Needs

Dynamic Techno - Economical Scenario Simulation Model for Sustainable Waterborne Activities and Transport

D3.1 Regional inland application of the model

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Document information	
Short description	Focusing on the inland shipping network, this deliverable describes the dataset that was developed and validated for applying the dynamic techno-economic model that is devised in WP1. All available relevant resources are exploited to this end, allowing in turn to set and properly describe the base-case scenario.
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Executive summary

This deliverable developed the structure and the input dataset for the detailed regional inland application of the model for inland waterway transport in Europe, focussing on the Rhine area. The types of vessels and fleet families those vessels belong to, as well as representative journeys they perform, have been identified from previous research (mainly Horizon 2020 project PROMINENT and studies made for CCNR for the energy transition roadmap). Data on the fleet families and journeys was collected and updated where possible. The vessel types / fleet families distinguished and proposed for the model are:

- Motor cargo vessels (MV) >= 110 m
- Motor tankers (MT) >= 110 m
- Motor cargo vessels (MV) 80-109 m
- Motor tankers (MT) cargo 80-109 m
- Motor vessels (MV) < 80 m
- Push boats with P > 2000 kW
- Coupled convoys

The following table presents an overview of the representative journeys considered. The trips are ranked (high to low) based on the total cargo flow on the route.

Nr.	Port A	Port B	Type	Most dominant vessel type on journey	Commodity
1	Rotterdam	Duisburg	Dry bulk	Push B4	Ore
2	Rotterdam	Antwerp	Container	C3L/B	Containers
3	Rotterdam	Karlsruhe	Liquid Bulk	MT 135m	Crude oil
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	Coal
5	Rotterdam	Basel	Container	C3L/B	Containers
6	Antwerp	Thionville	Dry bulk	MV110m	Coal
7	Amsterdam	Antwerp	Container	C3L/B	Containers
8	Rotterdam	Krotzenburg	Dry bulk	C3L/B	Coal
9	Amsterdam	Rotterdam	Liquid Bulk	MT 135m	Oil
10	Antwerp	Mainz	Container	MV 135m	Containers
11	Breisach	Cuijk	Dry Bulk	MV 110m	Sand&gravel
12	Antwerp	Duisburg	Container	C3L/B	Containers
13	Rotterdam	Duisburg	Container	MV 110m	Containers
14	Rotterdam	Ludwigshafen	Liquid Bulk	MT 86m	Chemicals
15	Rotterdam	Kampen/Zwolle	Liquid Bulk	MT 110m	Oil
16	Rotterdam	Strassbourg	Dry Bulk	MV110m	Agribulk
17	Amsterdam	Heilbronn	Dry bulk	MV 105m	Animal Fodder
18	Duisburg	Antwerp	General cargo	MV 110m	Metal products

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19	Rotterdam	Alphen a/d Rijn	Container	MV 105m	Containers
20	Terneuzen	Rotterdam	Liquid Bulk	MT 110m	Chemicals
21	Wesel	Enkhuizen	Dry Bulk	MV 67m	Sand&gravel
22	Rotterdam	Herne	Dry Bulk	MV 86m	Metal (scrap)
23	Dusseldorf	Antwerp	Dry Bulk	MV 110m	Agribulk
24	Antwerp	Gent	Dry bulk	MV 110m	Coal
25	Rotterdam	Duisburg	Dry bulk	MV 86m	Agribulk

For these vessels and journeys all information was systematically collected and presented in Excel files. Updates and missing information were obtained through consultations with a shipyard and fuel/energy providers regarding bunker, recharge, and swap times and bunker capacity on board vessels. This was mainly needed for the bunkering capacity (ranging between 20- 150 m3) and for the characteristics of alternative fuels which are less developed (lower TRL) and for which data from real world experience is not yet much available, such as hydrogen, methanol and battery containers.

Notably the current bunker speeds have been updated, resulting in the following overview:

	Speed of bunkering per form of bunkering and speed of swapping			
Energy/fuel	**Truck-to-Ship**	**Ship-to-Ship**	**Bunkerstation-to-Ship / Shore-to-Ship**	**Swapping energy container[1]**
Fossil diesel		550 litre per minute	550 litre per minute	
HVO		550 litre per minute	550 litre per minute	
LNG	18 ton per hour	25 ton per hour[2]	250 kg per minute	
LBM	18 ton per hour	25 ton per hour	250 kg per minute	
Electricity			188 kW per hour	30 minutes
H2	3,6 kg per minute		3,6 kg per minute	30 minutes
MeOH	550 litre per minute	550 litre per minute	550 litre per minute	

It can be seen already that much more time will be needed for the bunkering or recharging processes of inland vessels with the new forms of energy as compared to the traditional bunkering of diesel. The latter can even take place during navigation (ship-to-ship) resulting in no time-loss at all.

[1] The swapping time includes (un)mooring and swapping the container. Each additional container will take around 10 minutes each. A vessel already calling at a container terminal where containers can also be swapped immediately does not have to deal with the additional (un)mooring time of around 20 minutes compared to a ship going specifically to a container terminal for a swap of energy container(s). The swappable container of 2MWh can recharged at the terminal within 2 hours (1MWh capacity)

[2] This speed applies to LNG pontoons supplying ocean-going vessels at relatively high speeds. In theory, these pontoons can also be used to supply inland vessels with LNG, but in practice this does not happen.

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Technical and financial information related to alternative propulsion techniques and energy has been identified and was presented in detailed MS Excel files. The data will be used for the scenario simulation.

IWT experts have been consulted during a workshop and their recommendations have been taken into account. However, this shows that there is still an information and data gap in inland waterway transport for conducting (quantitative) research. For example data gaps became clear on the specific energy consumption of the auxiliary engines on board of vessels. Also the specific bunkering behaviour is not known in detail.

A recommendation for future research with the simulation model is therefore to collect more data. There are ongoing studies that may result in new information related to e.g. the fleet and technologies. More ship-related (e.g. consumption information in port areas) and transport journey information can be obtained, allowing more detailed simulation to be made.

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List of abbreviations

CAPEX	Capital Expenditures
CCNR	Central Commission for Navigation on the Rhine
DME	Dimethylether
H2	Hydrogen
HVO	Hydrotreated Vegetable Oil
IWT	Inland Waterway Transport
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LOHC	Liquid organic Hydrogen Carriers
LBM	Liquified Bio Methane
MV	Motor (cargo) vessel
MT	Motor tank vessel
MeOH	Methanol
OPEX	Operational Expenditures
TRL	Technology Readiness Level
WP	Work Package

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1. Introduction and methodology

The objective of this deliverable is to develop the structure for the detailed regional application for inland waterway transport (IWT) in Europe, focussing on the Rhine area. Hence, this deliverable developed the categorisation of inland vessel types and types of operational profiles for the IWT sector in Europe, focusing on the wider Rhine navigation area. This is the main objective of this deliverable, and this is used as input for the generic dynamic techno-economic model developed in Work Package (WP) 1. Waterway-related information is available in existing databases of project partner MARIN and will be integrated into the simulation model. This deliverable does therefore not elaborate on the waterway infrastructure, but does focus on the fleet characteristics, the representativeness of journeys and the costs and operational data for the bunkering, fuel and energy conversion systems on board of vessels.

The categorisation distinguishes different types of vessels and sailing profiles with different journeys on a variety of waterway trajectories. Data from previous studies and projects is assessed and updated where possible and necessary. Most relevant sources were the Horizon 2020 project PROMINENT and the studies made by SPB/EICB and DST for the CCNR in the framework of their development of the roadmap for the energy transition of the inland fleet. Additional data was collected by means of expert consultations from the fuel and hardware supply industry as well as from barge owner/operators who already have experience with alternative energy and emission reduction systems.

For example, relevant information is retrieved concerning bunker capacity on board of vessels and the expected time needed to bunker, charge and swap energy. Information related to clean alternative propulsion systems and information about the corresponding expected capital expenditures (CAPEX) and operational expenditures (OPEX) is retrieved from existing and recent literature.

The categorisation and retrieved data are discussed and validated by means of a so-called “NEEDS workshop” with selected experts from the Inland Waterway Transport (IWT) sector which took place on 15 December 2022. In addition to the categorisation and data, parameters have been defined according to which scenarios for inland waterway transport in the Rhine area will be analysed in WP3 using the dynamic techno-economic model.

2. Categorisation of vessel types

The European IWT fleet has a large variety in terms of vessel sizes, vessel types and their suitability to transport different types of goods or passengers. In the H2020 project PROMINENT[3] (2015-2018) an extensive elaboration took place to take stock of the inland waterway fleet and to categorise the European fleet into groups of comparable vessels, so-called fleet families. In addition, also the journeys made by these vessels were assessed. For freight transport, a mapping was made of the most intensive operations in relation to the transport performance (tonkilometres) and the amount of energy used and emissions generated. This led to an overview of the most important origin and destinations for journeys and the type of commodities for which the transport service is carried out by inland vessels. Moreover, also the sailing profile of vessels was investigated. This led to an estimate of the annual energy consumption of all vessels active in Europe and to a more detailed energy consumption profile for specific journeys which are most critical for the transport performance.

Based on this mapping and stock taking and assessments, vessels were categorized on the basis of their expected, or most common, area of operation and their sailing profile. This categorisation was taken as a basis in the study funded by Central Commission for Navigation on the Rhine (CCNR) called "Assessment of technologies in view of zero-emission IWT"[4], which was a cornerstone for the CCNR roadmap for reducing inland navigation emissions[5]. In this CCNR study the PROMINENT categorization was slightly extended in 2021. Table 1 below provides an overview of fleet families in the European IWT sector:

Table 1: overview of fleet families which may be relevant for the NEEDS Regional inland application on the Rhine area

Fleet family	Description
Motor cargo vessels (MCV) >= 110 m	a vessel equal to or longer than 110 m, intended for the carriage of dry goods and containers and built to navigate independently under its own motive power
Motor tankers (MT) >= 110 m	a vessel equal to or longer than 110 m, intended for the carriage of goods in fixed tanks and built to navigate independently under its own motive power
Motor cargo vessels (MCV) 80-109 m	a vessel with length between 80 and 109 m, intended for the carriage of dry goods and built to navigate independently under its own motive power
Motor tankers (MT) cargo 80-109 m	a vessel with length between 80 and 109 m, intended for the carriage of goods in fixed tanks and built to navigate independently under its own motive power
Motor vessels (MV) < 80 m	a vessel shorter than 80 m and longer than 19 metres, intended for the carriage of all type of goods and built to navigate independently under its own motive power

[3] More information on PROMINENT project: https://www.prominent-iwt.eu/ and https://cordis.europa.eu/project/id/633929
[4] https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition2.pdf
[5] https://www.ccr-zkr.org/12090000-en.html

Push boats with P[6]< 500 kW	a vessel specially built to propel a pushed convoy and equipped with a total propulsion power of less than 500 kW
Push boats with 500 < P < 2000 kW	a vessel specially built to propel a pushed convoy and equipped with a total propulsion power of more than 500 kW but less than 2000 kW
Push boats with P > 2000 kW	a vessel specially built to propel a pushed convoy and equipped with a total propulsion power of more than 2000 kW
Coupled convoys	a motor vessel (generally longer than 95 m) intended to be operated with one or several lighters
Ferries	a vessel providing a service crossing the waterway
Large cabin vessels	a passenger vessel longer than 86 m and with overnight passenger cabins
Day-trip and small cabin vessels	a passenger vessel for day-trip operation as well as a passenger vessel with overnight passenger cabins but shorter than 86 m

The fleet families take into account commercial transport of goods and passengers on the connected waterways in Europe. This means that recreational crafts and also floating equipment for construction works are not included in the overview above. These vessels also have a much lower contribution to energy usage and emissions. Furthermore, given the specific type of operations of these vessels (concentrated in limited number of locations), they were also less relevant to the scope of the studies that developed and updated the fleet families as there are less questions and uncertainties on their energy supply in the future. For example, for ferries on direct relatively short routes for passenger transport, battery-electric drives seem the most straightforward technology for the transition to zero-emission.

For the cargo vessels, the classification was made by size and type of cargo. For the size, the length of the vessel is seen as the element to distinguish the vessel classes. The length of the vessel relates also to the passage at locks. The sizes for the fleet families are below 80 m length, between 80 and 110 m length and above 110 m length of the vessel. There is also an extra fleet family that includes motorvessels that can sail as a coupled convoy, since these motorvessels have a significantly higher installed power on board to be able to push one or more additional barges. For push boats, the classification follows the installed power on board of the vessel and three categories are distinguished for these push boats.

Fleet families for passenger transport are categorized into three, namely ferries, large cabin vessels, and day-trip and small cabin vessels. This categorization was developed in order to take account of the significant differences that exist regarding, among others, age, installed power and energy demand between the smaller and larger vessels of this type.

Estimations have been made for the corresponding number of vessels per fleet family in the latter mentioned study “Assessment of technologies in view of zero-emission IWT”, including the fleet development towards 2050. This estimation was made based on combining the PROMINENT data and data from the CCNR study.

[6] P= Total Power installed

The "PROMINENT" and "Assessment of technologies in view of zero-emission IWT" studies make a distinction between the Rhine and other waterway countries and the Danube countries.[7] Since the NEEDS project will focus on the Rhine area, the number of vessels active on the larger Rhine area, i.e. in the Rhine and other waterway countries, has been estimated. Table 2 illustrates the total number of vessels for the larger Rhine area in 2015 including the expected development towards 2050.

Table 2: fleet families in numbers and development towards 2050

Fleet families	Nr. of vessels in 2015 in Europe	Est. nr of vessels in 2020 in Europe	Est. nr of vessels in 2035 in Europe	Est. nr of vessels in 2050 in Europe	Nr. Of vessels in 2015 in Rhine and other waterways	Est. nr of vessels in 2020 in Rhine and other waterways	Est. nr of vessels in 2035 in Rhine and other waterways	Est. nr of vessels in 2050 in Rhine and other waterways
Large cabin vessels	346	361	406	451	319	333	375	416
Push boats <500 kW	890	840	690	540	798	753	619	484
Push boats 500-2000 kW	520	525	540	555	332	335	345	354
Push boats ≥2000 kW	36	36	36	36	25	25	25	25
Motorvessels dry cargo ≥110m	610	630	690	750	580	599	656	713
Motorvessels liquid cargo ≥110m	602	567	597	627	599	564	594	624
Motorvessels dry cargo 80-109m	1802	1792	1762	1732	1713	1703	1675	1646
Motorvessels liquid cargo 80-109m	647	622	637	652	631	607	621	636
Motorvessels <80 m	4463	3938	2813	1688	4285	3781	2701	1621
Coupled convoys	140	145	160	175	140	145	160	175
Ferries	103	103	103	103	95	95	95	95
Day trip and small cabin vessels	2207	2257	2407	2557	2038	2084	2222	2361
Sum	12366	11816	10841	9866	11555	11025	10088	9151

[7] Rhine and other waterway countries: Belgium, France, Germany, the Netherlands, Luxembourg, Switzerland and Czech Republic;
Danube countries: Bulgaria, Hungary, Croatia, Moldova, Ukraine, Austria, Romania, Serbia and Slovakia.

As it can be seen from table 2, the European IWT fleet can predominantly be found in the larger Rhine area with the fleet travelling on the Rhine waterway being estimated at about 6,900 vessels, making it the key waterway for IWT in Europe.[8]

For the purpose of this study, not all vessel types from the two tables will be included for the simulation scenarios. The simulation analysis will consider the representative transport journeys as explained in chapter 3 and the corresponding vessels for those journeys. However, in line with the aim of the NEEDS project, a future-proof simulation model will be delivered that will be able to be used for simulations of other vessel types in other regions even after the NEEDS project is completed.

[8] https://www.ccr-zkr.org/12030100-en.html#:~:text=The%20fleet%20travelling%20on%20the,Wikipedia%20Rhine

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3. Representative transport journeys

In addition to the fleet families, most representative transport journeys have been identified in the PROMINENT project. For the Rhine region, 25 representative journeys and corresponding vessels have been identified in total. Here the focus is not primarily on the largest volumes transported or the largest contribution in tonne-kilometres.

Efforts have also been made to ensure representativeness through including various types of ships and cargoes. For the purpose of this study, several stakeholders were also approached to retrieve information for representative journeys with passenger vessels, but unfortunately this did not elicit any input. In addition, push boats with a power of less than 2000kW were also not included, as they also do not appear in the top 25 most representative journeys. Also, some of these vessel types are much less relevant to the specific simulation work in this study. The fleet family Ferries is such an example. Given the relatively short direct distances between two ferry landings, necessary clean energy infrastructure for these types of vessels can simply be placed on the ferry landings and therefore does not require in-depth analysis in the NEEDS project. Therefore, these vessel types were excluded from the techno-economic model for the Rhine region.

The list of most representative transport journeys on the Rhine is illustrated in table 3. Although these journeys have been identified as representative in the PROMINENT project based on 2015 data, the market structure is basically unchanged and the rationale behind the creation of this list is therefore still very relevant today and useful for the NEEDS project. Hence, these are the journeys and vessel types to be considered for the analysis in the NEEDS techno-economic model. Given the nature of the model, other journeys and vessel types can of course be added if the necessary information on vessel and journey characteristics becomes available. This also makes the model valuable for possible future analysis for other ship types in other areas of Europe.

The data also includes vessel and journey specific characteristics such as vessel dimensions, installed power, payload carried, journey duration and distance, operational hours, number of trips, etc. Also, economic data is made available by PROMINENT for these representative journeys, which includes cost information related to insurance, depreciation, interest, repair and maintenance, port dues, fuel costs, labour costs and other fixed costs. This information is slightly updated for two of the representative journeys[9] in a recent study named "Study on a financial instrument for greening the IWT sector"[10].

[9] For journeys 1. Rotterdam-Duisburg and 5. Rotterdam-Basel.
[10] https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_G_and_H.pdf

Table 3: top 26 representative journeys and corresponding fleet families

Nr.	Port A	Port B	Type	Most dominant vessel type on journey	Commodity
1	Rotterdam	Duisburg	Dry bulk	Push B4	Ore
2	Rotterdam	Antwerp	Container	C3L/B	Containers
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	Crude oil
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	Coal
5	Rotterdam	Basel	Container	C3L/B	Containers
6	Antwerp	Thionville	Dry bulk	MVS110m	Coal
7	Amsterdam	Antwerp	Container	C3L/B	Containers
8	Rotterdam	Krotzenburg	Dry bulk	C3L/B	Coal
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	Oil
10	Antwerp	Mainz	Container	MVS 135m	Containers
11	Breisach	Cuijk	Dry Bulk	MVS 110m	Sand&gravel
12	Antwerp	Duisburg	Container	C3L/B	Containers
13	Rotterdam	Duisburg	Container	MVS 110m	Containers
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	Chemicals
15	Rotterdam	Kampen/Zwolle	Liquid Bulk	MTS 110m	Oil
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	Agribulk
17	Amsterdam	Heilbronn	Dry bulk	MVS 105m	Animal Fodder
18	Duisburg	Antwerp	General cargo	MVS 110m	Metal products
19	Rotterdam	Alphen a/d Rijn	Container	MVS 105m	Containers
20	Terneuzen	Rotterdam	Liquid Bulk	MTS 110m	Chemicals
21	Wesel	Enkhuizen	Dry Bulk	MVS 67m	Sand&gravel
22	Rotterdam	Herne	Dry Bulk	MVS 86m	Metal (scrap)
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	Agribulk
24	Antwerp	Gent	Dry bulk	MVS 110m	Coal
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	Agribulk

In terms of representativeness, the considered transport journeys account for approximately 16% of the total transport performance in tonkm in Europe and approximately 20% of the total transport performance in the Rhine countries (Belgium, France, Germany, Luxembourg, the Netherlands, Switzerland).[11]

The share of the fuel consumed on these transport journeys in the total fuel consumption is likely higher than the share of 20% in the total transport performance given that the vessel types belonging to the representative voyages have a relatively high share in total fuel consumption. Table

[11] The 25 representative journeys account for approximately 21,9 billion tonkm. The total transport performance in Europe in 2021 was 137 billion tonkm. The Rhine countries account for approximately 84% of the total transport performance. Source: https://inland-navigation-market.org/chapitre/2-freight-traffic-on-inland-waterways/?lang=en

4 below shows the average share of total fuel consumption by fleet family. This gives a good indication of the high share in total fuel consumption of the selected fleet families.

Table 4: Average fuel consumption fleet families

Fleet families	**Average annual fuel consumption in m^3**
Passenger vessels (hotel/cruise vessels)	54
Push boats <500 kW (total engine power)	32
Push boats 500-2000 kW (total engine power)	158
Push boats ≥2000 kW (total engine power)	2070
Motor vessels dry cargo ≥110m length	339
Motor vessels liquid cargo ≥110m length	343
Motor vessels dry cargo 80-109m length	162
Motor vessels liquid cargo 80-109m length	237
Motor vessels <80 m. length	49
Coupled convoys	558

Source: https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_23_PROMINENT_D1.1-List-of-operational-profiles-and-fleet-families-V2.pdf

4. Technological solutions and OPEX&CAPEX

This chapter includes information relating to the greening technologies and forms of energy, and the corresponding OPEX and CAPEX details for each technology and fuel solution for each selected vessel and journey. This information is retrieved from the study "Assessment of technologies in view of zero-emission IWT". More information regarding the applicability of technologies and the particular scenarios to be analysed are included in Deliverables 3.2 “Analysis of the potential of the inland region” and 3.3 “Scenarios for the inland region”, respectively. Information on fuel characteristics, such as gravimetric and volumetric density, and hence its potential impact on cargo space loss, is already present in MARIN's databases and the simulation model.

The technologies and corresponding forms of energy considered for the energy transition are illustrated in figure 1. The figure illustrates a shortlist of most feasible technologies and corresponding forms of energy for the transition towards 2050, based on the current state of knowledge. It was decided to focus on a set of technologies with a technology readiness level (TRL) of 5 and above. Some technologies and energy carriers were therefore not considered mature enough to be used, especially in light of current cost predictions. The illustrated techniques and forms of energy in Figure 1 are considered in the simulation model.

These options are considered in the simulation model when choices have to be made for the switch to cleaner technologies and forms of energy. Switching to drop-in solutions such as bio-diesel and bio-LNG (for ships already running on diesel and LNG, respectively) are not considered a retrofit, as the choice to sail on these can be made without any significant engineering intervention on board the ship.

Based on the given information today, the techniques and forms of energy shown in Figure 1 are the most feasible. However, based on technological, economic and political developments, other techniques and forms of energy may make it to the shortlist shown in Figure 1. These could include, for example, Dimethylether (DME) C2H6O, Liquid organic Hydrogen Carriers (LOHC), Direct Fuel cells ammonia, BioEthanol, Bio LPG, etc. As such, the presented shortlist is certainly not a static list and its composition may change. It is therefore necessary to continuously monitor developments.

This also applies in particular to hydrogen, where breakthroughs may arise if a lot of subsidy is invested in building a European hydrogen economy and further incentives are implemented in the fuel market (e.g. implementation of the revision of the Renewable Energy Directive II). Furthermore, there is still uncertainty about the most effective hydrogen form as energy for IWT, which also depends on further RD&I efforts. The question is what the most effective and efficient hydrogen carrier of the future will be: whether this is compressed H2gas, liquified H2, LOHC, methanol, ammonia or other solutions?

The cost information considered for the simulation model consists of operational costs (OPEX) and hardware costs (CAPEX) of the greening solutions and existing diesel installation. Annex 1 presents detailed tables for the fuel/electricity, hardware, installation and as well as the maintenance costs.

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Figure 1: greening technologies and corresponding forms of energy

Technologies considered in the pathways	**Description**	**TRL** (1-9) **vessel application**	**TRL** (1-9) **fuel/energy production and supply**	**Emission reduction potential** (in an ideal upstream chain)		
				GHG/ CO_{2e}	**NO_x**	**Particulate matters**
CCNR 2 or below, Diesel	Fossil diesel in an internal combustion engine which complies with the emission limits CCNR 2 or older engine.	9	9	0%	0%	0%
CCNR 2 + SCR, Diesel	Fossil diesel in an internal combustion engine which complies with the emission limits CCNR 2 and equipped with an additional Selective Catalytic Reduction system.	9	9	0%	82%	54%
Stage V, Diesel	Fossil diesel in an internal combustion engine which complies with the emission limits EU Stage V.	9	9	0%	82%	92%
LNG	Liquefied Natural Gas in an internal combustion engine which complies with the emission limits EU Stage V.	9	9	10%	81%	97%
Stage V, HVO	HVO in an internal combustion engine which complies with the emission limits EU Stage V. HVO stands for hydrotreated vegetable oil itself (without blending with fossil fuels) and all comparable drop-in biofuels (including e-fuels) as well as synthetic diesel made with captured CO_2 and sustainable electric power.	9	9	100%	82%	92%
LBM	Liquefied Bio Methane (or bio-LNG) in an internal combustion engine which complies with the emission limits EU Stage V.	9	8	100%	81%	97%
Battery	Battery electric propulsion systems, with fixed or exchangeable battery systems.	8	7	100%	100%	100%
H_2, FC	Hydrogen stored in liquid or gaseous form and used in fuel cells.	7	7	100%	100%	100%
H_2, ICE	Hydrogen stored in liquid or gaseous form and used in internal combustion engines.	5	7	100%	82%	92%
MeOH, FC	Methanol used in fuel cells.	7	6	100%	100%	100%
MeOH, ICE	Methanol used in internal combustion engines.	5	6	100%	82%	92%

Source: https://www.ccr-zkr.org/files/documents/Roadmap/Roadmap_en.pdf

5. Bunker capacity and bunker speed

In addition to information of the vessel types, operational profiles, alternative propulsion technologies and forms of energy and the related cost information, also more practical insights are needed for the simulation, i.e. as regards the bunker capacity of vessels and the expected bunker speed for the various forms of energy considered. This is of relevance since the model has to simulate the bunker/charging/swapping behaviour of vessels.

Based on expert consultations, the following overview can be provided as regards the bunker capacity of the considered fleet families:

Table 5: estimated fuel tank capacity

Fleet families	**Capacity fuel tank (in m3)**
Large cabin vessels	150m3
Push boats <500 kW	10-25m3
Push boats 500-2000 kW	25-50m3
Push boats ≥2000 kW	150m3
Motorvessels dry cargo ≥110m	65m3
Motorvessels liquid cargo ≥110m	65m3
Motorvessels dry cargo 80-109m	50m3
Motorvessels liquid cargo 80-109m	50m3
Motorvessels <80 m	30m3
Coupled convoys	50m3
Ferries	
Day trip and small cabin vessels	2-5m3

The values given are averages based on knowledge of the fuel tank sizes of currently operating ships. There are no standard fuel tank sizes in IWT. This depends entirely on the vessel owners' requirements and wishes. Also, the fuel tank(s) on board vessels are used for other purposes rather than fuel storage only, e.g. for the vessel trim, etc.

For ferries, which incidentally is not included in the simulation, there is no possibility of making any meaningful statement about an average fuel tank size because within this fleet family there is simply too much diversity in type and size of vessels, and hence in their fuel tanks.

As regards the bunker speed, table 5 provides an overview of the expected bunker speed for the considered forms of energy. This information was obtained from existing experience, existing literature and consultations with energy/bunker suppliers.[12]

[12] For H2 the following source is consulted: http://marigreen.eu/wordpress_marigreen/wp-content/uploads/2018/11/Hydrogen-Feasibility-Study-MariGreen.pdf (p56/123)
For Methanol the Gent University and Methanex have been consulted.
For diesel the companies Slurink and Bunkerstation Delta Stolk & Berends have been consulted.
For shore-side charging experiences with the Sendoliner have been taking as a basis, see also https://www.schuttevaer.nl/nieuws/scheepsbouw-en-reparatie/2019/02/20/sendo-liner-emissieloos-de-eerste/
For information about the swapping speed ZES and Darel have been consulted.

Table 6: bunker and swapping speed

	Speed of bunkering per form of bunkering and speed of swapping			
Energy/fuel	**Truck-to-Ship**	**Ship-to-Ship**	**Bunkerstation-to-Ship / Shore-to-Ship**	**Swapping energy container[13]**
Fossil diesel		550 litre per minute	550 litre per minute	
HVO		550 litre per minute	550 litre per minute	
LNG	18 ton per hour	25 ton per hour	250 kg per minute	
LBM	18 ton per hour	25 ton per hour	250 kg per minute	
Electricity			188 kW per hour	30 minutes
H2	3,6 kg per minute		3,6 kg per minute	30 minutes
MeOH	550 litre per minute	550 litre per minute	550 litre per minute	

Table 5 shows the currently applied and expected to be applied form of bunkering, recharging or swapping for each form of energy. The grey-coloured cells mean that the specific form of energy transfer is not considered feasible.

The presented information concerns the time required for the actual transfer of energy, any additional time that might be needed for, e.g., filling in checklists or the administrative time required for planning a bunker is not included. No clear information on this is currently available and these activities can also be done during the navigation of the vessel. But it is safe to assume that, especially in an initial phase, significantly more time will be involved in both the preparations and the actual bunkering, swapping, charging of alternative energy compared to fossil diesel. Furthermore, also the availability will be lower, therefore, possibly the vessels will need to make detours or more stops to arrive at a recharging, swapping or bunkering facility.

As regards charging, the information for shore-to-ship charging is based on the case of the SendoLiner which needs 3 full hours to charge its battery which has a capacity of 564 kWh. However, in the meantime technological developments have taken place and a best practice example is of ZES, where the battery pack of 2MWh can be charged within two hours. It could be assumed that a fixed battery pack on board of a vessel could perhaps be charged with a shore-to-ship installation reaching the same speed.

[13] The swapping time includes (un)mooring and swapping the container. Each additional container will take around 10 minutes each. A vessel already calling at a container terminal where containers can also be swapped immediately does not have to deal with the additional (un)mooring time of around 20 minutes compared to a ship going specifically to a container terminal for a swap of energy container(s).

6. Conclusions and recommendations

This deliverable inventoried the information to be included in the development and running of the inland navigation-related simulation scenarios in the simulation model.

The types of vessels and fleet families they belong to, as well as representative journeys they perform, have been identified from existing literature and is updated where possible and needed. Additional information was successfully obtained through consultations regarding bunker, recharge, and swap times and bunker capacity on board vessels. This information already shows that the time needed for bunkering clean/alternative fuels or recharging is longer as compared to fossil diesel and needs to be properly taken into account in the modelling in WP3.

To simulate the bunker behaviour of fossil diesel and clean alternatives, and their effects on infrastructure, information was also needed on alternative forms of propulsion and associated clean forms of energy. This information from recent research has also been identified and presented and will be included in the development of the simulation model.

Recommendations of IWT experts voiced at the "NEEDS workshop" have been taken into account as far as possible. For example, these include the distinction between retrofit and new build in fleet development and the loss of cargo space due to alternative energy storage on board ships.

However, given the information available today, it has not been possible to obtain all the desired information. This is a recommendation for future research with the simulation model to be developed. The simulation model will eventually lend itself to wider research on various cases, in addition to the current Rhine case for inland navigation and the maritime case on the Greek islands.

There are ongoing studies and projects, such as Horizon Europe funded projects SYNERGETICS and RH2IWER[14] which will bring new information which will be useful for updating data and also for simulation of vessel types which are currently not included in the modelling in WP3, for instance with (small) passenger vessels, smaller push boats and ferries.

More ship-related (e.g. consumption information in port areas) and travel information can also be obtained, allowing more detailed simulation to be made.

[14] See for more information:
SYNERGETICS project: https://cordis.europa.eu/project/id/101096809,
RH2IWER project: https://cordis.europa.eu/project/id/101101358

Annex 1 - Detailed tables

Table 7: fuel/electricity cost overview

Costs fuel	Prices €/kg																				
	min							avg							max						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
Diesel	0.55	0.55	0.55	0.58	0.60	0.60	0.60	0.60	0.61	0.63	0.69	0.76	0.76	0.76	0.65	0.68	0.70	0.81	0.91	0.91	0.91
HVO	0.65	0.65	0.57	0.66	0.74	0.74	0.74	0.75	0.75	0.75	0.75	0.75	0.75	0.75	1.05	1.05	1.13	1.28	1.43	1.43	1.43
LNG, fossil	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Electricity. €/kWh	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.12	0.12	0.12
H_2. grey	2.75	2.75	2.75	2.75	2.75	2.75	2.75	4.40	4.40	4.40	4.40	4.40	4.40	4.40	6.00	6.00	6.00	6.00	6.00	6.00	6.00
H_2. green	10.00	10.00	10.00	8.00	6.00	6.00	4.00	11.00	11.00	11.00	9.00	7.00	7.00	5.33	12.00	12.00	12.00	10.00	8.00	8.00	6.67
LBM	0.85	0.85	0.85	0.85	0.85	0.85	0.85	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.72	1.72	1.72	1.72	1.72	1.72	1.72
MeOH	0.57	0.57	0.32	0.32	0.32	0.32	0.32	0.86	0.86	0.44	0.46	0.47	0.47	0.47	1.14	1.14	0.56	0.59	0.62	0.62	0.62

Source: https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition2.pdf

The NEEDS project has received funding from Horizon Europe research and innovation programme under grant agreement No 101056938

Table 8: cost for technologies

	Prices €/kW, €/kWh																				
	min							avg							max						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
Stage V+. Euro VI	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375	€ 375
Gas engine	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450
Battery	€ 500	€ 383	€ 267	€ 150	€ 133	€ 100	€ 80	€ 750	€ 575	€ 401	€ 225	€ 216	€ 199	€ 188	€ 1,000	€ 767	€ 534	€ 300	€ 298	€ 297	€ 295
H_2 FC	€ 1,500	€ 1,500	€ 1,500	€ 1,500	€ 1,500	€ 1,500	€ 1,000	€ 2,000	€ 2,000	€ 2,000	€ 2,000	€ 2,000	€ 2,000	€ 2,000	€ 2,500	€ 2,500	€ 2,500	€ 2,500	€ 2,500	€ 2,500	€ 2,500
Electric engine	€ 120	€ 120	€ 120	€ 120	€ 120	€ 100	€ 100	€ 180	€ 180	€ 180	€ 180	€ 180	€ 180	€ 170	€ 240	€ 240	€ 240	€ 240	€ 240	€ 240	€ 240
H_2 ICE	€ 585	€ 578	€ 570	€ 563	€ 555	€ 548	€ 540	€ 618	€ 610	€ 602	€ 594	€ 586	€ 578	€ 570	€ 650	€ 642	€ 633	€ 625	€ 617	€ 608	€ 600
MeOH FC	€ 3,000	€ 2,667	€ 2,333	€ 2,000	€ 2,000	€ 2,000	€ 1,750	€ 3,000	€ 2,834	€ 2,667	€ 2,500	€ 2,500	€ 2,500	€ 2,125	€ 3,000	€ 3,000	€ 3,000	€ 3,000	€ 3,000	€ 3,000	€ 2,500
MeOH ICE	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 450	€ 475	€ 475	€ 475	€ 475	€ 475	€ 475	€ 475	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500	€ 500
Old Diesel	€ 250	€ 250	€ 250	€ 250	€ 250	€ 250	€ 250	€ 275	€ 275	€ 275	€ 275	€ 275	€ 275	€ 275	€ 300	€ 300	€ 300	€ 300	€ 300	€ 300	€ 300

Source: https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition2.pdf

	Large cabin vessels	Push boats < 500 kW	Push boats 500-2000 kW	Push boats ≥ 2000 kW	MCV ≥ 110 m	MT ≥ 110 m	MCV 80-109 m	MT 80-109 m	Motor vessels < 80 m	Coupled convoys	Ferries	Day trip and small cabin vessels
Average fuel consumption per year (in m³)	500	32	158	2,070	339	343	162	237	49	558	99	54
Average total engine power installed (kW)	1,000	247	847	3,458	1,742	1,780	764	954	302	2,237	374	500
Installation. system and equipment costs [€]												
Electrification. min	397,500	173,483	351,983	460,064	359,123	364,775	327,290	383,815	189,845	432,754	211,265	248,750
Electrification. avg	482,500	194,478	423,978	562,940	433,158	440,425	392,230	464,905	215,515	527,826	243,055	291,250
Electrification. max	525,000	204,975	459,975	614,378	470,175	478,250	424,700	505,450	228,350	575,363	258,950	312,500
LNG-system price. min	2,000,000		1,900,000	3,100,000	1,800,000	1,800,000				2,300,000		
LNG-system price. avg	2,150,000		2,000,000	3,200,000	1,900,000	2,000,000				2,400,000		
LNG-system price. max	2,300,000		2,100,000	3,300,000	2,000,000	2,200,000				2,500,000		
Installation Diesel engine	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Installation H_2/MeOH engine	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
SCR base	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
SCR per installed kW*	75	75	75	75	75	75	75	75	75	75	75	75
H_2 tank per kg capacity*	800	800	800	800	800	800	800	800	800	800	800	800
Maintenance (% of CAPEX)												
ICE Diesel/MeOH	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%	7%
ICE Stage V	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
LNG/ H_2 ICE + system (tank+tcs)	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
H_2 FC	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
Battery	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
MeOH FC	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
SCR	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%

Table 9: Installation costs per technique and fleet family

Note: The *(annual)* maintenance costs are expressed in % of the investment.
Source: https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition2.pdf

Annex 2 – Interviews and workshop

The following organisations were consulted during the work for this study. This was done to obtain technical information that was required as input for the simulation model. The consulted organisations are:

- PON POWER
- Slurink bunkerstations
- Bunkerstation Delta Stolk & Berends BV
- Titan LNG
- ZES
- BALance

The obtained technical information is related to vessel characteristics, bunkering of fuel, charging of batteries and swapping of energy containers.

The following organisations attended the onlinw “NEEDS workshop” which took place on 15 December 2022:

- CCNR
- DST
- IWT Platform
- CERTH
- MARIN
- EICB