship with only one person on-board dangerous according to Dutch and French policy makers and it is also not allowed on the Rhine. These concerns invite further research but the debate should be started at the level of the CCNR, European Commission, CESNI QP and the MS. It is the role of the innovators to prove with *hazid* (Hazard Identification) Studies of independent verification agencies, that enlarging the legal regime for single crew vessels such as the PSB and Watertruck+ corresponds to the minimum safety level that is required by regulatory bodies and which could decrease the crew costs and increase competition with road haulage.

4. Automated vessel

To improve or support the innovation of the automated vessel (AV), the role of policy within the existing institutional framework is recommended to address a number of challenges related to automation such as:

- **Investment in digital infrastructure**: cybersecurity, data sharing, secured and reliable connections (digitally optimal and safe connections with shore control centres (SCC's), on-shore automated docking stations, training facilities and SCC's); full internet coverage (5G). To avoid problems in cross-border interoperability and compatibility between systems, a coordinated RIS approach could be advisory to develop common standards that technology-universal and future proof[189].
- **Automation infrastructure**: Invest in automated "bollard" and fender systems such as the example of the MF Folgefonn which includes wireless power charging through induction. Infrastructure is needed in locks and in the surrounding of bridges, but is still in development;
- Decreased **compliance, monitoring and enforcement costs** by introducing automated systems at government side such as e-documents and transparent derogation procedures. This could avoid multiple penalties on one trip and improve enforcement and monitoring of vessels. Ports, fairway

[187] Systems such as FOSO in Belgium for the maritime, the further development of the SOS data and the nautical accident monitor in the Netherlands, the finally real launch of Havaris in Germany, and improved data of Eurostat, could help researchers, inspections, verification agencies, sector stakeholders and policy makers in making of keeping the sector safe.

[188] A vessel of 56m needs a two-headed crew, while a 55m long vessel needs only one (and complying to national regulations only for a limited number of waterways).

[189] The emergence of the automation industry for maritime and inland waterways comprises many types of devices, scanners, operating systems but still needs machine learning and auxiliary innovations. This variety of options makes it challenging to determine standards. Without exploring the possible impact on stakeholders, innovators and the market in general, new regulation for automation can limit the creativity that is needed to improve the innovation and alternative solutions may suffer as innovators are focused to comply to a given standard, especially when it is tailor-fitted for a small market such as IWT. Regulation therefore should be future proof and technology-universal as possible.

managers and river police in collaboration with the sectoral organisations could provide in this support for automated vessels. The benefits of such systems are not only for automated vessels, but can reduce administrative burdens for the entire fleet.

- **One legal regime and definitions:** Create a level playing field at CESNI level, within one legal regime for as many inland navigation countries as possible; legal definitions for degrees of automation next to liability questions and the legal statute of SCC operators and engineers; need for a legal definition of the nautical error when an accident does happen with an AV**.**
- **Training:** Support education programs for SCC operators; a special "CESNI/QP" could be organized explaining what automated systems should be able to do and what the minimal essential requirements are to maintain the comparable level of safety and quality of service, next to the proper described training for shore personnel in a SCC with clear limit of the remote-control vessels per person ratio. Additional training requirements for official state inspectors and for private verification agencies concerning automation is needed.
- **Data:** Improve accident data quality for learning (machine & human) and to further increase the safety benefit. MS should be demanded to deliver more data and perform transparent analysis of accident casuistry as they do for road haulage.
- **Multimodal:** multimodal policy framework dedicated for all automated vehicles and vessels in close cooperation with and fuelled by the expertise of the river commissions and their network. The funding, monitoring and enforcement instruments of the European Union and the MS should be kept in sync and transparent for all modes but with equal treatment for all modes.

5. Alternative fuels: the LNG case

Rivers do not stop at borders as do air pollutants and the impact of global warming. The environmental and climate change challenges are the most outspoken examples of cross-border externalities. IWT has the advantage to be the transport mode with the lowest external costs compared to road haulage (lowest emissions for each tkm) but may be losing this advantage if its emissions are not further decreased. Policy makers such as supranational actors in multilateral platforms (structural, formal or informal) on different levels, MS, fairway and port managers, are together with the industry crucial players in addressing these challenges. Policy makers are recommended to consider the following:

- **Measurement:** Improved measurement of emissions and greenhouse gases in real life situations without interrupting operations with modern equipment and in a standardized way. This could be beneficial for both monitoring maritime as inland navigation and can be done by port authorities. The further reduction of GHG and improvement of the LNG implementation and its engines, could benefit, from a more accurate and uniform way of exhaust measurement in different real life situations and on different locations on the vessel.
- **Avoidance of defragmentation:** subsidies, tax cuts, enforcement, monitoring, inspection are mostly concentrated at the level of the MS that have significant inland navigation.
- **Infrastructure:** the implementation of the LNG masterplan with on-shore bunkering installations. Although the additional costs of more complex logistics of truck-to-ship bunkering lightly affect (relatively) the examined business case and it is not proven that bunker prices will decrease by installing on-shore facilities. The transaction costs (e.g. time needed to plan bunkering) will certainly be lower if sufficient bunkering facilities are implemented.
- **Funding:** subsidies for smaller and medium-sized companies (majority of the fleet) should be feasible and accessible to increase market potential. The first wave of LNG vessels is mainly owned by relatively large companies.
- **Methane slip:** engine manufacturers need to solve the methane slip problem. In order to achieve the goals of the Paris declaration concerning greenhouse gases and climate change, policy makers should stimulate engine manufacturers to solve this problem thanks to public funding or enforcement at EU level. If the SCBA model could be adjusted for other types of vessels and with more improved measurements, values can differ, but within the findings of the model in this

research, after adjusting the CO_2 equivalent factor to 34 as pointed out by the international panel of climate change, the dual fuel engine has no benefits for climate change. But as transition fuel, LNG offers a significant reduction in air pollutants which still leads to significant lower external costs than a conventional vessel. The total social benefit is still higher than without this innovation.

- **Regulation:** regulation has been adjusted for LNG as a fuel and cargo in a shorter time frame than expected, but this has not led to significant more investments yet. The upcoming European Non-Road Mobile Machinery regulation (NRMM) with the new stage V emission standard in 2019/2020[190], will probably give more insight in the engine and fuel choices of vessel owners that are now being made.
- **Fuel tax:** as the innovation is sensitive to price differences between diesel and LNG, a fuel tax could weaken the business case and is advised not to implement.
- **Market:** The upcoming LNG market in the IWT is a monopsony in the short run where one customer determines largely the market. This could lead to innovation failure and needs policy makers to be aware of the costs and benefits of a possible monopsony market situation [191] but the latter invites further research.

[190] The NRMM or Non-Road Mobile Machinery regulation will be further elaborated in the case analysis and regulates the emission levels of engines.

[191] In case of a monopsony, there is only one customer at the demand side against several companies at the supply side. In case of LNG, the role of Shell, determines almost every implementation of LNG in the inland navigation so far. It is obvious that the further implementation of the LNG IWT vessel depends on the business strategy of Shell which is in most cases the main customer with a long term fixed contract. Other players such as Total-Fina are aiming at the bunkering market with truck-to-ship bunkering and the development of the first onshore facility in Cologne.

XI. Discussion and further research

The following questions and points lay outside the scope of this research or were not possible to address during the time frame of this research.

First of all, 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 on the market, this analysis and other literature can be improved. The CCNR II engines do not comply with stage V starting from 2019 for the IWT. To improve the analysis, the baseline scenario should be a conventional vessel but with an engine complying to stage V. The SIA can also be applied on the engine manufacturer in this regard to give more insight in the bottlenecks they come across and the reasoning behind their market behaviour concerning IWT.

It was not the main objective to develop a fuel cost forecast. By starting the first year of operation in 2012, the analysis could take in account real data until the end of 2018. Most consulted literature used forecasts of the international energy agency of 2015 that did not predict the decreasing gap or spread between LNG and diesel spot prices. The latest forecasts show a slightly more pessimistic evolution as LNG and diesel are converging towards each other. This issue requires frequently monitoring and research as it determines the business case.

Also, the forecast of the freight rate and the expected earnings do not take in account the possible changes on 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 took changes of water depth in account. This seasonal phenomenon can change in the future by canalizing the Rhine or because of a modal shift towards railways and trucks due to the higher IWT freight rates and lack of capacity. Although this approach can be debatable, it could improve forecasting because it takes in account periods of high and low freight rates and leaves the conventional linear forecasts. Further research could improve or reject this approach.

From an emission perspective, the LNG dual fuel vessel shows already a reduction of 52% compared to a conventional vessel, but the greenhouse gases only show a five percent reduction (methane factor = 25). If the methane factor is put at 34, the greenhouse gases from tank-to-propeller are even worse than a vessel running on 100% diesel (-0.2%). More research is needed to measure emissions in real life from different places on board of a vessel and during different situations.

As technology evolves rapidly, other alternative fuels or after-treatment systems could offer better business cases. The method as developed in this research could also be applied on other fuels such as Hydrogen or on electrical propulsion. It can be adjusted to another type of vessel, but needs sufficient research to quantify the costs and benefits. Every vessel is unique and active in a certain part of the market. A vessel transporting dry bulk, will have differences such as regulation, crew training costs, safety procedures, ship design, engine power, fuel consumption and capital value. Also, the researcher has to answer a number of questions concerning the number of annual trips, operational hours, which operational mode, technical compliance mode and so on. The market structure of the vessel should be taken in account. For example, LNG vessels need further economic research, as the market has the tendency to evolve to a monopsony in the short run dominated by Shell.

The zero emission fuel does not exist in WTP. Even if a vessel would be electrical, the electricity is generated according to the energy mix of a country's transformation sector. Also the case of hydrogen, which is generally made from methane, entails external costs, but these (an others) invite further research as the IWT and transport in general looks for sustainable innovation to reduce its impact on climate, health and the environment.

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ANNEXES

1. Annexes to methodological framework

1.1. Discussed cases during case selection

1500 m3 Heeling Pump
Automated or remote vessels
Barge heavy lift RO-RO hybrid
BCTN Barge slots
Containerisation
Coupled barges
Crane technology
Digitization of on-board documents
Double hulls
Dual Fuel Motor
e-Booking
Fuel water emulsion
Full electric
Gas engines
GTL fuel
Hybrid propulsion
Incident Reporting and Analysis System
Magnetic mooring
Means of communication
Modal shift scans
Non-fossil passengers ferry
Automated platooning
Optical Character Recognition
Pallet Shuttle Barge
Q-Barge
Scheldehuid
Selective Catalytic reduction + diesel Particular filter
Small barge convoy on small waterways
Smart distribution
Synchromodal transport
z-drive

1.2. Applied questionnaire for in-depth-interviews

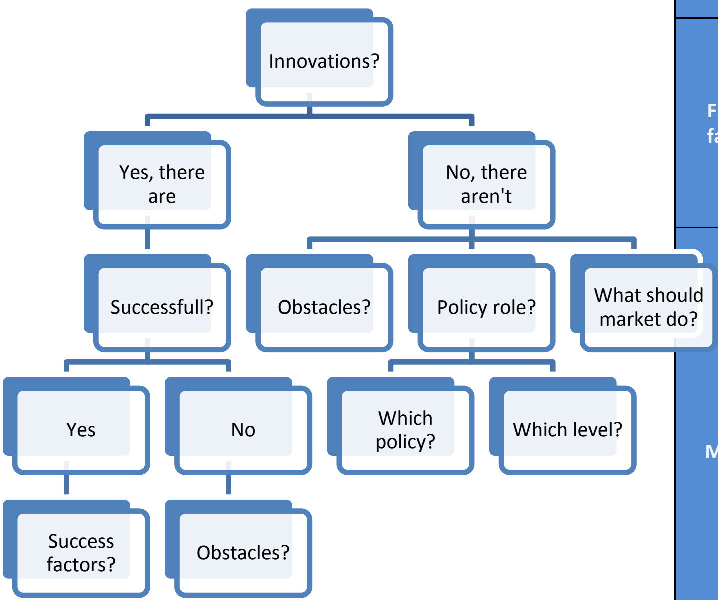
A. Objectives

Gaining information about innovation in IWT in general, in cases (insight, barriers, costs, success factors)

B. Target group

- Stakeholders (EBU, ESO, ITF, individual skippers/charterers, verification agencies, INE)
- Experts (CCNR, EICB, EIBIP,EBIS, EDINNA, EUROMOT…)

C. Question tree



D. Outside table

- If you were a skipper with a 40 year old ship, in what kind of innovation would you invest?
- If you could start over, in what would you not invest?
- How will the fleet/market/inland navigation might look like in 10/20/30 years from now?
- How much does the mentioned innovation cost?
- How much would you be willing to pay?
- Who would benefit of the innovation?

issue	target	question	Expected answers
Innovation	Ideas for cases	What are the first innovations that come to mind in the inland waterways? Which innovation project should be investigated?	Unmanned, green engines, AIS
Success factors	Listing success factors	How can such an innovation be successful? / Do you consider these innovation promising or successful?	Costs, people skills, access to information, market pressure, low freight rates, to small firm, conservative culture, education
Failure factors	Listing failure factors	What do you think are the main barriers holding innovation down? What causes failure?	
Market	Market conditions favoring innovation	What should market do to improve innovation?	Invest, be reorganized, transparent
	Market prospects	How would market look like in future?	Unmanned, greener, cheaper for customers, more costs
	Players	Who are the main players in innovation in the Inland waterways?	big size ship or big company, liquid, containers, young people, other modes (sea vessels), policy
Policy	Location of policy, benchmark	Which country does the most innovation? (also market question)	Netherlands, Germany
	Acts of Policy	What should policy do?	Subsidize, research and develop, adapt fitted regulation quickly
	Ideal level of support	Which policy maker?	EU, MS, CCNR

1.3. List of interviewees, contributors and participants of expert meeting

Without the contribution of following experts, policy makers, innovators and stakeholders, this research was not possible. The time and willingness to answer all questions added a significant value to the research.

Interview respondents	
Names	**Organisations/firms**
Ad Hellemons	Aquapol
Alain De Vos	CITBO
Antoon Van Coillie	Blue Line Logistics
Axel Goetze-Rohen	Bargelink
Bas Joormann	Lloyd's Register
Ben Maelissa	Danser Group
Benjamin Boyer	CCNR
Bente Braat	CCNR
Cornelis van Dorsten	Mercurius Shipping Group
Dick Van Doorn	Van Doorn Consultancy
Didier Bacon	Touax River Barges
Dirk Beernaert	DGT
Eloi Flipo	VNF
Erwin Fessman	CCNR
Filip Verbeke	Watertruck +
Gernot Pauli	CCNR
Guillaume Legeay	CCNR
Gunther Jaegers	Reederei Jaegers Gruppe
Hester Duursema	ESO
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
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2. Annex of the Small barge convoy case

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
1	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	-		-		-	-
2	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	1	-		2	1
		apprentice	- 1	1	$1^{1)}$		-	1
		engineer or engine-minder	- -	-	-		-	-
3	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	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
		engineer or engine-minder	- -		-	-	- -	-
4	Pusher + 2 Pushed barges *) Motor vessel + 1 Pushed barge *)	boatmaster	1	1	2	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 -
5	Pusher + 3 or 4 Pushed barges *) Motor vessel + 2 or 3 Pushed barges *)	boatmaster	1 or 1	1	2	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	1	2	-	2 2	- -
		apprentice	- 2	1	$1^{1)}$	$2^{1)}$	$1^{1)}$ -	2 1
		engineer or engine-minder	1 1	1	1	1	1 1	1 1
6	Pusher + more than 4 Pushed barges*)	boatmaster	1 or 1	1	2	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 2	1	3	1	3 3	1 1
		apprentice	- 2	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.

3. Annexes of the automation case

3.1. Draft standards of competence for the management level

A. Supervision

The boatmaster shall be able to instruct other deck crew members and supervise the tasks they excercise, as referred in Section 1 of Annex II of directive (EU) 2017/2397 on the recognition of professional qualifications in inland navigation and repealing Council Directives 91/672/EEC and 96/50/EC[192], implying adequate abilities to perform these tasks.

Persons willing to qualify as a boatmaster who have neither completed an approved training programme based on the standards of competence for the operational level nor passed an assessment of competence by an administrative authority aimed at verifying that the standards of competence for the operational level set out in Annex II of the standards are met, are required to demonstrate the following additional competence:

0.1 Navigation; the boatmaster shall be able to:

COLUMN 1 **COMPETENCE**	**COLUMN 2** **KNOWLEDGE AND SKILLS**
1. demonstrate mooring, unmooring and hauling (towage) operations;	1. Knowledge of equipment, material and procedures used for mooring, unmooring and hauling (towage) operations. 2. Ability to use materials available on board such as winches, bollards, ropes and wires considering relevant work safety measures including the use of personal protective and rescue equipment. 3. Ability to communicate with the wheelhouse using intercom communication systems and hand signals. 4. Knowledge of the effects of water movement around craft and local effects on sailing circumstances including the effects of trim, shallow water relating to craft’s draught. 5. Knowledge of the water movement affecting the craft during manoeuvring including the interaction effects when two craft pass or overtake each other in narrow fairways and the interaction effects on a craft moored alongside when another craft proceeds in the fairway and passes at a short distance.
2. demonstrate coupling operations of push barge combinations;	1. Knowledge of equipment, material and procedures used for coupling operations. 2. Ability to connect and disconnect push/barge combinations using the required equipment and materials. 3. Ability to use equipment and materials available on board for coupling operations considering relevant work safety measures including the use of personal protective and rescue equipment. 4. Ability to communicate with deck crew members involved in coupling operations of push barge combinations.
3. demonstrate anchoring operations;	1. Knowledge of equipment, materials and procedures used for anchoring operations. 2. Ability to demonstrate anchor manoeuvres: prepare anchor equipment for anchoring operations, presenting anchor, giving sufficient amount of cable/chain to veer initially and to determine when the anchor holds the craft at its position (anchor bearing) and to secure anchors on the completion of anchoring and to use dragging anchors in various manoeuvres and to handle the anchor signs. 3. Ability to use equipment and materials available on board for anchoring operations considering relevant work safety measures including the use of personal protective and rescue equipment. 4. Ability to communicate with the wheelhouse using intercom communication systems and hand signals.
4. take appropriate actions for safety of navigation;	1. Ability to immediately warn the craft’s crew and to use personal protective and rescue equipment. 2. Ability to secure the water tightness of the craft. 3. Ability to demonstrate and to execute the work according to the checklist on deck and in the living quarters such as waterproofing and securing of the hatches and holds.
1. describe the various types of locks and bridges in relation to their operation;	1. Knowledge of the shape, layout and facilities of locks and bridges, lockage (locking process), types of lock gates, bollards and stairs, etc. 2. Ability to explain and demonstrate the applicable procedures to deck crew member while passing locks, weirs and bridges.
6. respect the general provisions, signals, signs and marking system.	1. Knowledge of police regulations applying to the relevant inland waterways. 2. Ability to handle and maintain the craft´s day and night marking system, signs and sound signals. 3. Knowledge of buoyage and marking system according to SIGNI and IALA part A.

0.2 Operation of the craft; the boatmaster shall be able to:

1. distinguish various types of craft;	1. Knowledge of the most common types of craft including convoys used in European IWT and their corresponding construction, dimensions and tonnages. 2. Ability to explain the characteristics of the most common types of craft including convoys used in European IWT.
2. apply knowledge of the documentation required for the craft’s operation.	1. Knowledge of the craft´s obligatory documentation. 2. Ability to explain the importance of documentation in relation to international and national requirements and legislation.

0.3 Cargo handling, stowage and passenger transport; the boatmaster shall be able to:

[192] Directive (EU) 2017/2397 of the European Parliament and of the Council of 12 December 2017 on the recognition of professional qualifications in inland navigation and repealing Council Directives 91/672/EEC and 96/50/EC (OJ L 345, 27.12.2017, p. 53).

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
1. explain European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN), labelling and passenger transport safety procedures;	1. Ability to explain ADN labelling of dangerous goods. 2. Ability to explain the passenger transport safety procedures including application of Regulation (EU) No 1177/2010.[193] 3. Ability to communicate effectively with passengers.
2. explain and demonstrate the use of the ballast system;	1. Knowledge of the function and use of the ballast system. 2. Ability to explain the use of the ballast system for example by filling or emptying the ballast tanks.
3. check the amount of cargo.	1. Knowledge of manual and technical methods of determination of the cargo weight on various types of craft. 2. Ability to use methods to determine the amount of cargo loaded or discharged. 3. Ability to calculate the amount of liquid cargo using the soundings and/or tank tables.

0.4 Marine engineering and electrical, electronic and control engineering, the boatmaster shall be able to:

1. operate machinery including pumps, piping systems, bilge and ballast systems;	1. Knowledge of procedures to follow for safe operation of machinery and of the bilge and ballast system as well as of correct waste disposal. 2. Ability to operate and control the machinery in the engine room following procedures. 3. Ability to explain safe function, operation and maintenance of the bilge and ballast system including: reporting incidents associated with transfer operations and ability to correctly measure and report tank levels. 4. Ability to prepare and operate shut-off-operations of the engines after operation. 5. Ability to operate pumping bilge, ballast and cargo pumping systems. 6. Ability to explain the necessity to collect, store and deliver waste products in a correct and safe manner. 7. Ability to use hydraulic and pneumatic systems.
2. prepare, start, connect and change generators and control their systems and shore supply;	1. Knowledge of the power installation. 2. Ability to use switchboard. 3. Ability to use shore supply.
3. use required tools and materials;	1. Knowledge of characteristics and limitations of processes and materials and tools used for maintenance and repair of engines and equipment. 2. Ability to apply safe working procedures.
4. perform the daily maintenance work on the main engines, auxiliary machinery, and control systems;	Ability to maintain and to take care of the engine room, main engine, main machinery, auxiliary equipment and control systems.
5. perform the daily maintenance work on machinery including pumps, piping systems, bilge- and ballast systems.	Ability to maintain and to take care of pumps, piping systems, bilge- and ballast systems.

0.5 Maintenance and repair, the boatmaster shall be able to:

1. protect health and environment when performing maintenance and repair;	1. Knowledge of applicable cleansing and preserving procedures and rules of hygiene. 2. Ability to clean all accommodation spaces, the wheelhouse and keeping the household in a proper way complying with the rules of hygiene including responsibility for their own accommodation space. 3. Ability to clean the engine rooms and engines using the appropriate cleansing materials. 4. Ability to clean and to preserve the outer parts, the hull and the decks of the craft in the correct order using the appropriate materials according to environmental rules. 5. Ability to take care of the craft and household waste disposal according to environmental rules.
2. maintain technical devices according to technical instructions;	1. Knowledge of technical instructions for maintenance and repair programmes. 2. Ability to maintain and take care of all technical equipment according to technical instructions. 3. Ability to use maintenance programmes (including digital) under supervision.
3. safely handle wires and ropes;	1. Knowledge of characteristics of different types of ropes and wires. 2. Ability to use and store them according to safe working practices and rules.
4. make knots and splices according to their use and maintain them.	1. Knowledge of procedures to follow in order to ensure safe towage and coupling with means available on board. 2. Ability to splice wires and ropes. 3. Ability to apply knots according to their use.

[193] Regulation (EU) No 1177/2010 of the European Parliament and of the Council of 24 November 2010 concerning the rights of passengers when travelling by sea and inland waterway and amending Regulation (EC) No 2006/2004 (OJ L 334, 17.12.2010, p. 1).

	4. Ability to maintain wires and ropes.

0.6 Communication, the boatmaster shall be able to:

1. present facts using technical terms.	1. Knowledge of the required technical and nautical terms as well as terms related to social aspects in standardised communication phrases. 2. Ability to use required technical and nautical terms as well as terms related to social aspects in standardised communication phrases.

0.7 Health and safety and environmental protection, the boatmaster shall be able to:

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
1. apply rules for the safety at work and prevention of accidents;	1. Knowledge of safe working practices. 2. Knowledge of the nature of on board hazards. 3. Ability to prevent dangers related to on board hazards, for example: • movements of the craft, • provision of safe embarkation and of disembarkation the craft (e.g. gangplank, ship´s boat), • safely stow movable objects, • working with machinery, • recognizing electric hazards, • fire precautions and firefighting, • professional use of hand tools, • professional use of portable power tools, • compliance with health and hygiene and • removal of slip, fall and tripping hazards. 4. Knowledge of the relevant health and safety working instructions during activities that take place on board. 5. Knowledge of applicable regulations concerning safe and sustainable working conditions. 6. Ability to prevent activities which might be hazardous to personnel or craft, for example: • loading/unloading cargoes, • mooring and unmooring, • working aloft, • working with chemicals, • working with batteries, • during presence in engine-room, • lifting loads (manually and mechanically) and • entry into and working in enclosed spaces.
2. use personal protective equipment to prevent accidents;	1. Knowledge of procedures to use the required equipment for safe working on board. 2. Ability to use personal protective equipment, for example: • eye protection, • respiratory protection, • ear protection, • head protection and • protective clothing.
3. swim and assist in the case of rescue operations;	1. Ability to use swimming skills for rescue operations. 2. Ability to use rescue equipment in the case of rescue operations. 3. Ability to rescue and transport a casualty.
4. use emergency escape routes ;	1. Knowledge of procedures to follow in an evacuation situation (according to local features on board). 2. Ability to keep escape routes free.
5. use internal emergency communication and alarm systems;	Ability to use emergency communication and alarm systems and equipment.
6. distinguish the elements of a fire and types and sources of ignition;	1. Knowledge of the possible causes of fire during different activities as well as classification of fires according to the European standard EN or equivalent. 2. Knowledge of the elements of the combustion process. 3. Ability to apply the basics of firefighting procedures.
7. distinguish and use different types of fire extinguishers.	1. Knowledge of different characteristics and classes of fire extinguishers. 2. Ability to apply various methods of firefighting and extinguish equipment and fixed installations for example: • classes of fire extinguishers, • use of different types of portable extinguishers and • influence of wind while approaching the fire.

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
8. Perform medical first aid	1. Knowledge of general principles of first aid including appreciation of body structure and functions on board a craft after assessment of a situation. 2. Ability to maintain physical and mental condition and personal hygiene in the case of first aid. 3. Knowledge of relevant measures in the case of accidents in accordance with recognized best practices. 4. Ability to assess needs of casualties and threats to own safety. 5. Ability to perform required measures in cases of emergency, including to: a) position casualty, b) apply resuscitation techniques, c) control bleeding, d) apply appropriate measures of basic shock management, e) apply appropriate measures in the event of burns and scalds, including accidents caused by electric current, and to f) rescue and transport a casualty. 6. Ability to improvise bandages and materials in emergency kit.

B. Navigation

1.1 The boatmaster shall be able to plan a journey and conduct navigation on inland waterways including being able to choose the most logical, economic and ecological sailing route to reach the loading and unloading destinations taking into account the applicable traffic regulations and agreed set of rules applicable in inland navigation.

The boatmaster shall be able to:

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
1. navigate on European inland waterways including locks and lifts according to navigation agreements with agent;	1. Knowledge of national and international waterways used by inland navigation, geographical location of rivers, canals, seaports, inland harbours and the relationship with cargo flows. 2. Knowledge of Conference of the European ministers of transport (CEMT) classification of inland waterways, dimensions of the waterway in relation to craft dimensions using modern information systems. 3. Ability to calculate with water levels, depth and (air) draught using relevant information sources. 4. Ability to calculate distances and sailing time using information sources concerning distances, locks, restrictions and sailing speed/time. 5. Knowledge of liability and insurance. 6. Ability to instruct crew members and shipboard personnel to perform tasks in a safe way.
2. respect and apply traffic regulations applicable to navigation on inland waterways to avoid damage;	1. Knowledge of the rules of the road such as the agreed set of rules applicable in inland navigation for the inland waterway which is being sailed to avoid damage (e.g. collision). 2. Ability to apply relevant traffic regulations applicable to the waterway which is being sailed.
3. consider economic and ecological aspects of the craft operation in order to use the craft efficiently and respect the environment;	1. Knowledge of the environmental aspects when sailing on inland waterways. 2. Ability to perform environmentally sustainable and economical navigation with regard to e.g. fuel efficiency, bunkering, emission levels, shallow water effects, connection to shore electricity and waste management.
4. take account of technical structures and profiles of the waterways, and use precautions;	1. Knowledge of the influence of engineering structures, waterway profiles and protection works on navigation. 2. Ability to navigate passing through various types of locks and the locking procedures, various types of bridges, profiles of canals and rivers and to make use of "safe harbours" and overnight ports.
5. work with up-to-date charts/maps, Notices to Skippers/Mariners and other publications;	1. Knowledge of navigation aids. 2. Ability to use navigation aids as applicable e.g. satellite position system. 3. Ability to use nautical charts considering factors relating to accuracy and chart reading such as chart date, symbols, soundings, bottom description, depths and datums (WGS84) and to use international charts standards such as Inland ECDIS. 4. Ability to use nautical publications such as notices to Skippers/Mariners in order to collect necessary information required for safe navigation stations, finding height of tide at any time, information on ice, high/low water levels, berths and port directory.
6. use relevant traffic supervision tools and be able to apply them;	1. Knowledge of signals. 2. Ability to use day and night signs such as lights to guide craft. Knowledge of Inland AIS, Inland ECDIS, electronic reporting and Notices to Skippers/Mariners, RIS, surveilled and non-surveilled vessel traffic services (VTS) systems and its components. 3. Ability to use traffic information tools.

1.2 The boatmaster shall be able to apply knowledge of the applicable rules on the manning of craft, including knowledge on resting time and on deck crew members composition; The boatmaster shall be able to:

1. ensure safe manning of craft in accordance with applicable rules;	1. Knowledge of minimum manning requirements and mandatory professional qualifications of crew members and shipboard personnel. 2. Knowledge of requirements of medical fitness and medical checks of crew members. 3. Knowledge of administrative procedure to record data in service record books. 4. Knowledge of applicable modes of exploitation and minimum resting time. 5. Knowledge of administrative procedure to record data in the logbook. 6. Knowledge of working time rules. 7. Knowledge of specific authorisation requirements. 8. Knowledge of specific manning requirements with respect to vessels covered by ADN, passenger vessels and for LNG craft where applicable. 9. Ability to instruct crew members when to take up and to end duty.

1.3 The boatmaster shall be able to sail and manoeuvre ensuring the safe operation of the craft in all conditions on inland waterways, including in situations that involve high traffic density or where other craft carry dangerous goods and require basic knowledge of the European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN). The boatmaster shall be able to:

COLUMN 1 **COMPETENCE**	**COLUMN 2** **KNOWLEDGE AND SKILLS**
1. navigate and manoeuvre taking into account geographical, hydrological, meteorological and morphological characteristics of the main inland waterways;	1. Knowledge of the hydrological and morphological characteristics of the main waterways, e.g. catchment area and watershed, types of rivers by water source, the slope and course of a river, flow velocity and current pattern, human intervention in the course of a river. 2. Knowledge of the meteorological effects on the main inland waterways, e.g. weather forecast and warning services, scale of Beaufort, district division for wind and storm warnings with factors such as air pressure, wind, high and low pressure areas, clouds, fog, types and passage of fronts, ice warning and high water warning. 3. Ability to apply geographical, hydrological, meteorological and morphological information.
2. give order to moor and unmoor craft and to haul towage operations;	1. Knowledge of technical requirements and documents on mooring and hauling operations. 2. Ability to initiate procedures of mooring and unmooring manoeuvre and to ensure that equipment on different types of craft complies with requirements of craft certificate. 3. Ability to communicate with deck personnel, e.g., to use communication systems and hand signals.
3. provide safe access to craft;	1. Knowledge of technical requirements on facilities to access craft. 2. Ability to organise safe access to craft whether sailing, moored or at anchor and to use e.g. stairway, gangplank, ship's boat, fall protection and illumination.
4. use modern electronic navigation aids;	1. Knowledge of functions and operation of navigation aids. 2. Knowledge of operating principles, limitations and sources of error of navigation aids. 3. Ability to use nautical sensors and indicators providing navigation information, e.g. (D) GPS, position, heading, course, speed, distance, depth, Inland ECDIS, Radar. 4. Ability to use River Information Services (RIS) and technologies, e.g. Inland AIS, Inland ECDIS, Electronic Reporting and Notices to Skipper, FIS (Fairway Information Services), TIS (Traffic Information Services), TMS (Traffic Management Services), CAS (Calamity Abatement Services), ITL (Information for Transport Logistics), ILE (Information for Law Enforcement), ST (Statistics), WCHD (Waterway Charges and Harbour Dues) distance, depth, also in connection with Radar. 5. Ability to detect misrepresentation of information and apply methods of correction.
5. respect technical requirements for inland navigation;	1. Knowledge of structure and content of the applicable technical requirements and of the content of the craft certificate. 2. Ability to initiate checks and certification procedures.

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
6. consider effects of current, waves, wind and water-levels in relation with interactions of crossing, meeting and overtaking craft as well as ship-shore (canal effect);	1. Knowledge of the influence of waves, wind and current on sailing, manoeuvring or stationary craft, including the effect of wind e.g. cross wind when manoeuvring, also at nautical superstructures or when entering or leaving ports, locks and secondary waterways. 2. Knowledge of the influence of current on sailing, manoeuvring, and stationary craft on waterways used by inland navigation such as the effect of current, e.g. when manoeuvring upstream and downstream or with empty or loaded craft and when e.g. entering and leaving ports, locks or secondary waterways. 3. Knowledge of the influence of water movement during sailing, manoeuvring and when stationary such as the influence of water movement regarding draught subject to water depth and the reaction to shallow water effects e.g. by decreasing sailing speed. 4. Ability to respect interaction effects when sailing, manoeuvring and when stationary in a narrow fairway and to recognise the interaction effects relating to empty or loaded craft. 5. Knowledge of the effect of cargo handling and stowing conditions during sailing, manoeuvring and when stationary relating to stability. 6. Ability to take into account trim, angle of heel, downflooding, lever principle, points of gravity.
7. use of propulsion and manoeuvring systems as well as appropriate communication and alarm systems;	1. Knowledge of propulsion, steering and manoeuvring systems and their influence on manoeuvrability. 2. Ability to use propulsion, steering and manoeuvring systems. 3. Knowledge of anchoring devices. 4. Ability to use anchor in various circumstances. 5. Knowledge of communication and alarm systems. 6. Ability to give instructions if necessary in the case of an alarm.
8. sail and manoeuvre also in situations that involve high traffic density or where other craft carry dangerous goods, requiring basic knowledge of the ADN.	1. Basic knowledge of structure of ADN, ADN documents and instructions and visual signals required by ADN. 2. Ability to find instructions in ADN and to identify visual signs for craft subject to ADN

1.4 The boatmaster shall be able to respond to navigational emergencies on inland waterways. The boatmaster shall be able to:

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
1. take precautions in an emergency when intentionally beaching a craft in order to prevent greater damage;	1. Knowledge of shallow places and banks of sandy character that can be used to beach the craft. 2. Ability to adequately use machines or anchoring devices if beaching becomes necessary.
2. refloat a grounded craft with and without assistance;	1. Knowledge of measures to take in the event of running aground including the sealing of leaks and the actions to be taken to redirect the craft into the fairway. 2. Ability to seal leaks, to redirect the craft with the assistance of other craft, e.g. tug or push vessels.
3. take appropriate actions if collision is imminent;	1. Knowledge of rules applicable if collision or accident is imminent. 2. Ability to navigate the craft when in an unavoidable collision situation in such a way that damage will be minimal to persons, e.g. for instance passengers and crew members, the colliding craft and other craft, the cargo and the environment.
4. take appropriate actions after a collision and assessment of damage.	1. Knowledge of rules applicable after a collision or accident. 2. Ability to take the appropriate measures in the event of damage, collision and running aground, including assessment of the damage, communication with the competent authority and obtaining permission to sail to a position of recovery.

C. Operation of the craft

2.1 The boatmaster shall be able to apply knowledge of inland waterway shipbuilding and construction methods to the operation of various types of craft and have basic knowledge of the technical requirements for inland waterway vessels, as referred to in Directive (EU) 2016/1629[194]. The boatmaster shall be able to:

1. respect the principles of inland waterway shipbuilding and construction;	1. Knowledge of importance and impact of craft dimensions and dimensions of inland waterway craft according to applicable rules. 2. Ability to operate craft according to their dimensions and applicable construction legislation. 3. Ability to supervise the compliance of craft with the applicable legislation taking into account construction work.
2. distinguish construction methods of craft and their behaviour in the water, especially in terms of stability and strength;	1. Knowledge of craft features as laid down in construction drawings of various types of craft and of the effect of the construction to the craft behaviour and its stability and strength. 2. Knowledge of the craft's behaviour in various conditions and environments. 3. Ability to supervise the craft's stability and to give instructions accordingly.
3. understand structural parts of craft and damage control and analysis;	1. Knowledge of key elements of craft and different types of craft including basic knowledge on the technical requirements for inland navigation vessels, as referred to in Directive (EU) 2016/1629. 2. Ability to monitor the craft's core elements for the different types of transport and give instructions accordingly. 3. Knowledge of the longitudinal and transversal structure and local reinforcements in order to prevent and analyse damage. 4. Ability to understand and control the functions of the equipment and usage of different holds and compartments in order to prevent and analyse damage.
4. take action to protect the craft's watertight integrity.	1. Knowledge of the craft's water tightness. 2. Ability to supervise the craft´s watertight integrity and give instructions accordingly.

2.2 The boatmaster shall be able to control and monitor the mandatory equipment as mentioned in the applicable craft certificate. The boatmaster shall be able to:

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
1. understand functionalities of craft equipment;	1. Knowledge of mandatory equipment of the craft. 2. Ability to use and control all equipment in relation to their functionalities according to applicable legislation, and give instructions and supervise accordingly.
2. respect specific requirements for transport of cargo and passengers.	1. Knowledge of the specific requirements relating to craft construction and equipment needed for the transport of different cargoes and passengers with different types of craft according to applicable legislation. 2. Ability to give instructions and supervise accordingly. 3. Ability to give instructions and supervise the correct application of the requirements of the certificate.

D. Cargo handling, stowage and passenger transport

3.1 The boatmaster shall be able to plan and ensure safe loading, stowage, securing, unloading and care of cargoes during the voyage. The boatmaster shall be able to:

1. understand relevant national, European and international regulations, codes and standards concerning the operation of transporting cargoes;	1. Knowledge of the national, European and international regulations involving loading, unloading and transport operations. 2. Apply relevant rules and standards for logistics and multimodal transport.
2. compose stowage plans including knowledge of loading cargoes and ballast systems in order to keep hull stress within acceptable limits;	1. Knowledge of the operational and design limitations of dry cargo (e.g. container) craft and tanker vessels (N, C, G). 2. Ability to interpret limits for bending moments and shear forces. 3. Knowledge of use of stowage and stability software. 4. Ability to compose stowage plans, including the use of stowage and stability software.

[194] Directive (EU) 2016/1629 of the European Parliament and of the Council of 14 September 2016 laying down technical requirements for inland waterway vessels, amending Directive 2009/100/EC and repealing Directive 2006/87/EC (OJ L 252, 16.9.2016, p. 118).

3. control loading and unloading procedures with regard to safe transport;	1. Knowledge of stowage plans and available ship borne data and its implementation. 2. Ability to stow and secure cargo including necessary cargo-handling gear and securing and lashing equipment. 3. Knowledge of the various methods of determination of the cargo weight on cargo vessels and tank vessels and other craft. 4. Knowledge of determination of the amount of loaded or discharged cargo and of calculation of the amount of dry and liquid cargo. 5. Knowledge of the possible detrimental effects of inadequate cargo handling. 6. Ability to use the technical means for handling cargoes in/from craft and ports, and labour safety measures during their use.
4. differentiate various goods and their characteristics in order to monitor and ensure safe and secure loading of goods as laid down in the stowage plan.	1. Ability to establish procedures for safe cargo handling in accordance with the provisions of the relevant safe working regulations. 2. Knowledge of effective communication and working relationships with all partners involved in loading and unloading procedures.

3.2 The boatmaster shall be able to plan and ensure the stability of the craft. The boatmaster shall be able to:

1. respect the effect on trim and stability of cargoes and cargo operations;	1. Knowledge of watertight integrity and stability for all types of cargo and craft. 2. Ability to use instruments to correct trim and stability.
2. check the effective tonnage of the craft, use stability and trim diagrams and stress calculating equipment, including ADB (Automatic Data-Base) to check a stowage plan.	1. Knowledge of dedicated software to calculate stability, trim and stress. 2. Ability to determine stability, trim and stress tables, diagrams and stress-calculating equipment.

3.3 The boatmaster shall be able to plan and ensure safe transport of and care for passengers during the voyage including providing direct assistance to disabled persons and persons with reduced mobility in accordance with the training requirements and instructions of Annex IV of Regulation (EU) No 1177/2010. The boatmaster shall be able to:

1. understand relevant national, European and international regulations, codes and standards concerning the transportation of passengers;	1. Knowledge of the applicable regulations and conventions regarding passenger transport. 2. Ability to ensure safe embarking and disembarking of passengers and their care during the voyage, with special attention to persons needing assistance, and direct assistance to disabled persons and persons with reduced mobility in accordance with the training requirements and instructions of Annex IV of Regulation (EU) No 1177/2010. 3. Ability to control proceedings in the case of leakage, fire, man over board, collision and evacuation, including crisis and crowd management.
2. arrange and monitor regular exercises on safety as laid down in the (safety) muster list in order to guarantee safe behaviour in potential situations of danger;	1. Knowledge of responsibilities under international and national regulations affecting the safety of the vessel, passengers and crew. 2. Ability to implement shipboard personnel management and training with respect to safety. 3. Apply medical first aid on board vessel.
3. respect impacts on stability of the passenger vessel in relation to weight distribution of passengers, behaviour and communication with passengers;	1. Knowledge of rules and regulations with regards to stability. 2. Ability to apply relevant measures regarding the watertight integrity, including influence on trim and stability of passenger vessels. 3. Knowledge of vessel's design relating to trim and stability, and actions to be taken in the event of partial loss of intact buoyancy/damage stability of passenger vessels. 4. Ability to use standardised communication phrases.
4. define and monitor on-board risk analysis of limited access for passengers as well as compile an effective on-board protection system in order to prevent unauthorised access;	1. Knowledge of and compliance with the limitation of the number of passengers according to the passenger vessel certificate. 2. Knowledge of safety and security systems preventing unauthorised access. 3. Ability to organise watchkeeping (i.e. night watch) systems with respect to safety and security.
5. analyse reports given by passengers (i.e. unforeseen occurrences, defamation, vandalism) in order to react appropriately.	1. Knowledge of passenger rights and complaints from passengers, and of risks connected to passenger transport for the environment. 2. Ability to prevent environmental pollution by passengers and crew.

	3. Ability to handle complaints and conflict management. 4. Ability to communicate with shipboard personnel and all interacting parties.

E. Marine engineering and electrical, electronic and control engineering

4.1 The boatmaster shall be able to plan the workflow of marine engineering and electrical, electronic and control engineering. The boatmaster shall be able to:

COLUMN 1 COMPETENCE	COLUMN 2 KNOWLEDGE AND SKILLS
1. use the functionality of the main engines and auxiliary equipment and their control systems;	1. Knowledge of operation of main engine and auxiliary equipment installations. 2. Knowledge of characteristics of fuels and lubricants. 3. Knowledge of control systems. 4. Ability to use various systems of different propulsion systems and auxiliary machinery and equipment.
2. monitor and supervise crew members when operating and maintaining the main engines, auxiliary machinery and equipment.	1. Ability to manage the crew with respect to operating and maintaining technical equipment. 2. Ability to manage start up and shut down main propulsion, auxiliary machinery and equipment.

4.2 The boatmaster shall be able to monitor the main engines and auxiliary machinery and equipment. The boatmaster shall be able to:

1. give instructions to prepare main engines and auxiliary machinery and equipment;	1. Ability to instruct the crew in the preparation and operation of main and auxiliary machinery and equipment. 2. Ability to set up and monitor checklists and to give instructions to properly use such checklists. 3. Ability to instruct crew on principles to be observed during engine surveillance.
2. detect malfunctions, common faults and take actions to prevent damage;	1. Knowledge of methods to detect engine and machinery malfunction. 2. Ability to detect malfunctions, frequent sources of error or inappropriate treatment, and to respond adequately. 3. Ability to instruct actions to be taken in order to prevent damage or to take measures for damage control.
3. understand the physical and chemical characteristics of oil and other lubricants;	1. Knowledge of the characteristics of the materials used. 2. Ability to use oil and other lubricants according to their specifications. 3. Ability to understand machinery handbooks. 4. Knowledge of operational characteristics of equipment and systems.
4. evaluate engine performance.	Ability to use and interpret manuals to evaluate engine performance and operate engines appropriately.

4.3 The boatmaster shall be able to plan and give instructions in relation to the pump and the pump control system of the craft. The boatmaster shall be able to:

1. monitor routine pump works, ballast and loading pump systems.	1. Knowledge of pump systems and pumping operations. 2. Ability to ensure monitoring of safe operation of bilge, ballast and cargo pump systems including adequate instructions to the crew, taking into account free surface effects on stability.

4.4 The boatmaster shall be able to organise the safe use and application, maintenance and repair of the electro-technical devices of the craft. The boatmaster shall be able to:

1. prevent potential damage to electric and electronic devices on board;	1. Knowledge of electro-technology, electronics and electrical equipment and safety devices e.g. automation, instrumentation and control systems to prevent damage. 2. Ability to apply safe working practices.
2. test control systems and instruments to recognise faults and at the same time take actions to repair and maintain electric or electronic control equipment;	1. Knowledge of the craft´s electro-technical testing devices. 2. Ability to operate, test and maintain control systems and take appropriate measures.
3. give instructions before and follow-up activities to connect or disconnect technical shore-based facilities.	1. Knowledge of safety requirements for working with electrical systems. 2. Knowledge of the construction and operational characteristics of shipboard electrical systems and equipment in relation to shore-based facilities. 3. Ability to give instructions to guarantee safe shore connection at any time and to recognise dangerous situations with regard to shore-based facilities.

4.5 **The boatmaster shall be able to control the safe maintenance and repair of technical devices. The boatmaster shall be able to:**

COLUMN 1 COMPETENCE	**COLUMN 2 KNOWLEDGE AND SKILLS**
1. ensure appropriate use of tools to maintain and repair technical devices;	1. Knowledge of the maintenance and repair procedures for technical devices. 2. Ability to organise and instruct on safe maintenance and repair using appropriate procedures (control), equipment and software.
2. assess characteristics and limitations of materials as well as necessary procedures used to maintain and repair technical devices;	1. Knowledge of characteristics of maintenance and repair material for technical devices. 2. Ability to apply maintenance and repair procedures on devices according to manuals.
3. evaluate technical and internal documentation.	1. Knowledge of construction specifications and technical documentation. 2. Ability to set up checklists for maintenance and repair of technical devices.

F. Maintenance and repair

5.1 **The boatmaster shall be able to organise safe maintenance and repair of the craft and its equipment. The boatmaster shall be able to:**

1. ensure safe behaviour of crew members with regard to the use of materials and additives;	1. Knowledge of safe and effective maintenance and repair procedures. 2. Ability to monitor and supervise crew to apply precautions and contribute to the prevention of pollution of the marine environment. 3. Ability to apply and observe the applicable labour regulations and safe working rules and ensure they are respected.
2. define, monitor and ensure work orders so that crew members are able to perform maintenance and repair work independently;	1. Knowledge of cost effective and efficient maintenance work and of applicable legal requirements. 2. Ability to use (digital) maintenance planning programmes effectively. 3. Ability to control the maintenance and repair of the craft's inner and outer parts considering applicable legal requirements such as safety data sheets. 4. Ability to manage the hygiene of the craft. 5. Ability to organise the waste management taking into account environmental regulations such as the CDNI Convention. 6. Ability to elaborate the periodic programme of maintenance for the craft. 7. Ability to monitor and control technical documents of the craft and keep maintenance logs.
3. purchase and control material and tools with regard to health and environmental protection;	1. Ability to administer the craft's stocks. 2. Ability to organise a safe working system on board including the use of hazardous materials for cleaning and conservation work. 3. Ability to check the quality of the repairs.
4. ensure wires and ropes are being used according to the manufacturer's specifications and intended purpose.	Ability to instruct and supervise the crew in accordance with the working procedures and safety limitations when using ropes and wires according to the craft's certificate and datasheets.

G. Communication

6.1 **The boatmaster shall be able to perform human resources management, be socially responsible, and take care of organisation of workflow and training on board the craft. The boatmaster shall be able to:**

1. organise and stimulate teambuilding and coach the crewmembers regarding shipboard duties and, if necessary, take disciplinary measures;	1. Knowledge of human resource management. 2. Ability to give instructions to the crew in an appropriate and professional way. 3. Ability to explain given instructions to the crew. 4. Ability to give feedback to the crew about professional and social behaviour on board. 5. Ability to apply task and workload management, including: planning and co-ordination, personnel assignment, time and resource constraints, prioritisation. 6. Ability to recognize and prevent fatigue.
2. instruct crew on information- and communication systems;	1. Knowledge of information- and communication systems available on board. 2. Ability to instruct the crew on the use of the craft's communication, media and IT systems.
3. collect, save and manage data with regard to data protection laws.	1. Knowledge of the use of all the craft´s computer systems. 2. Ability to collect and store data in accordance with applicable legislation.

6.2 The boatmaster shall be able to ensure good communication at all times, which includes the use of standardised communication phrases in situations with communication problems. The boatmaster shall be able to:

COLUMN 1 COMPETENCE	**COLUMN 2 KNOWLEDGE AND SKILLS**
1. describe circumstances by using relevant technical and nautical terminology;	1. Knowledge of the correct use of relevant technical and nautical terms. 2. Ability to master communication.
2. retrieve, evaluate and use information with relevance to safety on board as well as nautical-technical issues.	1. Knowledge of procedures to follow in all distress, emergency and safety communication. 2. Ability to use the standard communication phrases.

6.3 The boatmaster shall be able to foster a well-balanced and sociable working environment on board. The boatmaster shall be able to:

1. ensure a good social working environment;	1. Ability to take the lead in organising team meetings to keep the social atmosphere on board well balanced. 2. Knowledge and awareness of gender-related and cultural differences. 3. Knowledge of relevant rules applying to the training and education of students, apprentices and trainees. 4. Ability to guide students, apprentices and trainees on various levels. 5. Ability to apply basic team working principles and practice including conflict management.
2. apply national, European and international social legislation;	1. Knowledge of the various national, European and international social laws. 2. Ability to instruct crew members in using relevant parts of applicable social legislation.
3. follow strict alcohol and drug prohibition and react appropriately in cases of infringement, take responsibility and explain consequences of misbehaviour;	1. Knowledge of applicable rules on alcohol and drugs. 2. Ability to communicate and ensure compliance with applicable legislation and awareness of company rules concerning alcohol and drugs. 3. Ability to react appropriately on violation of legislation or company rules.
4. organise provisioning and preparation of meals on board.	1. Knowledge of principles of healthy nutrition. 2. Ability to instruct crew members in planning and preparing meals. 3. Ability to instruct and supervise crew members regarding hygienic standards. 4. Ability to instruct crew members in planning purchasing possibilities.

H. Health and safety, passenger rights and environmental protection

7.1 The boatmaster shall be able to monitor the applicable legal requirements and take measures to ensure the safety of life. The boatmaster shall be able to:

1. apply national and international legislation and take appropriate measures for health protection and the prevention of accidents;	1. Knowledge of legislation for health protection and prevention of accidents. 2. Ability to apply safety procedures based on applicable legislation in the field of safety and working conditions.
2. control and monitor validity of the craft's certificate and other documents relevant to the craft and its operation;	1. Knowledge of legislation on periodic checks of equipment and construction parts. 2. Ability to check the validity of certificates and other documents relevant to the craft and its operation.
3. comply with safety regulations during all working procedures by using relevant safety measures in order to avoid accidents;	1. Knowledge of safe working practices and safe working procedures. 2. Ability to organise safe working procedures, to motivate and monitor crew members to apply safe working rules.
4. control and monitor all safety measures necessary for cleaning enclosed spaces before persons open, enter and clean those facilities.	1. Ability to organise safety control and monitor safety procedures if crew or other persons enter enclosed spaces (e.g. ballast tanks, cofferdams, tanks, double hull spaces) including keeping watch. 2. Ability to conduct a risk assessment before entering enclosed spaces. 3. Knowledge of precautions to take before entering an enclosed space and while work is being carried out in an enclosed space, for example: • hazards of enclosed spaces, • atmosphere tests prior to entry, • control of entry into enclosed spaces, • safeguards for enclosed space entry, • protective equipment (e.g. harnesses and respiratory equipment), and • work in enclosed spaces. 4. Ability to take appropriate actions in the event of an emergency.

7.2 The boatmaster shall be able to maintain safety and security for persons on board including direct assistance to disabled persons and persons with reduced mobility in accordance with the training requirements and instructions of Annex IV of Regulation (EU) No 1177/2010. The boatmaster shall be able to:

COLUMN 1 **COMPETENCE**	**COLUMN 2** **KNOWLEDGE AND SKILLS**
1. use life-saving appliances and apply life-saving procedures for victims and own personal safety;	1. Knowledge of available life-saving equipment. 2. Ability to use life-saving appliances and to apply life-saving procedures for victims and own personal safety.
2. organise crisis management training exercises for behaviour in emergency situations, e.g. fire, leakage warning, explosion, collision, "person over board" and evacuation;	1. Knowledge of emergency procedures. 2. Ability to instruct crew members on emergency procedures. 3. Ability to organise periodic training of the crew on board the vessel in preparation for an emergency situation including organisation of firefighting and abandon craft drills.
3. give instructions related to fire prevention, personal protection equipment, methods, firefighting material, respirators and possible application of these devices in emergencies;	1. Knowledge of the applicable fire prevention laws and regulation on the use of tobacco and possible ignition sources. 2. Ability to comply with relevant regulations on fire detection systems; fixed and mobile fire-extinguishing equipment and related appliances e.g. pumping, rescue, salvage, personal protective and communication equipment. 3. Ability to control the monitoring and maintenance of fire detection and extinguishing systems and equipment. 4. Ability to instruct crew and shipboard personnel to apply safe working rules and to maintain personal protection and personal safety equipment.
4. perform first aid;	Ability to act in compliance of first aid standards and practises.
5. establish an effective on-board system to control life-saving appliances and correct application of personal protection equipment.	1. Knowledge of legislation applicable to life-saving appliance and safe working condition regulations. 2. Ability to maintain and perform periodic checks of operational condition of life-saving, fire-fighting and other safety equipment and systems. 3. Ability to instruct on, to motivate and supervise the correct use of (personal) safety equipment by crew members and shipboard personnel.
6. organise assistance for disabled persons and persons with reduced mobility.	1. Knowledge of training requirements and instructions of Annex IV of Regulation (EU) No 1177/2010. 2. Ability to perform and organize direct assistance to disabled persons and persons with reduced mobility.

7.3 The boatmaster shall be able to set up emergency and damage control plans, and handle emergency situations. The boatmaster shall be able to:

1. initiate preparations for rescue plans of different types of emergencies;	1. Knowledge of different types of emergencies which may occur such as collision, fire, flooding, sinking. 2. Ability to organise shipboard contingency plans for response to emergencies and to assign specific duties to crew members including monitoring and control.
2. train on methods to prevent fire, recognition of origin of fire and firefighting according to the different skills of crew members;	1. Knowledge of fire-fighting procedures with particular emphasis on tactics and command. 2. Knowledge of the use of water for fire-extinguishing with regard to the effect on vessel stability, and ability to take appropriate measures. 3. Ability to communicate and coordinate during fire-fighting operations including communication with external organisations and to actively take part in rescue and fire-fighting operations.
3. train on the use of life saving appliances;	1. Knowledge of particular characteristics and facilities of rescue devices. 2. Ability to launch and recover a ship´s boat and instruct crew members and shipboard personnel on the use of a ship´s boat.
4. give instructions on rescue plans, escape routes and internal communication and alarm systems.	1. Knowledge of legislation applying to rescue plans and safety rota. 2. Ability to give instructions on rescue plans, escape routes and internal communication and alarm systems.

7.4 The boatmaster shall be able to ensure compliance with requirements for environmental protection. The boatmaster shall be able to:

1. take precautions to prevent environmental pollution and use relevant equipment;	1. Knowledge of procedures to prevent pollution of the environment. 2. Ability to take precautions to prevent pollution of the environment. 3. Ability to apply safe bunkering procedures. 4. Ability to take measures and give instructions in the event of damage, collision and running aground including the sealing of leaks.
2. apply environmental protection laws ;	1. Knowledge of environmental regulations. 2. Ability to motivate crew members and board personnel to take relevant measures for environmentally friendly behaviour/to behave in an environmentally friendly way.
3. use equipment and materials in an economical and environmentally friendly way.	1. Knowledge of procedures to make sustainable use of resources. 2. Ability to instruct crew in using equipment and materials in an economical and environmentally friendly way.
4. instruct and monitor sustainable waste disposal.	1. Knowledge of legislation on waste disposal. 2. Ability to ensure sustainable waste disposal and to instruct crew members and board personnel accordingly.

3.2. Investment analysis of the AV (scenario 1)

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 (2011) and calculated with Excel. The values correspond with scenario 1 as elaborated in chapter 4.4. The first 13 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 11	YEAR 12		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	1,379,619	1,057,142		
inter		185,850	176,908	167,564	157,799	147,595	136,931	125,788	114,143	101,974	89,258	75,969	62,083		
Principal		198,710	207,652	216,996	226,761	236,965	247,629	258,772	270,417	282,586	295,302	308,591	322,477		
pay back loan		384,560	384,560	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	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	81,101	82,561		136,055
other(admin)	index	300	305	311	316	322	328	334	340	346	352	359	365		602
fixed costs		**452,710**	**453,937**	**455,186**	**456,457**	**457,751**	**459,068**	**460,409**	**461,775**	**463,165**	**464,580**	**466,020**	**467,486**		**136,656**
operational costs		**388,241**	**396,091**	**404,607**	**413,207**	**421,892**	**430,665**	**439,525**	**448,476**	**457,518**	**466,654**	**475,885**	**485,212**		**793,645**
Fuel	forecast	134,082	137,357	141,216	145,075	148,934	152,793	156,652	160,511	164,370	168,229	172,088	175,947		283,999
Compliance	index	6,750	6,872	6,995	7,121	7,249	7,380	7,513	7,648	7,785	7,926	8,068	8,214		13,535
SCC	index	190,960	194,397	197,896	201,459	205,085	208,776	212,534	216,360	220,254	224,219	228,255	232,364		382,918
Charterers provision	index	10,861	11,056	11,255	11,458	11,664	11,874	12,088	12,306	12,527	12,753	12,982	13,216		21,779
Fairway, port dues	Index	19,002	19,344	19,692	20,047	20,407	20,775	21,149	21,529	21,917	22,311	22,713	23,122		38,103
Maintenance en repair		26,586	27,065	27,552	28,048	28,553	29,067	29,590	30,122	30,665	31,217	31,779	32,351		53,311
revenu	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**	**1,298,213**	**1,321,581**		**2,177,868**
ebitda		629,705	640,178	650,315	660,703	671,348	682,255	693,426	704,869	716,587	728,585	740,869	753,443		1,247,567
EBIT		484,205	494,678	504,815	515,203	525,848	536,755	547,926	559,369	571,087	583,085	595,369	607,943		1,102,067
EBT		298,355	317,770	337,251	357,405	378,254	399,823	422,139	445,226	469,112	493,827	519,399	545,860		1,102,067
TAX		76,080	81,031	85,999	91,138	96,455	101,955	107,645	113,533	119,624	125,926	132,447	139,194		281,027
EAT		222,274	236,739	251,252	266,266	281,799	297,868	314,493	331,693	349,489	367,901	386,952	406,666		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	532,452	552,166		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	147,892	167,606		966,540

3.3. Identified actors in the automation of the inland navigation

3.4. 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	
l 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	5,7	5,4	5,4	5,2	1,4	1,4	1,1	1,1	1,5	1,4		
			CCC € per 1000 tkm	3,1	2,9	3,1	2,9	3,1	2,9	3,1	2,9	2,8	2,6	158	189
			U&D €ct / vkm	1	1,1	1	1	0,9	0,9	0,9	0,9	0,8	0,8		
		400-650	Air pollutants € per 1000	5,7	5,4	5,4	5,2	1,4	1,4	1,1	1,1	1,5	1,4		
			CCC € per 1000 tkm	3,1	2,9	3,1	2,9	3,1	2,9	3,1	2,9	2,8	2,6	248	297
			U&D €ct / vkm	1	1	1	1	0,9	0,8	0,9	0,8	0,8	0,8		
		650-1000	Air pollutants € per 1000	5,8	5,5	5,6	5,3	1,5	1,4	1,1	1,1	1,5	1,4		
			CCC € per 1000 tkm	3,1	3	3,1	3	3,1	3	3,1	3	2,8	2,7	608	729
			U&D €ct / vkm	1,2	1,1	1,2	1	1	0,9	1	0,9	0,9	0,8		
		1000-3000	Air pollutants € per 1000	4,4	4,2	4,2	4	1,1	1,1	0,9	0,8	1,1	1,1		
			CCC € per 1000 tkm	2,3	2,2	2,3	2,2	2,3	2,2	2,3	2,2	2	1,9	1356	1627
			U&D €ct / vkm	0,8	0,7	0,8	0,7	0,7	0,7	0,7	0,7	0,6	0,6		
	Pushed convoys	3000-6400	Air pollutants € per 1000	4,2	4,1	4	3,9	1,1	1	0,8	0,8	1,1	1,1		
			CCC € per 1000 tkm	2,3	2,2	2,3	2,2	2,3	2,2	2,3	2,2	2	1,9	2475	2970
			U&D €ct / vkm	0,7	0,9	0,7	0,9	0,7	0,7	0,7	0,7	0,6	0,6		
		6400-12000	Air pollutants € per 1000	2,8	3	2,7	2,9	0,7	0,8	0,5	0,6	0,7	0,8		
			CCC € per 1000 tkm	1,4	1,5	1,5	1,6	1,4	1,5	1,5	1,6	1,3	1,4	6240	7020
			U&D €ct / vkm	0,6	0,6	0,6	0,6	0,5	0,5	0,5	0,5	0,4	0,5		
		9600-18000	Air pollutants € per 1000	2,2	1,8	2,1	1,7	0,6	0,5	0,4	0,4	0,6	0,5		
			CCC € per 1000 tkm	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,2	1,1	1,1	9009	10530
			U&D €ct / vkm	0,4	1	0,4	1	0,3	0,6	0,3	0,5	0,3	0,5		
		Average	Air pollutants € per 1000	4,4	4,2	4,2	4,0	1,1	1,1	0,8	0,8	1,1	1,1		
			CCC € per 1000 tkm	2,4	2,3	2,4	2,3	2,4	2,3	2,4	2,3	2,1	2,0	2543	2957
			U&D €ct / vkm	0,8	0,9	0,8	0,9	0,7	0,7	0,7	0,7	0,6	0,7		

Table 73: Marginal costs of up- and downstream processes (well-to-tank emission and climate change costs) in €ct/vkm

Source: CE Delft (2011), RICARDO-AEA (2014); CCC= marginal climate change costs, evaluated at the central value for CO_2: €90/tons. Averages are own calculations, EU average (prices of 2010)

3.5. Accident of the TMS Waldhof

In case of the calamity with the double-hulled TMS Waldhof, 13th January, 2011 (WSV, 2013), loading 2,426 tonnes of sulphuric acid, the following factors were identified as causes: Crossway acceleration and heeling moments (stability of cargo[195], starboard low pressure area in river); together with unusual current conditions; passing of the MS Acropolis; upstream traffic density; and the absence of AIS.

Figure 64: Tanker accident of the TMS Waldhof
Source: Pauli G., 2011. Picture taken on 19th January 2011 by H. Weinandt.

As a consequence, two people died and two were injured. Thirty km of the Rhine between Bingen, and St. Goarshausen, near the famous Loreley cliff, was partially or fully closed for a 32 days - period. A number of 475 vessels were not able to continue their trip. Downstream traffic restarted on 2 February. Between 343 and 523 tonnes of sulphuric acid were leaked in the Rhine. Another 1,150 to 1,330 tonnes were drained into the Rhine under controlled conditions as part of the salvage operation. The rest of the cargo was pumped into another tanker (around 550 tonnes). The area is UNESCO world heritage and endured damage (Pauli G., 2011). Mammoet Maritime GmbH recovered the wreck with explosion hazard and difficult conditions, deploying 25 operatives and engineers from bases in the Netherlands and Germany together with sheerlegs, a crane pontoon, a tug and a pusher tug, winch pontoons and specialized sulphuric acid equipment (Mammoet Maritime, 2011). BASF, the manufacturers of the acid, lost almost 2000 tonnes of their product on its way to Antwerp.

Next to the clear environmental damage and human loss, other stakeholders also experienced damage. These stakeholders, identified by NEA (de Leeuw van Weenen R.P., Quispel M. & Visser J., 2011: 7-8), were: transport operators; insurance companies; shippers/forwarders/brokers; suppliers; ports; industries/consumers; terminals; and authorities. The image of inland navigation is possible also badly affected in the long run.

The NEA – study tried to explain the societal impact (queuing of ships; alternative transport; hindered industrial production /consumption; and direct damage) and the breakdown of the damage over different parties. The average damage for the waiting ships was approximately 19 million euro or on average per ship 40,000 euro. An indirect cost was the need for alternative and more expensive transport alternatives during the closure. Assuming that goods are shifted to other modes, total average value of the transported goods is 3,188,544,600 euro with an average transport cost between

[195] If cargo can move freely in a ship - as in the case of the TMS Waldhof where the centre tanks were not 100% liquid-filled - an inclination of the ship will lead to a shift of the cargo and thus of the vertical center of gravity VCGϕ to the side of the heeling. In this course, the righting arm hϕ is reduced. If the position of VCGϕ shifts to the side more than VCBϕ the ship capsizes (BAW, 2011). For 3D – simulation of the causes of this heeling moment, please visit https://www.youtube.com/watch?v=1CyFSbHDQvo.

25 and 30 euro for each tonnes or between 20 and 34 million euro extra transport cost (NEA, 2011:18-21). Looking at the supply chain, the Waldhof calamity caused stock piling and less production with a cost between millions to tenths of millions euro of damage.
The direct damage is comprised by the casualties, lost cargo, salvaging costs and the damage costs to the ship. According to the HEATCO research project, the fatalities in this accident can be reflected by 3-4 million euros (HEATCO, 2004, NEA, 2011:24)[196].
The loss of cargo is estimated as 10 ct/kg or 0.2426 million euro. Salvaging costs were not available in the NEA – study, but knowing that Mammoeth Maritime used 25 operators and engineers and a lot of material next to the damage experts and the ship-owner for a period of time, between 500,000 and a million euro can be added to the total costs. The total repair costs was not given by the owner, but in case of a total loss, a type C vessel, built in 1994, amount would rise up to 4.5-5.5 million euro.
The waiting 475 vessels also had other costs, such as the lack of sufficient berthing places, forcing vessels to anchor at unusual places and exposing themselves to a higher accident risk. In this regard, ADN - vessels were allowed to berth close to living quarters (NEA, 2011:30-31). Although an official report of the CCNR (CCNR, 2014:60), contests these number and estimates the number of waiting vessels around 200 and claims that enough berthing places were available.
NEA calculated a total cost of 50-55 million euros excluding the salvaging costs, the possible permanent modal shift cost, cost of negatively affected production and consumption.

The conclusions of the accident investigation of the capsized Waldhof led to new insights and regulation. The CCNR adjusted the Police Regulations for the Navigation of the Rhine (RPNR) and the Rhine Vessel Inspection Regulations (RVIR). Article 12 of the RPNR was changed with article 12.02 with the placement of new warning signs at Oberwesel – St. Goar (CCNR, 2013:75). Secondly, and more important, was the adding to article 4.07 of the RPNR protocol 16, that obliges the installation of AIS and ECDIS as explained in RVIR article 7.06.[197] Starting from the first of December 2014 all vessels, with some exceptions (small vessels), must have AIS and ECDIS. The European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways (ADN), was changed in 2013 with a new requirement for an approved computer loading instrument that went into force at the beginning of 2015 for type C - tankers. The stability software only found compliance mid-2014 with just over 700 ships. The sector, therefore, asked for postponing the requirements and discussions inside the Inland Transport Committee are still going on (UNECE, 2015).
The stability issues of the Waldhof also fed the European debate concerning the modernisation of training. It is generally accepted that most accidents are caused by human error. For example, sufficient knowledge of stability of cargo is a lifesaving element of training for boatmasters (EC, 2014:3). The German government acknowledged the importance of an inland shipping accident casuistry system and developed the HAVARIS – system but which is not yet operational.

[196] Based on the willingness-to-pay and the Value of a Statistical Life. An interesting paper can be found in the NBER Working Paper Series, Ashenfelter O. (2006), Measuring the Value of a Statistical Life: Problems and Prospects, National Bureau of Economic Research, Cambridge, 31 pag. http://www.nber.org/papers/w11916.pdf
[197] Automated Identification System and Electronic Chart Display and Information System

3.6. Legal context in a member state: case of Belgium

The law of the inland navigation chartering (Wet op de binnenbevrachting) of 5 May 1936 still applies on the Belgian inland waterways. Article 3 describes the sender of the goods as the person that loads the vessel. The addressed person or consignee is the one that has to receive the goods. The skipper or the one that is responsible for the transport is the skipper, the vessel owner or the serviced operator (*zetkapitein*). The law describes in article 6 that the skipper has to decide if the designated area is suitable and safe to avoid average on the vessel unless the consignee takes full responsibility for possible damage. If dangers are not visible, the consignee or the sender of the goods are liable. Also article 29 when a ship has to take in account the depth of the river during the trip, could be relevant.

Article 3 does not give a problem for automation. The article does not mention that the skipper has to be on board in the definition. Article 6 raises some practical issues in scanning the destination for an AOS. The system should be able to know the dangers of the waterway and of the destination area. But as negotiations for the contract of the trip are expected to remain between humans, this does need to be automated. The VO/O still decides concerning the contract and can express the experience of the waterway and destination. An AV should decide if the area is safe through scanning and could even perhaps improve the findings in real-time situations, programmed with the knowledge of the limitations of the vessel according to the law. Article 8 obliges that the operations concerning loading, stowing and unloading is under the supervision of the skipper while facilitating the operations. An AOS would be obliged to fulfill these requirements and regulation has to indicate who is liable. Article 10 mentions that the skipper is required to check the quantity of loaded or unloaded goods. To replace the skipper to have unmanned vessels, the AV has to be able to scan the cargo. Article 30 indicates that the skipper is liable for the loss and damage of goods if the skipper cannot prove reasons beyond his or her control. Article 31 describes the obligation to prepare the ship and the cargo space with all necessary measures.

Article 32 is problematic for automated unmanned vessels. To avoid liability of damage on goods due to a ship accident, the skipper has to prove that the ship is in compliance with the technical requirements during the accident and that he or she was present on board of the vessel and that the vessel was manned complying to the crew regulation. Without crew on board, the liability cannot be avoided concerning damage to the cargo caused by an accident even if the AV made the steering error according this article.[198] In Belgium, insurances for inland navigation are mandatory but are not enforced as the rest of the law of 3th June 2014. The Law on chartering and pricing in inland navigation indicates to a mandatory insurance but does not describe which one (art.5, paragraph 1). The law is still not applied because of state reform and questions about conformity with EU directive 96/75/EC of 19 November 1996 on the systems of chartering and pricing in national and international inland waterway transport in the Community (the regulation that abolished the turn-by-turnabout system).

The decision to invest in automation technology also includes opportunity costs. Investments in vacuum or magnetic technology could discourage research in other (perhaps better) systems. Policy decisions tend to take time and when they are finally made, the preferred technology could already be obsolete. This hidden cost is difficult to predict. Optimal information stream and large awareness of sector developments could prevent or minimize these costs. The transaction costs can be relatively high in trying to avoid this, but a wrong decision can more expensive leading to bad policy. The Belgian case provides a few elements of liability challenges for automation and makes it also clear that certain aspects should be addressed on a higher policy level than MS with the necessary knowledge and ability to address those responsible to perform efficient enforcement and monitoring to address the challenge of liability and many more as described in this research. The remaining questions such as concerning liability invites more research within a multidisciplinary approach

[198] Belgian legislation, Wet op de binnenbevrachting (1936), https://www.binnenvaart.be/images/Reglementeringen/wetopderivierbevrachting5MEI1936.pdf

3.7. Minimum 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
1	L ≤ 70 m	boatmaster...............	1		2		2	2
		helmsman	-		-		-	-
		able boatman...........	-		-		-	-
		boatman...................	1		-		1	-
		apprentice	-		-		1 [1)]	2 [1) 3)]
2	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
3	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.

4. Annexes of the LNG case

4.1. Emission limits for the IWT Regulation (EU) 2016/1628

Emission limits for the IWT according to the Regulation (EU) 2016/1628 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
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Stage V	IWP-v-1 IWP-c-1	19 ≤ P < 75	all	5	($HC + NO_x \le 4{,}70$)		0,3	—	6
Stage V	IWP-v-2 IWP-c-2	75 ≤ P < 130	all	5	($HC + NO_x \le 5{,}40$)		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
		kW		g/kWh	g/kWh	g/kWh	g/kWh	#/kWh	
Stage V	IWA-v-1 IWA-c-1	19 ≤ P < 75	all	5	($HC + NO_x \le 4{,}70$)		0,3	—	6
Stage V	IWA-v-2 IWA-c-2	75 ≤ P < 130	all	5	($HC + NO_x \le 5{,}40$)		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.

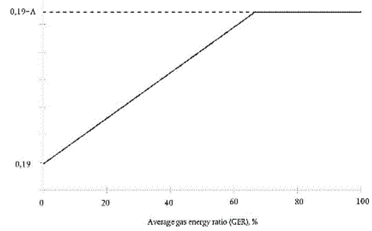

Table III-5: Dates of application of this Regulation for engine category IWP

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 ≤ 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 ≥ 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 ≤ 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 ≥ 300	IWA-v-4 IWA-c-4	1 January 2019	1 January 2020

4.2. Map of navigable waterways according to CEMT classification in Europe.

Source: https://www.unece.org/fileadmin/DAM/trans/main/sc3/European_inland_waterways_-_2012.pdf

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