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STUDY ON FINANCING THE ENERGY TRANSITION TOWARDS A ZERO-EMISSION EUROPEAN IWT SECTOR

CCNR Member States:

Study consortium:

DST
ECORYS
Expertise- en InnovatieCentrum Binnenvaart EICB
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pro DANUBE MANAGEMENT GMBH
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Study

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List of abbreviations

AC	Alternating Current
AFOLU	Agriculture, Forestry and Other Land-Use
BTL	Biomass to Liquid
BAU	Business as Usual
CAPEX	CAPital EXpenditures (Investment Costs)
CDNI	Convention Relative a la Collecte, au Depôt et a la Reception des Dechets Survenant en Navigation Rhenane et Intertieure (Convention on the Collection, Deposit and Reception of Waste Generated During Navigation on the Rhine and Other Inland Waterways)
DC	Direct Current
DNV GL	Det Norske Veritas
DPF	Diesel Particulate Filter
Euro VI	European truck engine emission standard (2013)
FC	Fuel Cell
GHG	Greenhouse Gas
GTL	Gas to Liquid
H2	Hydrogen
H2 ICE	Hydrogen Internal Combustion Engine
H2 FC	Hydrogen Fuel Cell
HT	High Temperature
HVO	Hydrotreated Vegetable Oil
ICE	Internal Combustion Engine
IWT	Inland Waterway Transport
IPCC	Intergovernmental Panel on Climate Change
LBM	Liquid Bio Methane (Bio-LNG)
LMG	Liquefied Methane Gas
LNG	Liquefied Natural Gas
LTO	Lithium Titanate Oxide Anode
LT	Low Temperature
MCV	Motor Cargo Vessel
MeOH	Methanol
MeOH FC	Methanol Fuel Cell
MeOH ICE	Methanol Internal Combustion Engine

MT	Motor Tanker
MV	Motor Vessel
NRE	Non-Road Engines, a category in NRMM directive
NRMM	Non-Road Mobile Machinery
OEM	Original Equipment Manufacturer
OPEX	OPerational EXpenditures (Operational costs)
PEM FC	Proton Exchange Membrane Fuel Cell
PM	Particulate Matter
PTL	Power to Liquid
PTX	Power to X
RED II	Renewable Energy Directive II (EU) 2018/2001
ROI	Return on Investment
RPM	Revolutions per Minute
SCR	Selective Catalytic Reduction
TCS	Tank Connection Space
TCO	Total Cost of Ownership
TRL	Technological Readiness Level
TTW	Tank to Wake
US EPA	United States Environmental Protection Agency
VDMA	Verband Deutscher Maschinen- und Anlagenbau (German Mechanical Engineering Industry Association)
WEO	World Energy Outlook
XTL	X to Liquid

Summary

A number of extensions and revisions have been made compared to the 1st version of the Research Question C. The following are most important:

- Development of the fleet families including number of vessels, engines types and emission performance.
- Development of the Business as Usual (BAU) scenario taking into account the available grant schemes and other assumptions, based on the current regulatory framework.
- Additional costs due to time loss and loss of payload is taken into account for alternative energy solutions.
- Cost assumptions have been updated for fuels and technologies.
- Emission performance assumptions have been refined for the internal combustion engines.
- OPEX and TCO calculations for the scenarios have been added as well as the related gap analyses.

Based on the further elaborations, the following conclusions can be made:

- The uncertainty of prices and availability of fuels and development of technologies is still quite substantial which is also reflected in the calculations. The uncertainty is especially large for the zero-emission technologies. Therefore, it is needed to regularly update the calculations and to follow closely the developments.
- The TCO gap with BAU is roughly a factor 2 higher for the innovative pathway compared to the conservative pathway (bandwidth 1.6 – 2.9). This illustrates that the conservative pathway would be most cost efficient to reach the 90% emission reduction objective for 2050 compared to 2015.
- The main economic challenges and financial gaps arise from 2030 onwards for the conservative pathway and the innovative pathway as soon as expensive zero-emission technologies are assumed to be applied at increasing growth rates (e.g. fuel cell systems and batteries). Clearly the economic challenge is the biggest for the innovative pathway.
- The aggregated TCO costs for the drivetrains for period 2020-2050 for the conservative pathway are 8% higher than BAU while for the innovative pathway it is 23% higher.
- The gap between the TCO pathway scenarios and the BAU scenario is mainly caused by the higher capital costs which is the result of higher CAPEX. The total aggregated gap for the 2020-2050 period is estimated between 2.6 and 7.7 bln

euro depending on the pathway and scenario. Compared to BAU where the CAPEX is around 2.6 billion euro, this means that the increase of CAPEX is roughly 1.5 times higher for the conservative pathway and around 2.5 times higher for the innovative pathway.

- It turns out that the OPEX for the pathways is around the same level or even lower levels than OPEX for BAU on longer term (2035 - 2050). However, it shall be remarked that the 30% energy efficiency assumed for the pathways compared to 15% energy saving in BAU plays a substantial role in the calculations. The average impact on the OPEX for the conservative pathway is a 3.3% reduction compared to the OPEX for BAU scenario while for the innovative pathway the reduction is limited to 0.4%. The difference between conservative and innovative pathway is caused by higher maintenance costs in the OPEX, resulting from higher shares of battery and FC technologies.
- Further analyses of the calculations for specific technologies per fleet family showed that there is no business case for the average fleet family. There is no situation found where savings on OPEX can cover the additional capital costs. As result, in general, there is no return on investment for (near) zero-emission technologies for the ship-owner/operator compared to BAU.

1 Introduction

This report is the second edition of the study "Assessment of technologies in view of zero-emission IWT" that was published in October 2020.

Given the objective and results of the first edition of the study, the purpose of the second edition is mainly to elaborate further on the:

- Total Cost of Ownership (TCO) for the greening techniques and fuels.
- The Business as Usual (BAU) scenario.
- Transition pathways.

This elaboration is needed for the conclusions and recommendations to be made in the studies for research questions I (What is the added value of a new European funding and financing scheme for IWT and how could this work?) and J (What accompanying measures and follow-up steps are needed?) of the overarching study. The BAU scenario is based on hypotheses that were reviewed by stakeholders for the preparation of this report. The comments received from the delegations and stakeholders during the different consultation phases were implemented where possible.

This second edition of the study on Research Question C is structured through five tasks which are addressed one by one in this report. These tasks are:

Task 0. Transition pathways
The development of transition pathways for reaching the intermediary and final objectives of the Mannheim declaration by 2035 and 2050 as well as a BAU scenario are the results of this task. Two transition pathways are identified, one conservative and a more innovative one to reach an emission reduction of at least 90% by 2050 compared to 2015. As regards the BAU scenario, 7 hypotheses are drafted that form the basis for it. The BAU scenario is an educated guess about how the European fleet[1] will develop towards 2050 based on the status quo and announced developments. This is key for the analysis on the financial gap.

Task 1. Technologies for pathways
The objective of task 1 is the identification of the technologies for each pathway defined and their respective shares (understood as shares of the inland navigation fleet), in relation to their technical (in particular, emission reduction potential, technological maturity, operational risks/constraints) as well as their economic/business case assessments already performed in Edition 1. Justification as to why such choices were made is provided (on the basis of Edition 1).

Task 2. Upstream chain and fuel availability

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[1] The focus is on the European fleet for the commercial transport of passengers and goods on the connected waterways in Europe.

The results of task 2 provide a better understanding of the emissions in the upstream chain of alternative fuels and the possible future availability of these fuels for IWT.

Task 3. TCO for transition pathways and BAU

The results of the TCO calculations provide the necessary insights to the range in CAPEX and OPEX for the identified transition pathways as well as for the BAU scenario for the European fleet.

Task 4. Financial gap

This task provides the results of the evaluation of the financial delta to be bridged (TCO for BAU compared to TCO for the transition pathways) to realise the 2035 and 2050 objectives as well as the differences in CAPEX and OPEX between the BAU scenario and the transition pathways.

Task 5. No-regret investments

This task elaborates for each pathway how no-regret investments can be best made from 2021 in the years towards 2050. The various investments are considered for the following periods: 2021-2025/2025-2030/2030-2035/2035-2040/2040-2050.

2 Starting points for the study

2.1 Task description

According to the offer for the study by DST and EICB, the task on the transition pathways (Task 0) concerns the following work:

> *Task 0: Transition Pathways*
>
> *Development of two transition pathways for the European fleet in order to reach the intermediary and final objectives of the Mannheim declaration by 2035 and 2050, as well as a business as usual (BAU) scenario. One pathway is more conservative in terms of the technologies used. The other is more innovative in terms of the technologies used. Milestones for the pathways include at least 2035 and 2050, but additional milestones can be proposed by the consultants if appropriate.*
>
> *Outcome*
>
> *- 7 main hypotheses forming the basis of the BAU*
>
> *- Excel-model for the BAU scenario*
>
> *- Propose two pathways to reach the final objective of > 90% reduction by 2050 and intermediary objective of 35% reduction by 2035*

2.2 CCNR objective and goals for the Transition pathways

In view of the task description, it is relevant to recall the objectives stated in the Mannheim declaration:

To further improve the ecological sustainability of inland navigation, we task the CCNR

to develop a roadmap in order to

- *reduce greenhouse gas emissions by 35% compared with 2015 by 2035,*
- *reduce pollutant emissions by at least 35% compared with 2015 by 2035,*
- *largely eliminate greenhouse gases and other pollutants by 2050.*

It is indicated that compared to 2015 the absolute emission levels shall be reduced by 35%. The wording '*largely eliminate greenhouse gases and other pollutants by 2050*' was clarified by the CCNR[2] to be at least a reduction of 90% compared to the 2015 emission levels.

In view of the study, these objectives concern the absolute amount of tons of CO_2 and CO_2-equivalent emissions for climate change (CO_2 and CH_4) and the absolute amount of tons of air pollutant emissions for NO_x and PM. Other emissions such as SO_2, HC[3] and CO are left out of scope because of the insignificance in relation to their share in the external costs of the emissions to air.

In view of understanding the financial impact of reaching 90% emission reduction in 2050, it is required to determine how much emission reduction can already be expected in a 'business as usual' scenario. The business as usual scenario follows the current legal framework and includes confirmed new legislation and interventions. It, therefore, excludes any intervention measures which are pending, uncertain and not decided upon yet.

Consequently, the business as usual scenario is based on assumptions on factors that determine the emission levels. This concerns factors such as:

- Transport demand for IWT services: developments in the cargo volumes (tons), number of passengers and changes in the origin-destinations, resulting in changing distances to be covered to move the passengers and goods from origin to destinations.
- The development of the IWT fleet, answering to the demand for IWT services, taking into account changes in the fleet structure (economies of scale) and improved vessel designs to optimise efficiency.
- The development of energy consumption of a vessel, taking into account improvements in the hardware (efficient powertrain, hull shape, propellors, energy management systems) as well as smart navigation (optimised sailing speeds) while coping with dynamic waterway conditions.
- The development of the transport / logistic efficiency: the average load rate of the vessel (tons, TEU, m^3 or passengers), including the share of empty sailing.
- The development of the emission profile of a vessel, i.e. the powertrain characteristics: the volume of emissions emitted in relation to MJ or kWh of energy required to move the vessel.

2.3 Modelling inland navigation emissions and the limitations

The modelling follows the edition 1 of the report and concerns professional transport of goods and passengers on the connected waterways in Europe.

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[2] RV meeting June 2020. To be noted that delegations considered this interpretation as a first step and are committed to a regular reassessment of it.

[3] HC emissions are included for LNG, since methane slip for engines running on methane gas (LNG and LBM) is incorporated in the analysis.

This means that recreational crafts and also floating equipment for construction works are left out of scope. It needs to be remarked however that floating equipment is also under the scope of the NRMM Stage V regulation (Regulation (EU) 2016/1628) for engines in inland waterway vessels and they use the same fuel as vessels for inland navigation.

2.4 Definition of the fleet families

The fleet families were based on the H2020 project PROMINENT [1] and slightly extended in edition 1 based on the IVR database. The definitions were adjusted to the ES-TRIN 2021/1 terminology as follows:

- 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;
- Push boats with P[4] < 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.

Additional remarks:

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[4] P = Total Power installed

For the cargo vessels, the classification was made by size and type of cargo. The sizes for the fleet families are below 80 m, between 80 and 110 m and above 110 m. There is also an extra fleet family that includes vessels that can sail as a coupled convoy, since these vessels have a significantly higher installed power to be able to push one or more additional barges.

The fleet family “Day trip and small cabin vessels” was composed by extracting the fleet family “Large cabin vessels” from the PROMINENT fleet family “Passenger vessels (cabin/cruise vessels)” which consisted in all kinds of passenger vessels (except ferries). This categorisation was proposed to take account of the significant differences regarding, among others, age, installed power and energy demand between the smaller vessels and the larger vessels of the type passenger vessel. These differences have a major impact on the suitability of the technologies under consideration.

2.5 Technologies

The background information on the considered technologies was introduced in Edition 1[5] of this study. The following selection amongst the technologies was made for Edition 2:

- **Fossil diesel:** Especially when it comes to vessels with a large energy consumption, a fluid and, energy dense carrier is useful. Since it is not known how much HVO or synthetic diesel (PTL) will be available for IWT in the future, a small amount of fossil diesel for some fleet families is granted in the transition pathways. With after treatment systems (e.g. SCR, DPF refit or new Stage V / NRE or Euro VI engine) the air pollutant emission levels will be very low.

- **HVO:** HVO in the pathway description stands for HVO itself and all comparable drop-in biofuels as well as synthetic diesel made with captured CO_2 and sustainable electric power (PTL). These fuels are also called paraffinic diesel fuels and defined in the EN15940 standard.

- **LBM:** Liquefied Bio Methane is the sustainable alternative to LNG. In the pathways it replaces LNG since there are promising LBM production sites by today. Further in the future synthetic methane (CH_4) can be considered in this pathway, made with captured CO_2 and sustainable electric power (PTG). Strictly speaking, LBM would be a misnomer for non-bio-based methane production. In this case, the abbreviation LMG (for Liquefied Methane Gas) is sometimes used.

- **Batteries**: Full Battery-electric systems are an important part of the transition pathways in case of transport on shorter distances on fixed routes. They are full zero-emission and have the highest energy efficiency which is favourable for the operational costs. Their energy demand can be met quite good with fixed batteries on board, while also exchangeable battery systems are possible for more intensive energy users in IWT on stable routes. The drawback is however the

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[5] https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition_1_Oct2020.pdf

high investment costs, low lifetime and low energy density. In this study, only the 'fixed battery on board' is however assumed for the calculations, with energy prices for electricity from grid for the operational costs.

- **H2 FC:** The hydrogen fuel cell is suitable for most vessels with a moderate energy demand. The technology can be used for nearly all fleet families. The economic drawback is the limited lifetime and high investment costs. The energy efficiency of hydrogen fuel cell systems is marginally better compared to modern diesel combustion engines (e.g. 45% average for FC systems compared to 42% for the diesel engine).

- **H2 ICE:** Not only can hydrogen be used as a fuel for fuel cell systems but also for the internal combustion engines (ICE). Lately manufacturers have started the development of commercially available engines.[6] In contrast to today's fuel cell systems or batteries, no rare raw materials are needed for the production of the combustion engine, lifetime is higher and investment costs are lower compared to fuel cell systems.
- **MeOH FC:** In the pathways this describes a hydrogen fuel cell that extracts the hydrogen from the methanol using a cracker. The great advantage of methanol is that it can be stored in liquid form at ambient temperature and pressure in normal tanks.
- **MeOH ICE:** Methanol can also be used directly as fuel in the internal combustion engine. This will have lower costs and higher lifetime, but the downside is the NO_x emissions for which a SCR can be applied.

For each fuel this study considers the mono-fuel version. In practice also dual-fuel engines could be applied like the dual-fuel LNG engines. When running in gas mode, these engines usually only use a very small amount of diesel as a pilot fuel.[7] This could also apply to the methanol and H2 ICE's once these will enter the market.

Table 1 presents the emission reduction impact for each technology or fuel. The baseline for the comparison is the average CO_{2e}, NO_x and PM performance of the fleet in 2015 which consists of CCNR 2 engines and below.

For the Green House Gas emissions, the IPCC methodology is applied (see also chapter 3). For the CCNR 2 engine using an SCR catalyst it is assumed, that the NO_x-reduction is the same as for the Stage V engines. Since a CCNR 2 engine performs relatively better in terms of pollutant emissions as compared to the 2015 baseline, also PM emissions are lower despite the absence of a particulate filter. Within the study it is assumed that new internal combustion engines using H_2 or methanol do reach at least the Stage V

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[6] There is little data for H2 ICEs, but it is claimed that lean mixtures allow higher efficiencies compared to diesel especially in partial load states. Efficiencies of FC and ICE would be pretty close. See e.g. https://doi.org/10.1007/978-3-658-26528-1_23

[7] For example, the LNG dual-fuel engines of Wärtsilä (https://cdn.wartsila.com/docs/default-source/product-files/engines/df-engine/brochure-o-e-w20df.pdf)

pollutants emissions. Furthermore, the values from Edition1 regarding LNG were updated with the latest findings from the LNG-breakthrough project [2].

Table 1: Emission reduction potential per technique/fuel

Technology	GHG / CO_{2e}	NO_x	PM
CCNR 2 and below	0%	0%	0%
CCNR 2+SCR	0%	82%	54%
Stage V, Diesel	0%	82%	92%
Stage V, HVO	100%	82%	92%
LNG	10%	81%	97%
LBM	100%	81%	97%
Battery	100%	100%	100%
H_2 FC	100%	100%	100%
H_2 ICE	100%	82%	92%
MeOH FC	100%	100%	100%
MeOH ICE	100%	82%	92%

It shall be noted that for HVO, LBM, Battery, H_2 and MeOH it is assumed that renewable energy is used: green electricity (e.g. wind, solar energy) to charge the batteries and for electrolyses to make H_2 or renewable/bio feedstocks for HVO or methanol production.

2.6 Hypothesis and assumptions

Given all the known and unknown variables, it is extremely complex to develop a comprehensive business as usual (BAU) scenario which will form the basis for the overall study on the economic and technical assessments of the greening techniques contributing to the energy transition of the IWT sector towards zero emissions. Therefore, 9 main hypotheses and assumptions are formulated serving as basis for the BAU scenario. These hypotheses and assumptions are extensively elaborated upon in Annex I. In short:

- The freight transport demand for IWT and the overall tonkilometre performance is kept stable. The passenger transport sector is however expected to grow.
- No differentiation in costs between new and existing vessels.
- The IWT fleet is divided into a number of representative fleet families with assumptions for the fleet development per fleet family (12 in total) in the periods 2015-2020, 2020-2035 and 2035-2050. The relative change in number of vessels in 2050 as compared to 2015 is approximately -20%.
- A renewal rate is assumed for the drivetrains for each of the fleet families (12 in total) in the periods 2015-2020, 2020-2035 and 2035-2050. This is based on existing literature and expected developments based on announced measures.
- Four types of Stage V solutions can be distinguished (IWA/IWP < and > 300 kW, NRE engines 56 < P < 560 kW and EURO VI marinised truck engines). For simplicity, the costs for the various types of engines are assumed to be equal.

- It is assumed that the energy consumption of the entire fleet will in total reduce by 15% for the BAU scenario and 30% for the two transition pathways. The higher reductions for the transition pathways are explained due to the increased awareness and larger economic incentive to reduce energy consumption and installed power on board as result of high energy costs and high investment costs for the zero-emission technologies and energy carriers. For the pathways, besides a fund it is likely that additional accompanying measures are implemented to promote fuel efficiency and lowering of carbon footprint of IWT.
- For the BAU scenario only the existing legislative frame-work and existing incentives and drivers have been taken into account, while for the pathways this is still an open discussion, for example concerning regulations and arrangements for new financial instruments as well as more strict emission standards, increased pressure on reporting of carbon footprint in IWT, energy index systems for vessels, emission labels for vessels, stronger incentives by ports (port dues differentiation) as well as a the role of banks to favour green technologies.
- According to IPCC methodology and RED II directive biofuels are seen as climate neutral from tank-to-wake perspective. In the BAU scenario it is assumed that the share of biofuels gradually increases to a share of 7% in 2050.
- Figures are retrieved from existing literature for the air pollutants based on the emission standards of the engine to estimate the emissions of the fleet.

2.7 BAU scenario

Based on the hypothesis and assumptions as described in the previous chapter and as extensively described in Annex I, a BAU scenario is developed predicting the development for the average engine and technology distribution towards 2050. This overview is visualised in Figure 1 below.

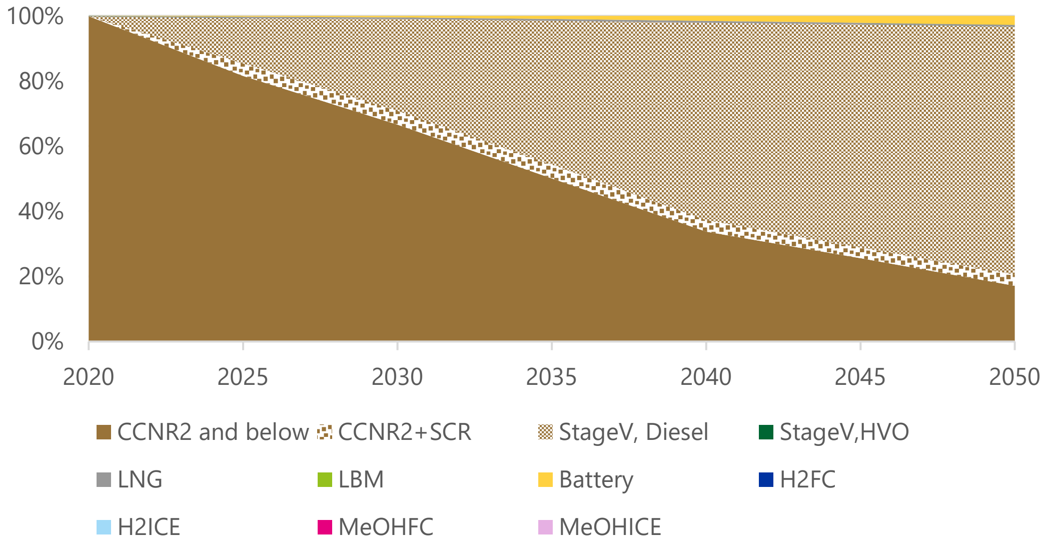

Figure 1: Development of engine and technology distribution in the fleet

It can be seen that by 2050 a very large part of CCNR 2 and older engines are replaced or scrapped. The share of CCNR 2 and older engines in 2050 is expected to be around 17%. In addition, around 3% of the fleet will be equipped with a CCNR 2 engine with SCR as result of funding schemes[8] promoting the retrofit with SCR technology.[9] The share of Stage V diesel engines is expected to grow up to 47% in 2035 and 76% in 2050 as result of new-build vessels and engine replacements at existing vessels (retrofit). Shares of LNG and battery electric navigation are not significant, seen from the viewpoint of the fleet as a whole. This is different for the share in specific fleet families. For example, it is expected that the share of full battery electric drivetrains will be around 17% for ferries in 2050. It can be seen that there is no development towards a wide spread in application of different technologies. But it should be considered that the increased use of engines with higher emission standards (Stage V) takes place. Furthermore, a slight increase in electric driven vessels is expected in the ferries and daytrip and small cabin vessel segments.

There is also a slight overall increase assumed in the use of biodiesel by the whole fleet as result of diesel blends consisting of biodiesel and conventional diesel provided by the fuel suppliers. Starting with 0% in the year 2015 this share linearly grows to the maximum 7% of the overall diesel consumption in 2050 (7% = current maximum according to EN590 fuel specification).

Given the expected development in fuels and techniques towards 2050, a calculation is made for the expected emission reduction towards 2050 in the BAU scenario for the inland fleet (passenger and freight transport). Table 2 below presents an overview of the expected emission reduction for the BAU scenario per 5 years with 2015 as a benchmark.

Table 2: Emission reduction levels of the fleet compared to 2015 in the BAU scenario

Year	CO_2e / GHG	NO_x	PM
2020	4%	5%	8%
2025	7%	28%	32%
2030	9%	30%	34%
2035	**14%**	**57%**	**63%**
2040	17%	68%	74%
2045	19%	72%	79%
2050	**22%**	**76%**	**83%**

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[8] Enabled by the 79 M€ subsidy scheme by Dutch government (2021-2030) to support installation of SCR to drastically reduce NO_x emissions, with a focus on deployment until 2025.

[9] Only the combination of a CCNR 2 engine with SCR has been taken into account, because of the Dutch subsidy programme that is only intended for the purchase of SCRs. It is expected that with this subsidy programme 920 ships will be equipped with SCR. In practice, an inland shipping entrepreneur may also choose to invest in a DPF on his own. However, it cannot be determined in advance whether this will actually happen and in what numbers. Furthermore, a vessel that is equipped with both a DPF and SCR already reaches the Stage V emission level, which is also already considered.

Table 2 clearly shows that the intermediary 2035 objective to reduce Green House Gas (GHG) emissions by 35% is not expected to be reached in the BAU scenario. The goal to reduce pollutant emissions by 35% will be reached though.

The final 2050 objective to largely eliminate GHG and other pollutants, i.e. reduce them by at least 90%, is not reached either in the BAU scenario. Hence, given the current existing legislative framework and existing incentives and drivers, the IWT sector is not expected to meet the 2050 objective of the CCNR as regards GHG emissions. Intervention measures will be needed to reach the GHG reduction objective.

It can however be seen that NO_x and PM emission levels will be reduced already with 76% (NO_x) and 83% (PM) which is already close to the 90% reduction target for 2050 (compared to 2015). The conclusion can be made that the biggest challenge will be to reduce the GHG emissions of the fleet.

3 Upstream chain and fuel availability

The possible future availability of alternative energy sources for inland navigation can be approached from a global perspective. The IEA's annual World energy outlook and the DNV GL's energy transition outlook also include global maritime transport in their analysis. Taking into account the specifics of inland navigation, possible scenarios can be derived from these forecasts. The answers to the following questions need to be found for a global perspective:

- How will the global energy mix evolve over the next 30 years?
- Which technologies will be able to achieve the necessary cost reduction?
- What technological leaps can be achieved in the coming decades?
- How will the fuel mix throughout the whole transport sector look like?

The initial question is how the global energy mix will develop over the next 30 years. To assess the situation, the IEA initially drafted three different scenarios [WEO2019]: the "Stated Policies Scenario", the "Sustainable Development Scenario" and the "Current Policies Scenario". Here the "Sustainable Development Scenario" is the most advanced regarding reduction of CO_2 emissions whereas the "Current Policies Scenario" is the most conservative.

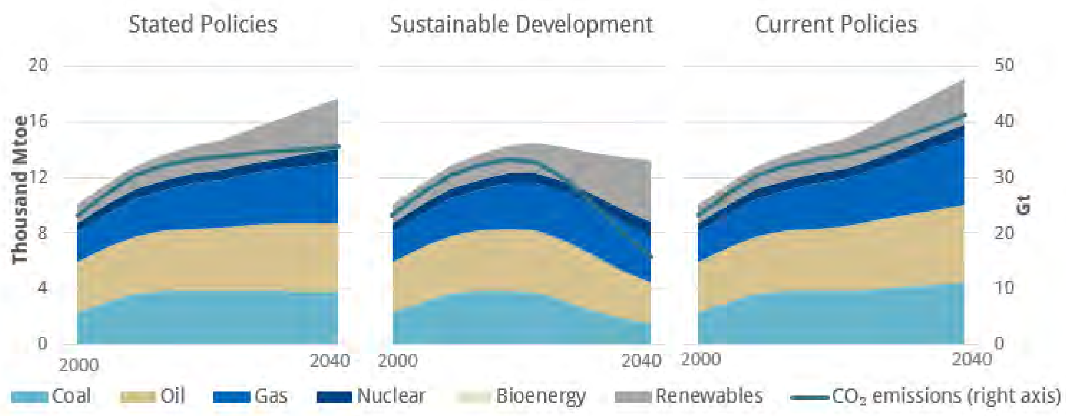

Figure 2: World primary energy demand by fuel and related CO_2 emissions by scenario [WEO2019][10]

Figures 3 and 4 provide insights into the use of biofuels in the transport sector and the overall global supply of low-carbon fuels for both the stated policies scenario and the sustainable development scenario.

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[10] The Current Policies Scenario shows what happens if the world continues along its present path, without any additional changes in policy. The Stated Policies Scenario, by contrast, incorporates today's policy intentions and targets. The Sustainable Development Scenario maps out a way to meet sustainable energy goals in full, requiring rapid and widespread changes across all parts of the energy system (WEO2019).

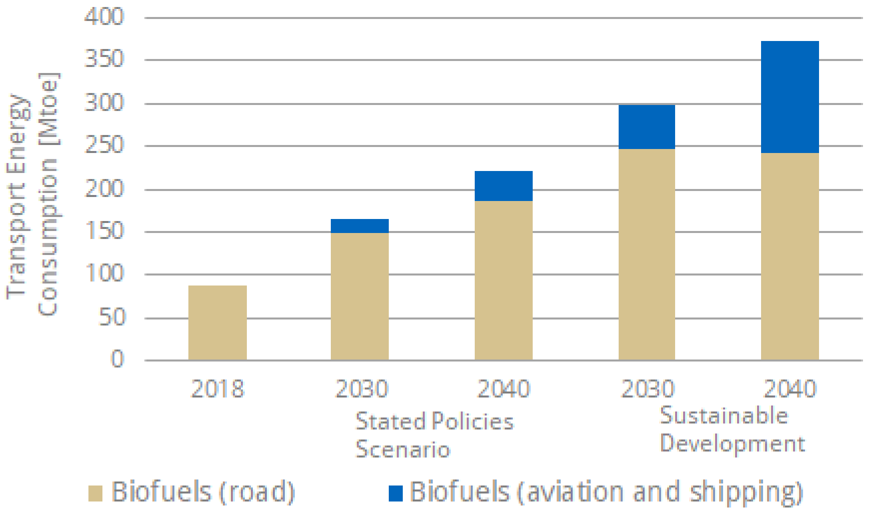

Figure 3: WEO 2019, Energy demand of the transport sector. Note: fossil fuel consumption is left out of the figure

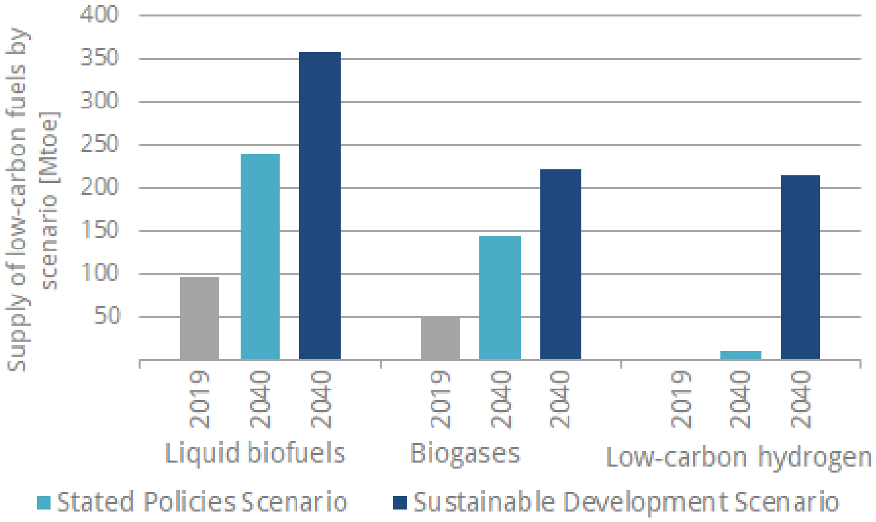

Figure 4: Global supply of low-carbon fuels by scenario [WEO2020]

In the WEO2020 a new scenario “Net Zero Emissions by 2050” was added. Here, the energy sector is expected to reach global net-zero emissions by 2050. Figure 5 shows the expectations for energy consumption for the different sectors industry, transport and buildings. Figure 6 shows the energy demand for the whole transport sector in the NZE 2050 scenario. The expected drop in energy demand is due to rising energy efficiency and other factors as also visualised in Figure 7.

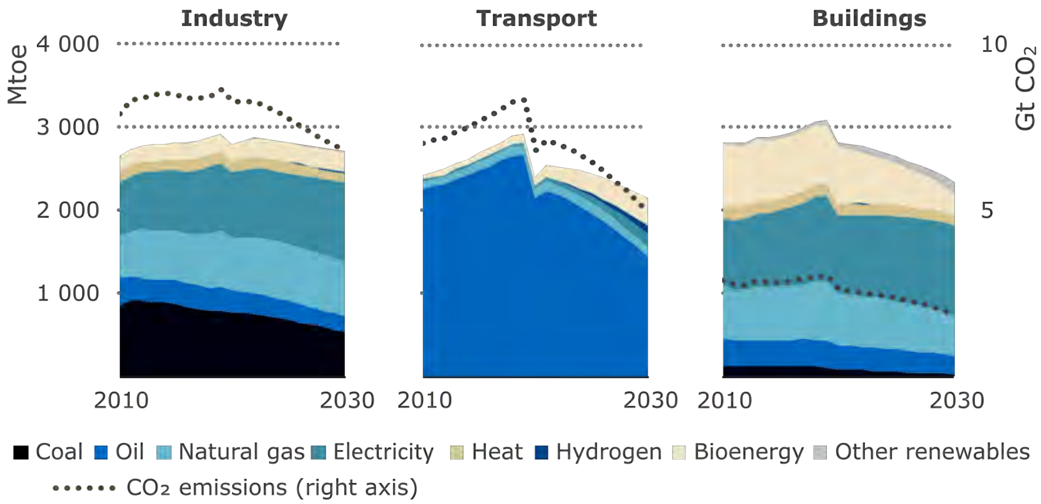

Figure 5: WEO2020, Energy demand of the whole transport sector in the NZE 2050 scenario

It can be seen in Figure 6, that in total for the whole transport sector, fossil fuels are expected to be still playing a role. According to the IEA the drop in energy consumption happens due to efficiency increase and a change in behaviour as well as an ongoing electrification of the private transport segment (e.g. private car owners).

The IRENA also gives an outlook towards 2050 for the transport sector. They assume a 58% share of renewables in 2050 for the whole sector. They come to the conclusion that "the transport sector is dominated by fossil fuels and needs to undergo a profound transformation" [IRENA – Global Energy Transformation – A Roadmap to 2050 (2019)].

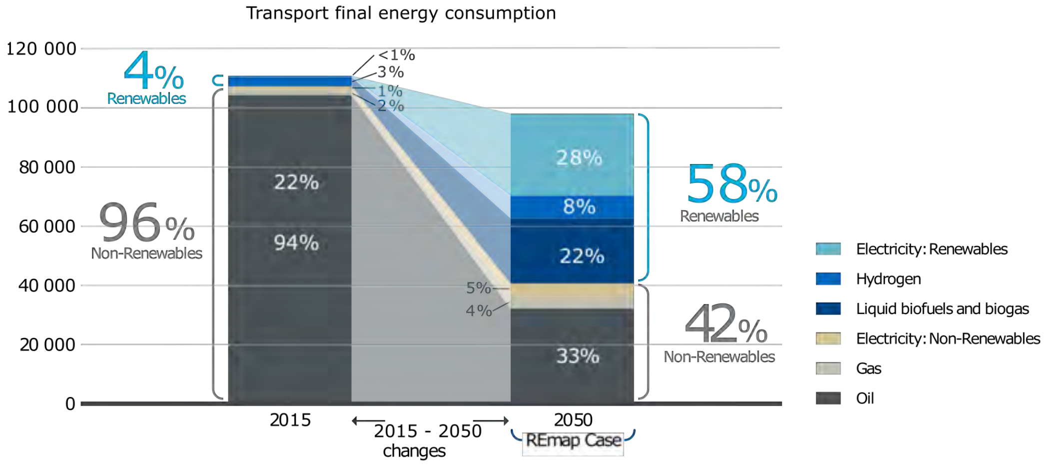

Figure 6: Transforming energy demand in the transport sector. A breakdown of final energy consumption in the transport sector, by source (PJ/year)

3.1 Fuel mix – IWT sector

The IWT sector is only a very small part of the global transport sector. The IWT sector has its own special drivers, barriers, regulatory and boundary conditions, but is also strongly dependent on developments in other parts of the transport sector. This interdependency will influence both the type and the amount of alternative energy carriers available to inland navigation. Also, technical developments and policies in the surrounding sectors are very influential. For example, the developments in much larger markers such as (short) sea shipping and road haulage can bring spin-off to inland navigation in terms of available technologies and their costs and the infrastructure for alternative fuel.

The following questions need to be answered from the IWT sector perspective:

- Which energy carriers will be established (production capacities, infrastructure, costs, safety)?
- How does the sustainability of energy carriers and converters chain evolve?
- Which technologies suit the IWT sector?

Figure 7 shows the IEA's assessment of the necessary development in the NZE2050 scenario until 2030 and how this can be achieved. In addition to the reductions achieved in the Sustainable Development Scenario (SDS) through the exchange of fuels, the factor "human behaviour" also plays a major role. For inland navigation, these factors include energy-efficient navigation and the optimisation of the logistics chain.

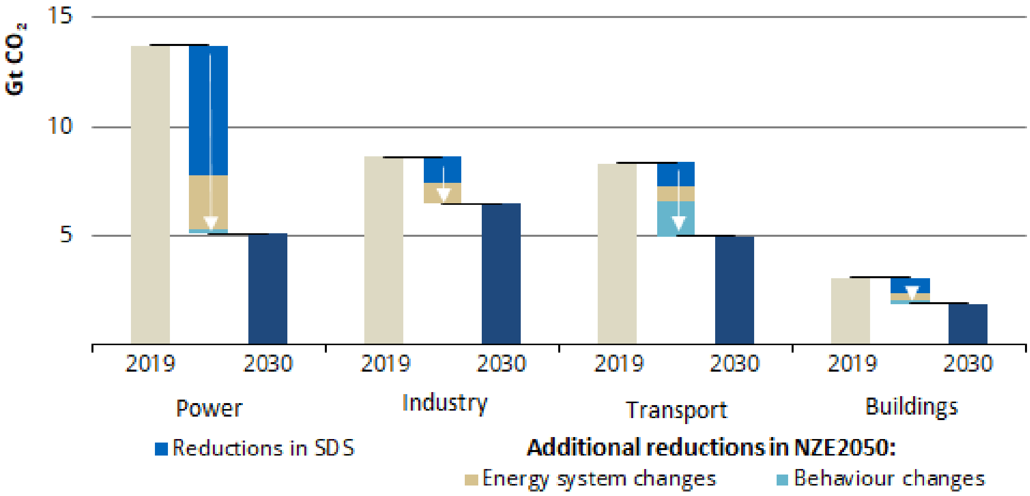

Figure 7: Factors for the reduction of emissions towards 2050 [WEO2020]

In its report [Energy transition outlook 2020], the DNV GL considers the possibilities for ocean shipping to become carbon neutral in 2050. The focus here is more on energy-rich liquid fuels than on pure hydrogen as can also be seen in Figures 8 and 9 below.

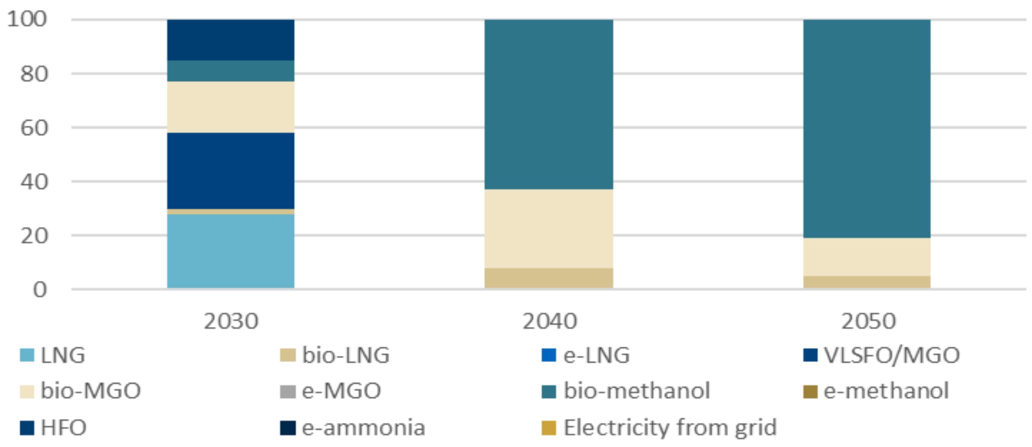

Figure 8: The DNV GL Energy transition outlook 2020 for the zero-emission pathway "Decarbonisation by 2040"

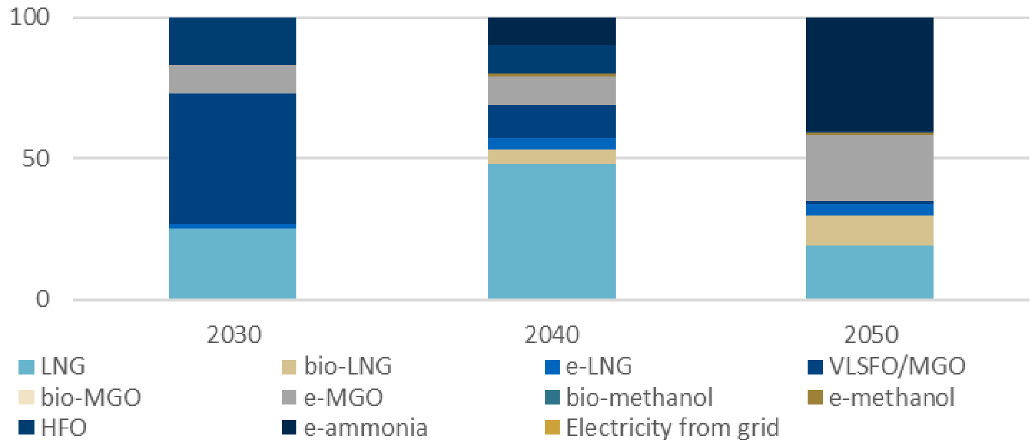

Figure 9: The DNV GL Energy transition outlook 2020 for the scenario "IMO ambitious pathway"

Overall, it is very difficult to state whether renewable fuels will be made sufficiently available for the IWT sector. This predominantly applies to biofuels, while there are a lot of uncertainties. These uncertain factors are for example the expected supply of biodiesel to the transport sector, and the expected demand from the transport sector. One of the key questions is whether certain transport segments like aviation will be prioritised for the delivery of biofuels since there are no other feasible alternatives for aviation on the short-term. Figures 3 and 4 compare the expected consumption and supply of biofuels until 2040. It seems that the demand and supply of liquid biofuels will be somewhat in balance. In case the demand exceeds the supply of liquid biofuels, then liquid biogases can be considered. Alternatively, if the feedstock to produce liquid and gaseous biofuels appear to be not enough[11], then it could be considered to produce e-fuels like e-diesel from green hydrogen and captured CO_2 to match the required

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[11] There are some analyses to the availability of biofuels. A study has been conducted by TNO and EICB (https://repository.tno.nl//islandora/object/uuid:c8ff78e0-34ef-4458-80dd-3c13ac7b6349). The production capacity of FAME and HVO is not considered a limiting factor. The availability of certain types of feedstock (e.g. UCO) could be a limiting factor though. This depends also on the priorities for distribution and use, e.g. whether aviation will be prioritised. No information is available on this topic.

demand. However, it should be noted that this will be considerably more expensive as compared to producing biodiesel from sustainable feedstocks which will be reflected in the final bunkering price.

The establishment of certain energy carriers is dependent on factors like production capacities, available infrastructure for both production and delivery, costs and safety issues. Nowadays a stimulation of hydrogen in several European countries can be seen. Whether this approach will lead to an immediate breakthrough in the inland navigation sector cannot be determined at this time.

Also, it is important not to ignore whether alternative fuels can be produced in a sustainable manner. Especially the consideration of the entire chain is important to identify truly sustainable alternatives.

In this section the assumptions for the upstream chain are explained. The main focus is on biofuels:

The IPCC provides the base that the biofuel CO_2 emission is already calculated and reported in the AFOLU sector (Agriculture, Forestry and Other Land Use) – IPCC volume 4[12]), so it shall not be reported in the emissions for transport/mobile combustion (IPCC volume 2). Furthermore, in the AFOLU sector also the CO_2 absorbed/removed from the air to make the feedstock for the biofuel is taken into account.

The basis laid down in IPCC is also included in the Directive (EU) 2009/28/EC[13]. The Directive uses that assumption to gain a zero-emission from a tank-to-wake (TTW) perspective for bio-fuels. In Annex V the following is stated:

> “10. The Commission shall review, by 31 December 2020, guidelines for the calculation of land carbon stocks drawing on the 2006 IPCC Guidelines[14] for National Greenhouse Gas Inventories – volume 4 and in accordance with Regulation (EU) No 525/2013 and Regulation (EU) 2018/841 of the European Parliament and of the Council. The Commission guidelines shall serve as the basis for the calculation of land carbon stocks for the purposes of this Directive.
>
> 11. Emissions from processing, ep, shall include emissions from the processing itself; from waste and leakages; and from the production of chemicals or products used in processing including the CO_2 emissions corresponding to the carbon contents of fossil inputs, whether or not actually combusted in the process. In accounting for the consumption of electricity not produced within the fuel production plant, the greenhouse gas emissions intensity of the production and distribution of that electricity shall be assumed to be equal to the average emission intensity of the production and distribution of electricity in a defined region. By way of derogation from this rule, producers may use an average value for an individual electricity production plant for electricity produced by that plant, if that plant is not connected to the electricity grid. Emissions from

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[12] https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028
[14] https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

> processing shall include emissions from drying of interim products and materials where relevant.
>
> 12. Emissions from transport and distribution, e_{td}, shall include emissions from the transport of raw and semi-finished materials and from the storage and distribution of finished materials. Emissions from transport and distribution to be taken into account under point 5 shall not be covered by this point.
>
> 13. Emissions of the fuel in use, e_u, shall be taken to be zero for biofuels and bioliquids. Emissions of non-CO_2 greenhouse gases (N_2O and CH_4) of the fuel in use shall be included in the e_u factor for bioliquids."

In addition to Directive (EU) 2009/28/EC, also RED II (Directive (EU) 2018/2001[15]) incorporated the same line of reasoning. This formed the basis for the assumption in this study to consider no CO_2 emissions from a TTW perspective for bio-fuels.

As regards the upstream emissions the RED II Directive includes rules for calculating the greenhouse gas impact of biofuels, bioliquids and their fossil fuel comparators. And as such, also the default and typical values for the greenhouse gas emission savings of the presented biofuel production pathways are presented. The potential savings in CO_2 are for example lower for biodiesel produced from palm oil (32% default value GHG saving WTW) and soybean (55% default value GHG saving WTW) as compared to biodiesel produced from waste cooking oil (88% default value GHG saving WTW) and biogas produced from wet manure (up to 206% default value GHG saving WTW). This shows that, depending on the feedstock, even GHG reductions over 100% are achievable. This may give arguments to promote fuels for IWT based on these feedstocks, such as Liquefied Bio Methane made from wet manure.

The biggest benefits can be realised by using advanced biofuels and minimise the overall direct and indirect land-use change impacts. Such fuels were not on the market or only in negligible quantities in 2016 (see Annex V of Directive). For example, with diesel produced from waste and farmed wood using the Fischer-Tropsch method in free-standing plant default values for GHG savings WTW of respectively 85% and 82% are given. On average, the listed advanced biofuels perform better as compared to 'conventional' biofuels.

Table 2 below shows different sources for the alternative fuels. In each case the source material and the possible end products are shown.

Table 3: Sources for alternative fuels

Based on fossils	Diesel, methane (LNG, CNG)
Based on biomass degrading and gasification	Bio-methane, -ammonia, -methanol, bio-diesel
Based on electrolysis and synthesis with fossil electricity	Methane, ammonia, methanol, hydrogen

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[15] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

Based on electrolysis and synthesis with renewable electricity	Methane, ammonia, methanol, hydrogen

It can be seen that depending on the primary energy source used and the production energy employed, the value of the upstream chain can be easily influenced. Paths involving the use of fossil energy for production can form a transition to completely climate-neutral upstream chains.

Khalili et al. [3] assume in their analysis exactly this development: they expect a very positive development regarding the upstream chain for almost all fuel types. Table 3 below shows their expectations.

Table 4: Source: Global Transportation Demand Development with Impacts on the Energy Demand and Greenhouse Gas Emissions in a Climate-Constrained World, 2019 [Khalili et al.]

Fuel	Method	Unit	2015	2020	2025	2030	2035	2040	2045	2050
Electricity	TTW	gCO_{2eq}/kWh_{el}	0	0	0	0	0	0	0	0
Hydrogen	TTW	gCO_{2eq}/kWh_{H2}	0	0	0	0	0	0	0	0
LNG	TTW	gCO_{2eq}/kWh_{CH4}	237	237	237	230	194	135	54	0
Liquid fuel	TTW	gCO_{2eq}/kWh_{th}	266	266	266	258	218	151	71	10
Electricity	WTW	gCO_{2eq}/kWh_{el}	513	373	140	47	15	6	2	0
Hydrogen	WTW	gCO_{2eq}/kWh_{H2}	389	395	334	223	148	65	21	0
LNG	WTW	gCO_{2eq}/kWh_{CH4}	300	300	300	294	251	176	71	0
Liquid fuel	WTW	gCO_{2eq}/kWh_{th}	368	366	366	358	305	211	96	8

Following this expected development, also RED II has dedicated targets for advanced biofuels with a relatively smaller GHG impact which, over time, must acquire a larger proportion in the fuel consumption.[16]

All the targets and expected developments indicate that also the upstream emissions of biofuels, e-fuels and electricity will move downwards towards meeting the 2050 objective. It can be seen though from Table 3 that WTW emissions of Hydrogen and Electricity will reduce at a faster pace than the WTW emission of LNG and liquid fuels. This can be a consideration in structuring a possible roadmap for IWT.

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[16] https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii & https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN (p.23 for feedstocks of advanced biofuels).

4 Transition pathways

Two transition pathways are developed for reaching the intermediary and final objectives of the Mannheim declaration by 2035 and 2050. As can be concluded from the BAU scenario, the main challenge is to reach the reduction levels for the GHG emissions. The 2050 objective can be interpreted as reducing the emissions of GHG, by at least 90% compared to the emission levels in 2015[17], whereas the intermediary objective targets a 35% reduction.

The two pathways consist of a 'conservative' pathway and an 'innovative' one. The conservative pathway refers to a pathway in which mainly alternative fuels and techniques are considered which are relatively easy to implement and cost efficient at the short term. This concerns alternatives like advanced biodiesel (in the following summarised as HVO for simplification) that can be used in existing diesel internal combustion engines or LBM that can be used in gas engines. These are called 'drop-in' solutions. These are fuels and techniques which have a high TRL[18] and are already available on the market. Table 5 below provides an overview of the TRL levels for the technologies considered in this analysis[19], consistent with chapter 2, section 2.5 (monofuel ICE assumed and renewable / climate neutral LBM, HVO, H_2 and MeOH).

Table 5: TRL level for application on an inland vessel and TRL for the fuel / energy production and supply

Technology	**TRL (1-9) vessel application**	**TRL (1-9) fuel / energy production and supply**
Diesel	9	9
HVO	9	9
LNG	9	9
LBM	9	8
Battery	8	7
H_2 FC	7	7
H_2 ICE	5	7
MeOH FC	7	6
MeOH ICE	5	6

The innovative pathway takes a more innovative approach with less internal combustion engines into account. The innovative pathway includes fuels and techniques which are currently still in their infancy stage (TRL 5-7) and are significantly more expensive

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[17] Clarified by CCNR: RV meeting June 2020. To be noted that delegations considered this interpretation as a first step and are committed to a regular reassessment of it.
[18] TRL levels as defined in Horizon 2020 https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
[19] TRL levels based on EIBIP Final Report December 2019 and STEERER draft Deliverable D2.1

as compared to advanced biodiesel and LBM.[20] These concern alternative technologies with a currently lower TRL like fuel cells and battery-electric propulsion systems. These alternatives perform better though in reducing emissions as compared to drop-in fuels. Also, the business case may become more attractive on the long run, depending on the price scenario. In the short term though, there is no positive business case for most cases. The future economic attractiveness will depend largely on policies to promote and support these alternative fuels in the wider transport sector and European industry as a whole. IWT may then benefit from breakthroughs of technologies and new arising economies, for example for hydrogen fuel cells, batteries and green electricity.

The next figures provide an overview of the division in fuels and techniques for all fleet families in both pathways and for both points in time (2035 and 2050).

In both pathways, the targets for GHG/CO_2e reduction and NO_x and PM reduction are reached or exceeded. For nitrogen oxide and particulate emissions, this results on the one hand from the widespread use of new engines with the Stage V exhaust standard compared to 2015. For GHG/CO_2e reduction, which represents the critical parameter here, the over fulfilment results from a defined investment strategy, according to which from 2020 onwards, the fulfilment of the interim target of 2035 and the final target of 2050 is started. Thus, the interim target of 2035 is slightly overachieved in order to have a more logical and smoother path towards the final target of 2050. This also goes hand in hand with the expected availability of the new technologies for a large part of the fleet: here, too, availability growth is assumed to be continuous and not to increase in sudden leaps.

To reach the 35% reduction in 2035 in the conservative pathway, the combustion engine is used in large parts of the fleet as can be seen in Figure 10. However, in addition to diesel, a large proportion of HVO is assumed in the calculations. This proportion of HVO is sufficient that in the conservative scenario the targets can be achieved with a comparatively small proportion of advanced technologies such as fuel cells and batteries.

The emission reduction potential in this conservative pathway per emission category for 2035 as compared to the figures in 2015 is as follows:

- GHG/CO_2e: 37%
- NO_x: 73%
- PM: 80%

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[20] As result, the amount of biodiesel used in the innovative pathway will be significantly less as compared to the biodiesel consumption in the conservative pathway. The expected annual biodiesel consumption in 2050 in the conservative pathway will be around 220,000 m^3 as compared to 32,000 m^3 in the innovative pathway.

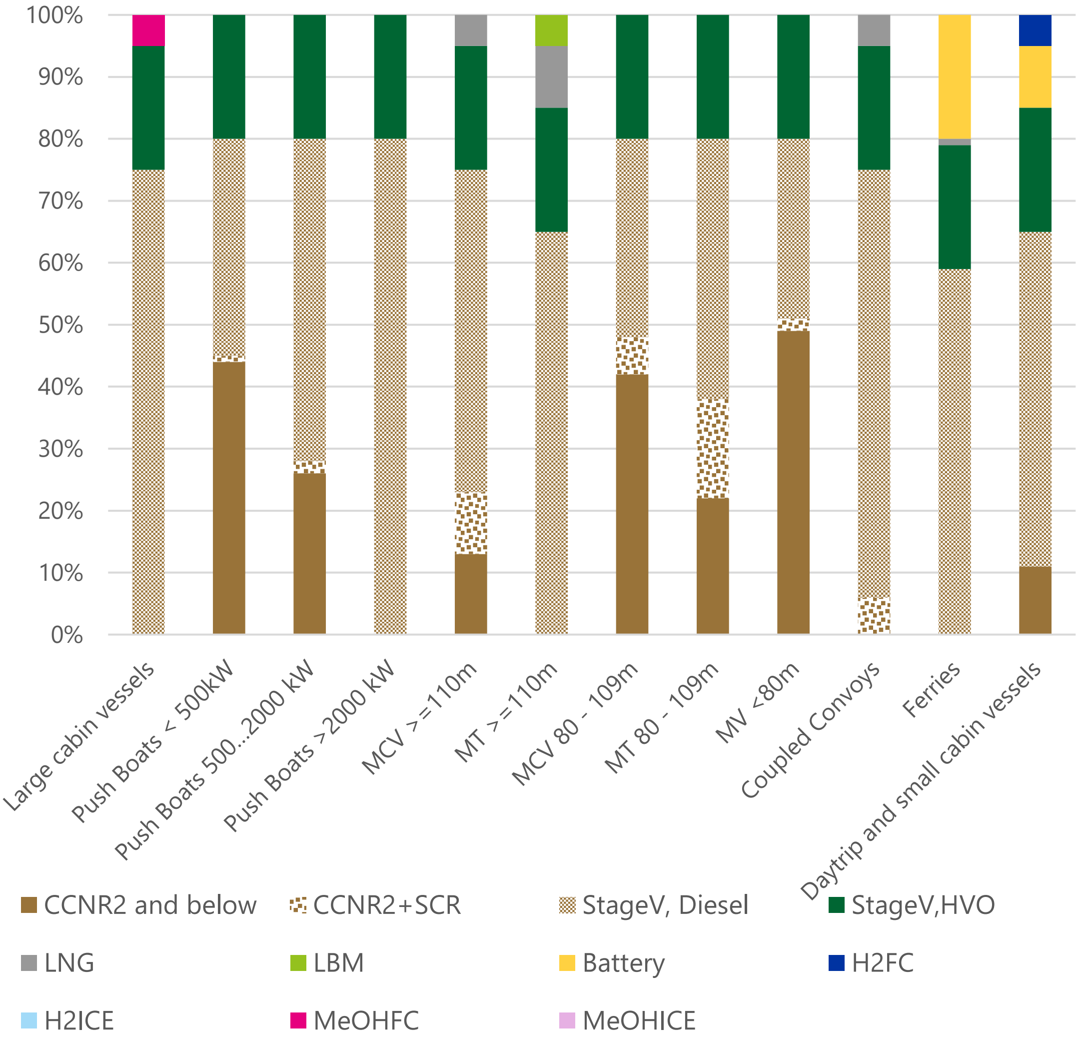

Figure 10: Fuels and techniques per fleet family in the Conservative Pathway in 2035

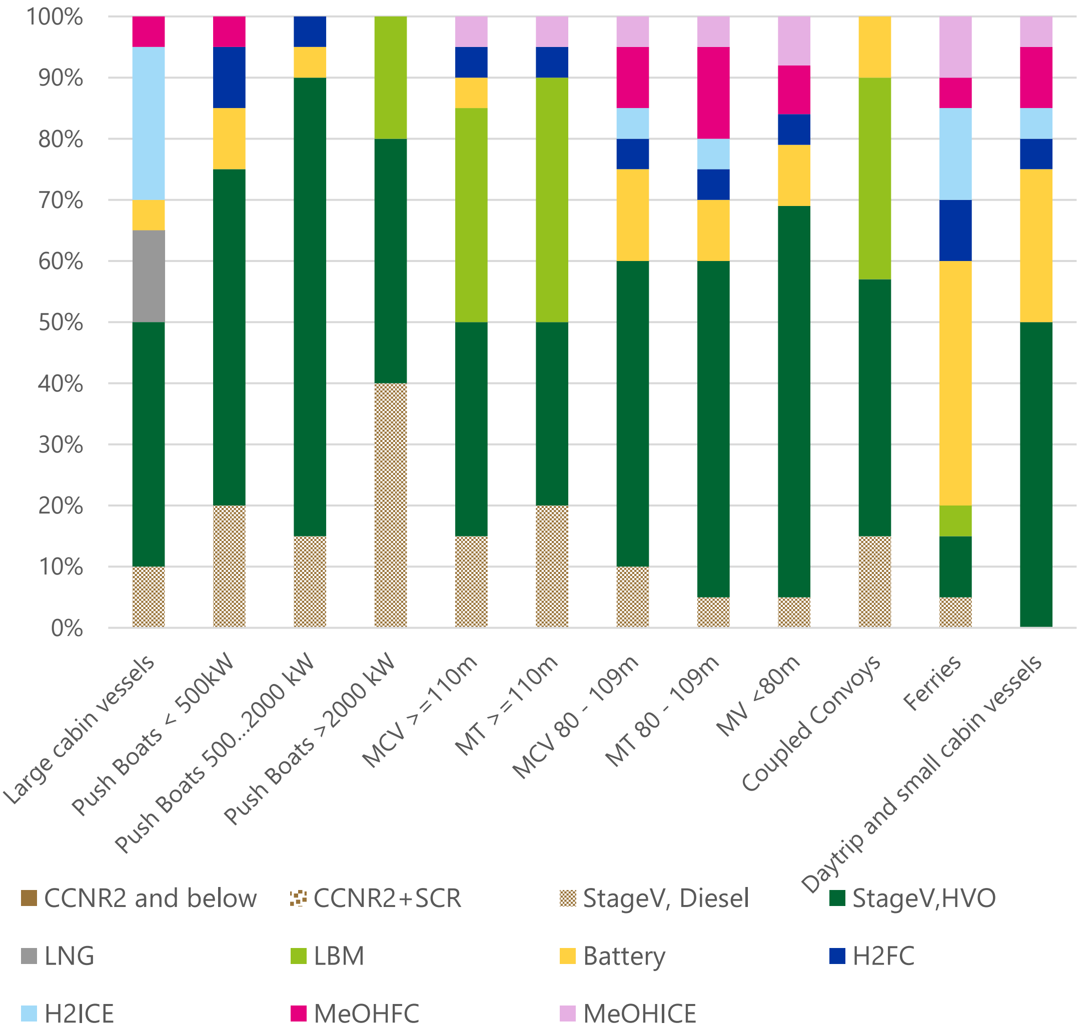

Figure 11: Fuels and techniques per fleet family in the Conservative Pathway in 2050

Figure 11 illustrates the division in fuels and techniques among the 12 fleet families in 2050 in the conservative pathway based on the number of vessels. The drop-in fuels HVO and LBM have a relatively large share, especially in the fleet families that have high engine powers installed and operating on medium/long distances. Vessels in those fleet families will be less suited for alternatives such as batteries due to the limited energy density (kWh per m^3 or kg) of a battery.

The emission reduction potential in this pathway per emission category for 2050 as compared to the figures in 2015 is as follows:

- GHG/CO_2e: 91%
- NO_x: 90%
- PM: 96%

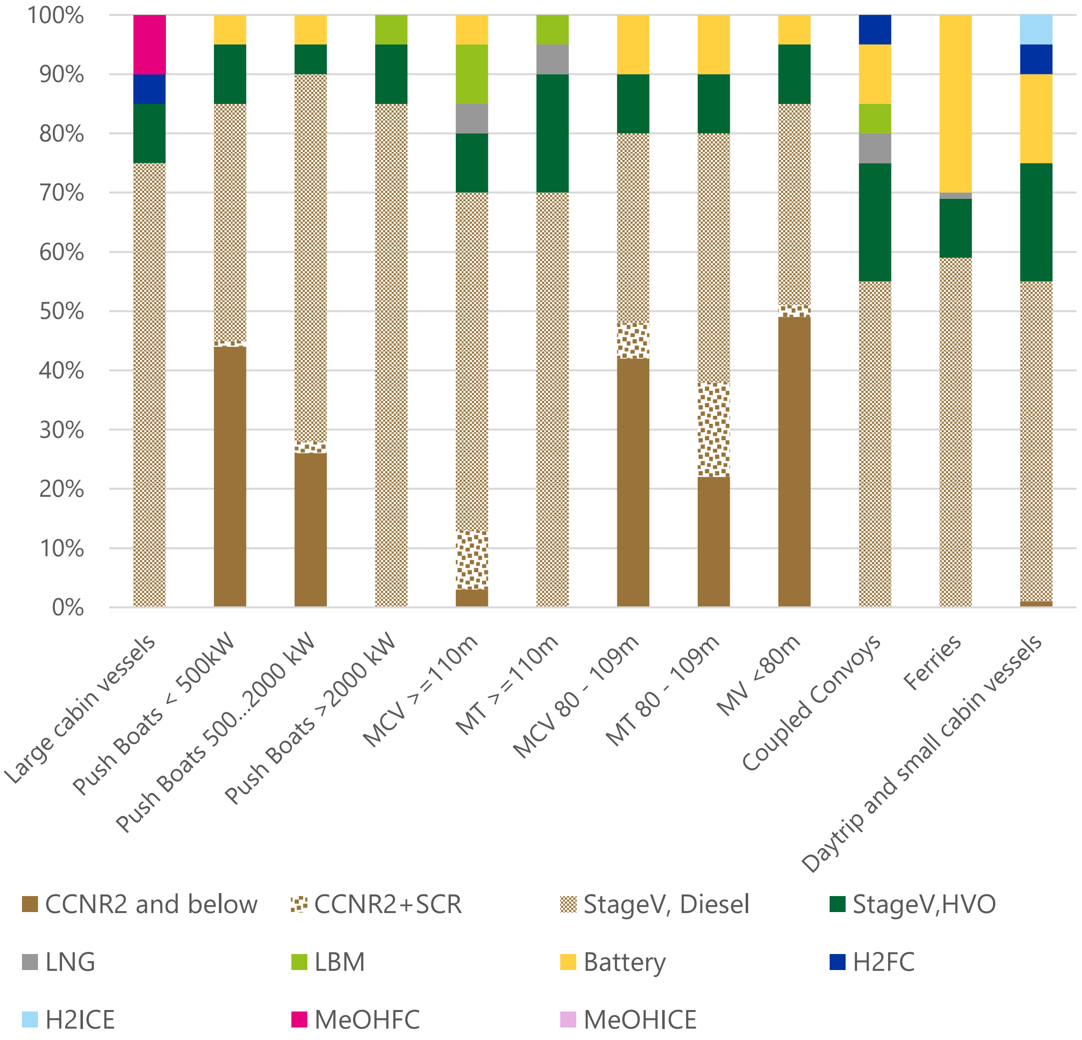

Figure 12: Fuels and techniques per fleet family in the Innovative Pathway in 2035

For the innovative path, a variety of different technologies will be used for all parts of the fleet as early as 2035. The proportion of HVO is correspondingly smaller. The distribution is shown in Figure 12.

The emission reduction potential in this pathway per emission category for 2035 as compared to the figures in 2015 is as follows:

- GHG/CO_2e: 36%
- NO_x: 76%
- PM: 82%

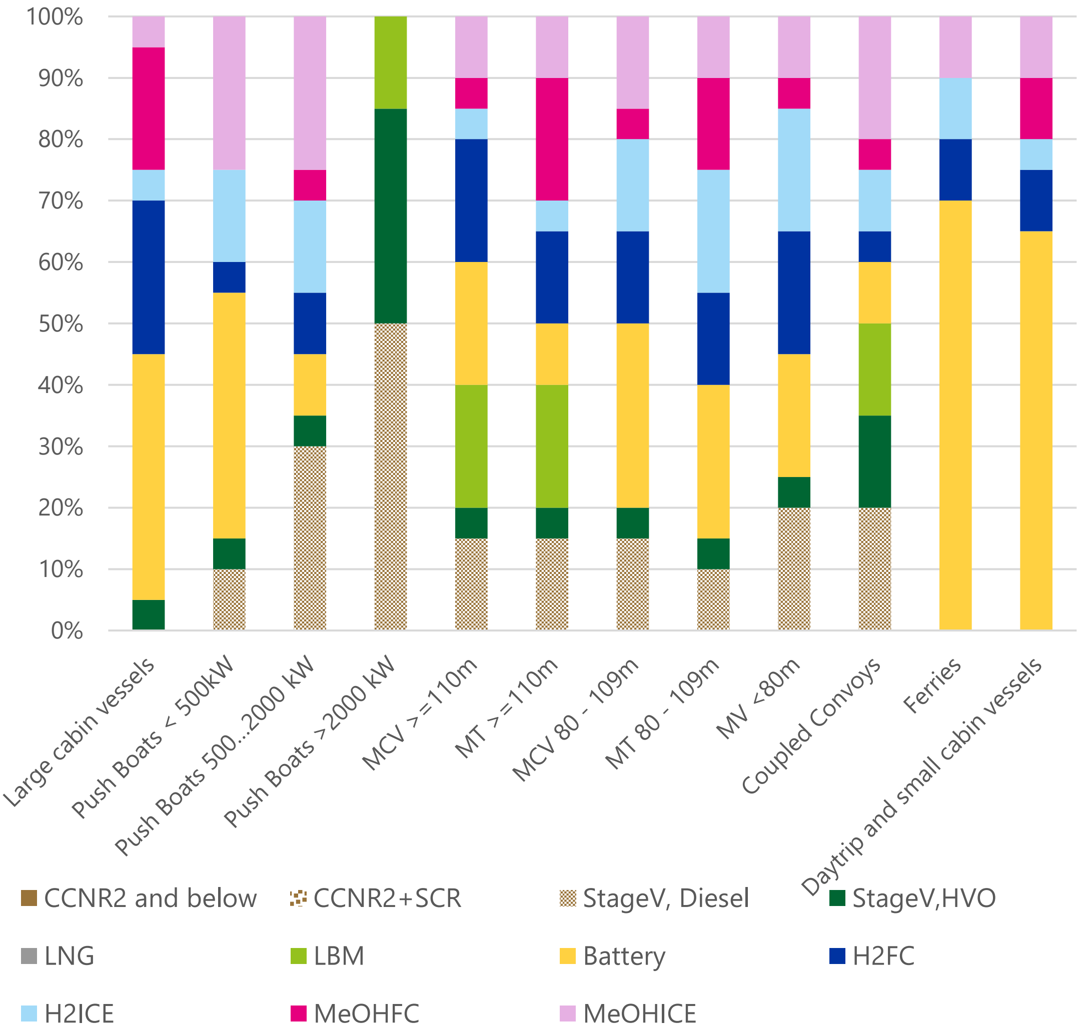

Figure 13: Fuels and techniques per fleet family in the Innovative Pathway in 2050

Figure 13 illustrates the division in fuels and techniques among the 12 fleet families in 2050 in the innovative pathway. It can be seen from the figure that the share of technologies is shifted towards battery-electric propulsion and both hydrogen and methanol. All of them being techniques which have a relatively lower TRL level as compared to HVO and LBM. An exception is the fleet family for the largest push boats (> 2000 kW). Those vessels are characterised by their high fuel consumption (highest in the sector on average), high installed power and limited suitability for alternative techniques/fuels. For example, batteries are less suitable since this would have a severe impact on the vessel given the required volume and weight of the batteries.

The emission reduction potential for year 2050 compared to year 2015 in this pathway is as follows:

- GHG/CO_2^{e}e: 91%
- NO_x: 94%
- PM: 98%

In addition to the detailed technology distribution per fleet family in the two periods, the figures below provide an overall overview in the technology distribution for the whole fleet from 2015 to 2050. Figure 1 for the BAU scenario already showed that diesel remains dominant as an energy source.

If one looks at the conservative pathway in comparison (see Figure 14), it becomes clear that the use of diesel will be significantly reduced by 2050 and that the largest shares will be taken over by the drop-in solution HVO. This matches the use of many internal combustion engines in this pathway.

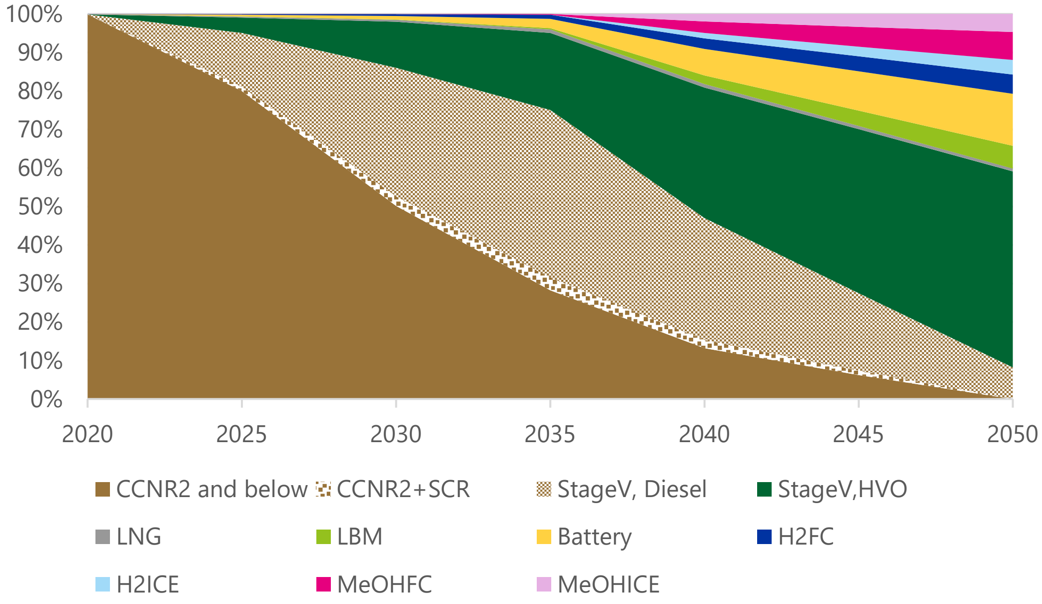

Figure 14: Development of fuel share in the Conservative Pathway

The innovative pathway (see Figure 15) shows that a large proportion of diesel will be replaced by methanol, hydrogen and batteries towards the year 2050. In contrast to the conservative pathway, the innovative pathway uses a greater variety of technologies. In particular the share of battery-electric sailing is expected to be large by year 2050, followed by the usage of hydrogen and methanol as energy carriers. As can be seen in the figure, the transition towards these energy carriers mainly takes place in the period 2035-2050.

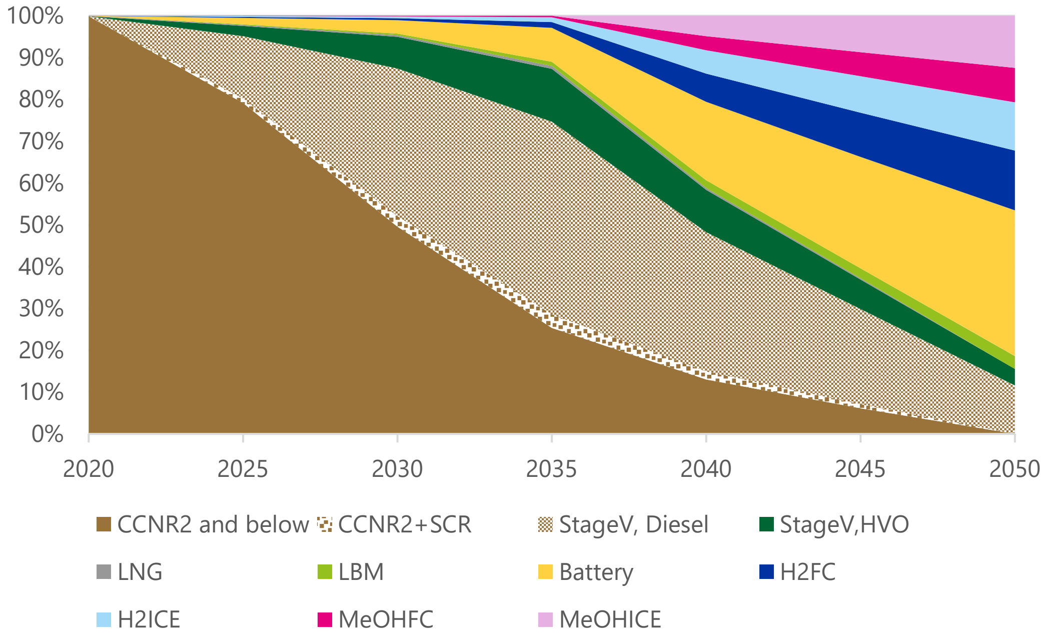

Figure 15: Development of fuel share in the Innovative Pathway

The next table presents the estimated quantities per fuel for the two pathways for years 2035 and 2050. In order to have a reference, in the year 2015 the IWT in Europe needed about 1.6 million tonnes of Diesel fuel.

Table 6: Needed fuel in the pathways in tonnes

Fuel	Conservative Pathway 2035	Conservative Pathway 2050	Innovative Pathway 2035	Innovative Pathway 2050
Diesel	907,365	170,312	899,489	190,322
HVO	277,102	509,481	148,420	73,809
LNG	20,082	8,832	13,462	0
LBM	14,775	113,287	26,482	61,038
H2FC	2,047	10,534	7,238	37,077
H2ICE	1,205	9,813	3,551	25,293
MeOHFC	20,025	87,784	38,530	159,546
MeOHICE	6,246	66,567	18,490	199,514

It shall be noted that the demand for electricity (for battery-electric sailing) can be expressed in energy in MWh. The following figures apply in addition to the table above:

- 2035 Conservative Pathway: 50,813 MWh per year
- 2050 Conservative Pathway: 381,005 MWh per year
- 2035 Innovative Pathway: 317,924 MWh per year
- 2050 Innovative Pathway: 1,120,359 MWh per year.

5 TCO for transition pathways and BAU

5.1 Definitions for the calculations

CAPEX: In this study we assume the CAPEX (Capital Expenditure) to be the initial **investment costs** consisting of the investment in the equipment (e.g. Stage V diesel engine, batteries, etc.) and the **installation costs** (e.g. installation of an engine, electrification of a vessel for FC and battery applications, etc.).

OPEX: In this study we assume the OPEX (Operational Expenditure) to be the costs consisting of the **fuel costs** and **maintenance costs**. Annual maintenance costs are expressed in a percentage of the initial capital expenditure (CAPEX). The annual OPEX is calculated as input for the TCO.

Capital costs: In this study we assume the annual capital costs to be the costs consisting of the yearly **depreciation costs** and **interest costs** based on the initial capital expenditure (CAPEX). It therefore takes into account the expected lifetime of the equipment for the depreciation costs and the interest rate for the interest costs. The annual capital costs are calculated as input for the TCO.

TCO: In this study we assume the TCO (Total Cost of Ownership) to be the sum of **Capital costs** and the **OPEX**. The TCO also takes into account the **time and payload loss**, resulting in less revenues for the ship owners a result of particular technologies (for example batteries).

Given the technology division throughout time for the BAU scenario and the two transition pathways, a further elaboration has been made on the CAPEX, OPEX and TCO and aggregated numbers have been made for the fleet as a whole.

A number of assumptions have been made. This includes price level assumptions for the techniques and fuels, but also concerning the expected prices for the installation, maintenance, capital costs and depreciation.

Figure 16 provides an overview of the fuel costs for fossil diesel and the considered alternative fuels that fit in the transition pathways. The figure illustrates the fuel cost range (min to max) for the periods 2020, 2035 and 2050.

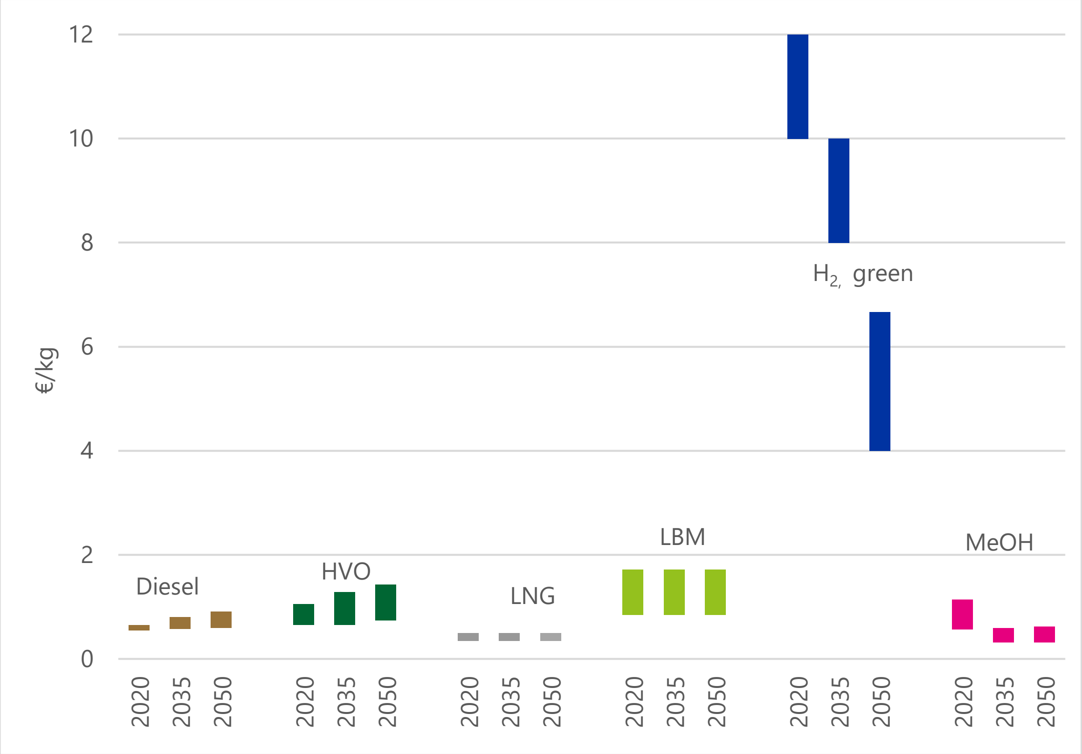

Figure 16: Fuel costs per kg

Table 14 in Annex II provides a more detailed overview of the prices. Three fuel price scenarios (minimum, average and maximum) are defined for each five-year period starting from 2020 until 2050. The prices are based on a number of sources and are fine-tuned based on expert knowledge. The main source used is the World Energy Outlook 2020 of the International Energy Agency. The price information in this outlook has been taken as a basis and has been further refined based on expert knowledge. The refinements are based on the following assumptions:

- Diesel prices according to International Energy Agency (IEA) scenarios; min and max estimated with ± 20% 2020/2035/2050 averaged Diesel price.
- LNG prices according to IEA and an additional factor for bunkering (3× higher than Wholesale price).
- Electricity price constant, price below 3 cents is not to be expected.
- By 2040, the supply costs for decarbonised gases are closing in on those for natural gas, especially if externalities are taken into account.
- H_2 prices according to IEA; prices 2040 = prices 2050. Green H_2 (from electrolyses) is expected to become cheaper in future. However, as can be seen there is a large bandwidth in the price predictions, which are reflected in the large bandwidth in Figure 16.
- Bio gas prices according to IEA; including CH_4 taxes.

- Methanol prices according to Methanol Market Services Asia (MMSA) and "E-Binnenschiff" and further refined based on the IEA Bioenergy report[21]. Prices for renewable methanol are expected to decline as result of developing technologies in production.

- Prices for HVO and LBM were based on this the IEA Bioenergy report. The price of HVO is expected to increase due to a growing demand and limited volumes of feedstock to produce the renewable fuel. For LBM the price is expected to remain stable but the bandwidth of uncertainty is significant.

In addition to the fuel costs, Figure 17 provides an overview of the costs for the considered techniques, also in a range (min to max) for three time periods. Except for the batteries, the prices for the technologies are based on expert consultations (e.g. with knowledge institutions and equipment suppliers in IWT) and knowledge from ongoing/completed projects. Information on battery prices is mainly retrieved from the Bloomberg & JRC report[22]. Prices for MeOH and H_2 concern the green variants, therefore either made from green electricity of renewable feedstocks. Table 15 in Annex II provides a more detailed overview of the technology costs.

Furthermore, Table 16 in Annex II provides an overview for the installation costs, maintenance costs, capital and depreciation costs, and the average fuel demand and installed power per fleet family.

The installation costs relate to the base costs for equipping a vessel with a particular technique, e.g. the electrification of a vessel in order to make it suited for a battery-electric propulsion or the system base price for an LNG drivetrain. These costs are based on market knowledge.

The capital costs are assumed to be at 6% interest rate and a depreciation period is assumed of 20 years for the overall system on board of the vessel. Hence, this excludes the lifetime of individual membranes in FC's or battery cells in the overall battery-electric system. The costs for overhauling/replacement of the specific parts in FC or batteries are covered in the maintenance costs and therefore are included in the OPEX. These costs are quite substantial compared to costs for internal combustion engines (ICE) which have a longer lifetime while the ICE is less costly per installed kW.

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[21] https://www.ieabioenergy.com/wp-content/uploads/2020/02/T41_CostReductionBiofuels-11_02_19-final.pdf

[22] Consulted sources are: Horváth & Partners; Bloomberg New Energy Finance, 2019. K. Baes, "Future of batteries," 2018. L. Goldie-Scot, "A Behind the Scenes Take on Lithium-ion Battery Prices," 2019. I. Tsiropoulos, D. Tarvydas and N. Lebedeva, "Li-ion batteries for mobility and station-ary storage applications Scenarios for costs and market growth," 12 2018.

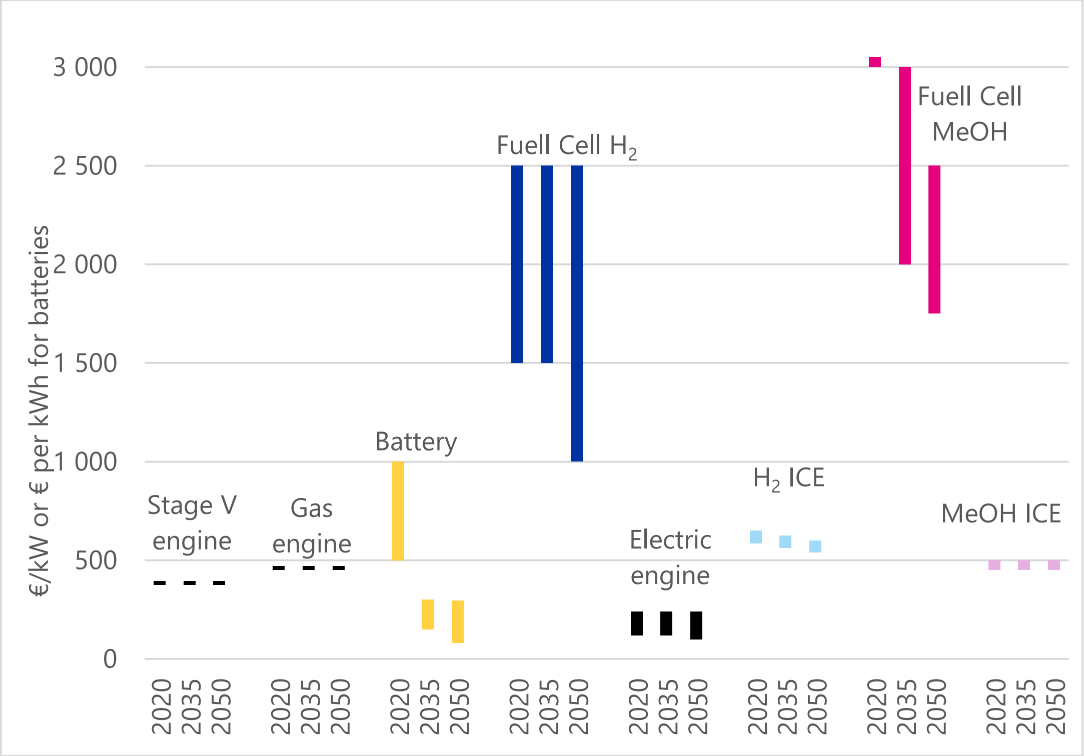

Figure 17: Energy cost per kWh for different energy sources, bandwidth minimum - maximum

The annual maintenance costs have been calculated and integrated as well. For details, please see Annex II Table 16. An average annual fuel consumption and average installed power is being assumed per fleet family.

Given the cost information CAPEX, OPEX and TCO calculations have been made for all three scenarios, i.e. the BAU scenario, the conservative pathway and the innovative pathway.

5.2 BAU Scenario

The series of figures below provide an overview of the CAPEX, OPEX and TCO (including share of capital costs) for the BAU scenario.

The scale “M€/a” means million euro per year (annum).

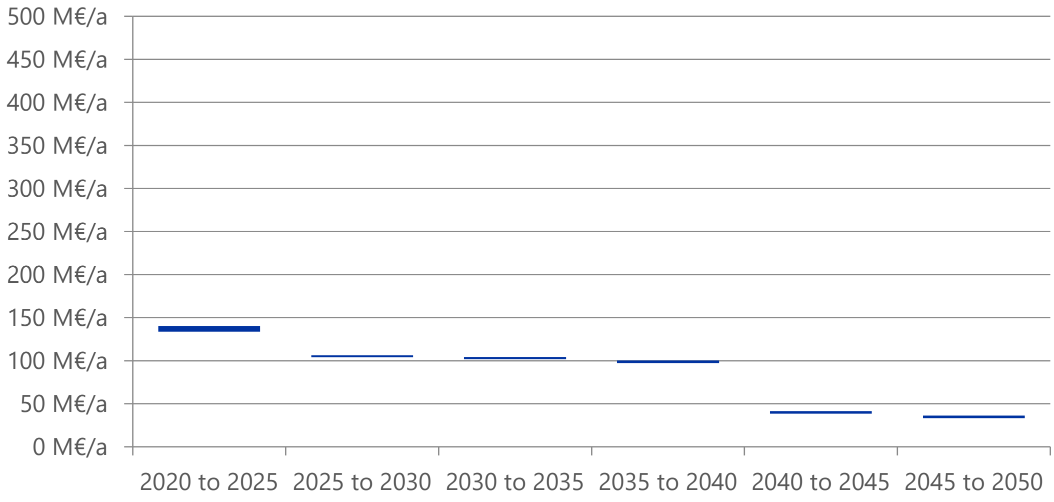

Figure 18: CAPEX per year in 5-year period in BAU scenario, including the range for minimum to maximum price levels

It can be seen that the CAPEX for the fleet will be relatively highest in the period 2020-2025. This is due to the grant schemes made available in The Netherlands for SCR retrofit and Stage V engine renewal which triggers investments. The CCNR 2 requirement for access to Port of Rotterdam from 2025 onwards is another driver for engine renewal in existing vessels.

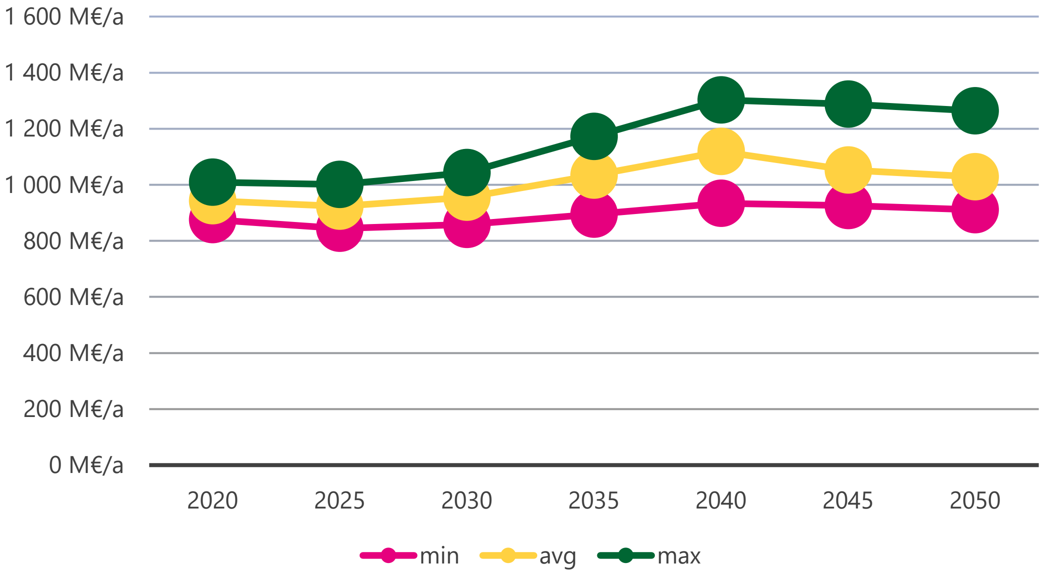

Figure 19: OPEX per year in BAU scenario, including the range for minimum to maximum price levels

It can be seen in Figure 19 that the operational costs for the BAU scenario strongly depend on the price assumptions. In particular in the maximum scenario an increase of the diesel price is expected towards 2040 resulting in higher OPEX. In the minimum scenario there is however not much change expected on the operational costs in the period towards 2050.

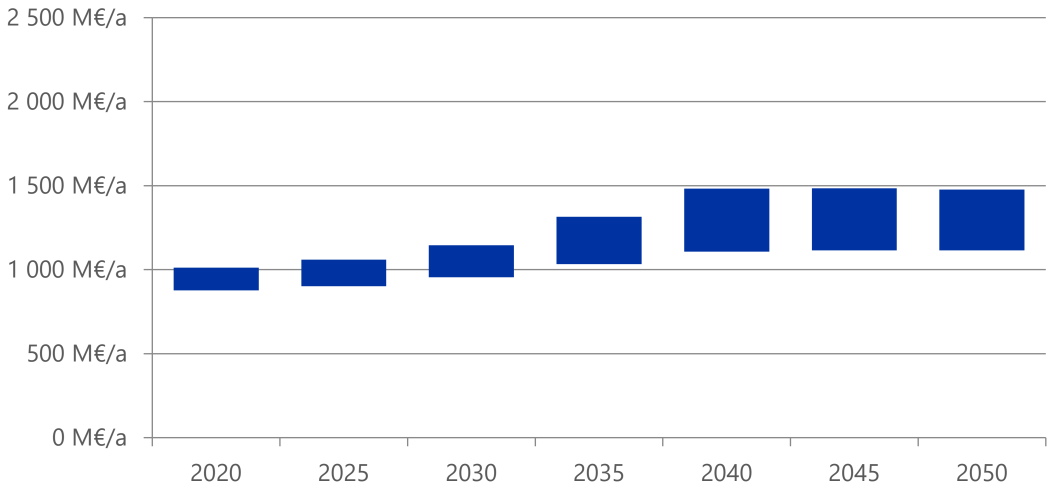

Figure 20: TCO for the fleet per year in the BAU scenario, providing the range between for minimum to maximum price levels

The Figure of the TCO for BAU shows that the expectation is that the costs will increase from a range between 0.9 – 1 billion euro per year in 2020 towards 1.5 billion euro per year in the period 2040-2050. This is mainly the result of the higher capital costs for the more expensive Stage V engines in combination with increasing fuel prices for diesel and HVO and increasing maintenance costs for the powertrain.

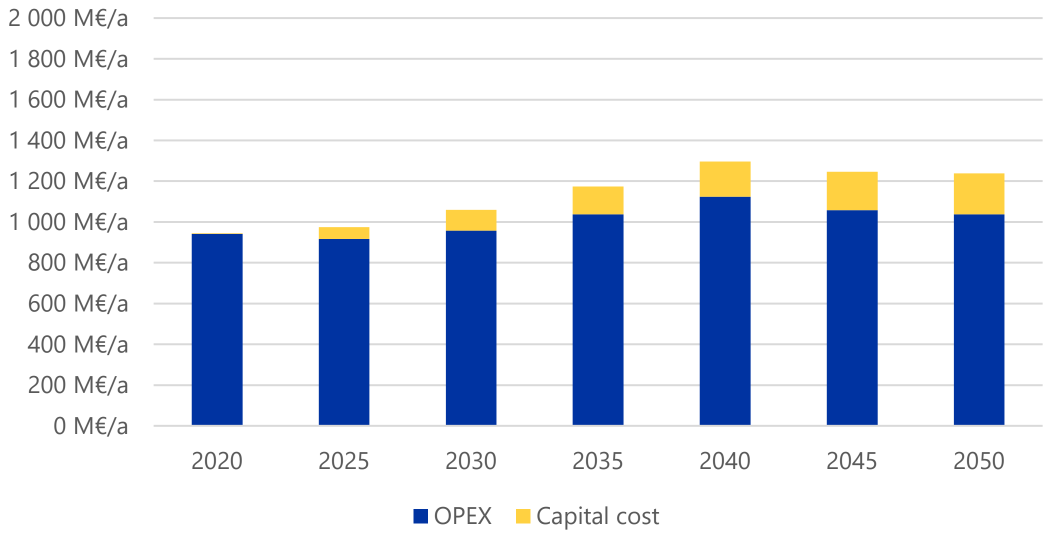

Figure 21: The split between capital cost plus depreciation and the rest of the TCO shows the numbers for the average price scenario[23]

The illustrated CAPEX investments per 5-year period in Figure 18 shows a drop in investments throughout the period, first after 2025 and a second time after 2040. This is related to the drop in engine renewals. Based on the engine renewal rate, it is expected that engine renewals (investments in new Stage V engines) will drop significantly after 2040. Investments in zero-emission technologies will take up slightly in the period after 2035 although in terms of numbers this is in stark contrast to the investments in Stage V diesel engines in the period before 2035.

Furthermore, the capital and depreciation costs for investments made between 2020-2050 are also included in the TCO and will grow as the share of more expensive techniques increases in the total fleet, e.g. batteries for passenger vessels. These costs are also highlighted in Figure 21.

5.3 Conservative Pathway

The next series of figures provide an overview of the CAPEX, OPEX and TCO (including share of capital costs) for the conservative pathway.

In contrast to CAPEX investments in the BAU scenario, the investments in the conservative pathway are significantly higher and increasing towards 2040 only to slightly fall again due to expected price reductions of technologies. The main reason for this contrast is, of course, the fact that in this scenario much more is invested in both Stage V diesel combustion engines and the more expensive technologies with a relatively larger

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[23] Only the capital costs for new technologies and fuels are considered in this overview.

emission reduction potential. It can also be observed that the cost range increases with time. This is due to greater price uncertainties towards the future.

The annual OPEX follows the same trend as the CAPEX investments. After 2035, more new technologies are expected to be applied on vessels. OPEX will have to develop first. Hence, they will diverge greatly at first. With increasing economies of scale, a price reduction is assumed.

The TCO is growing towards 2050, as the financing of technologies is also priced in here, and a growing number of vessels has to finance the installed technologies. These costs are highlighted in the last figure.

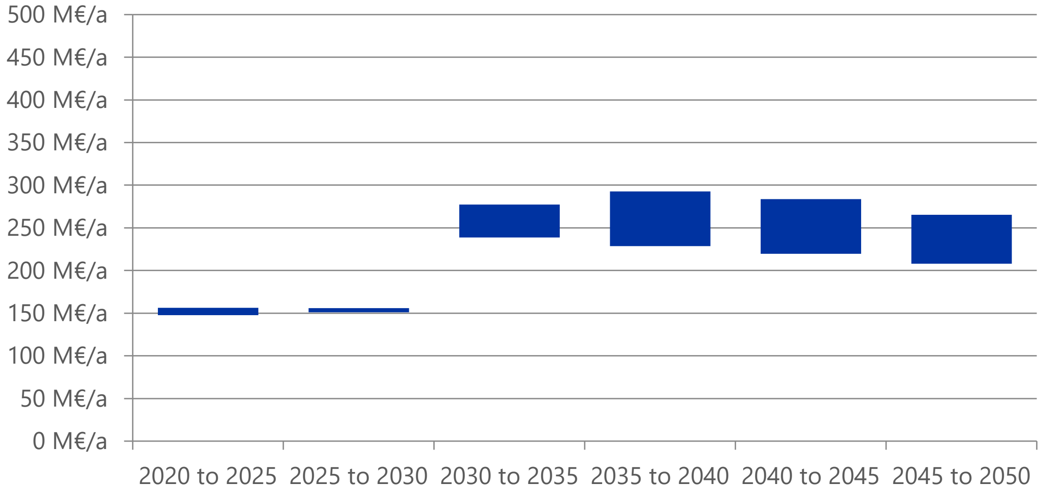

Figure 22: CAPEX per year per 5-year period in the Conservative Pathway

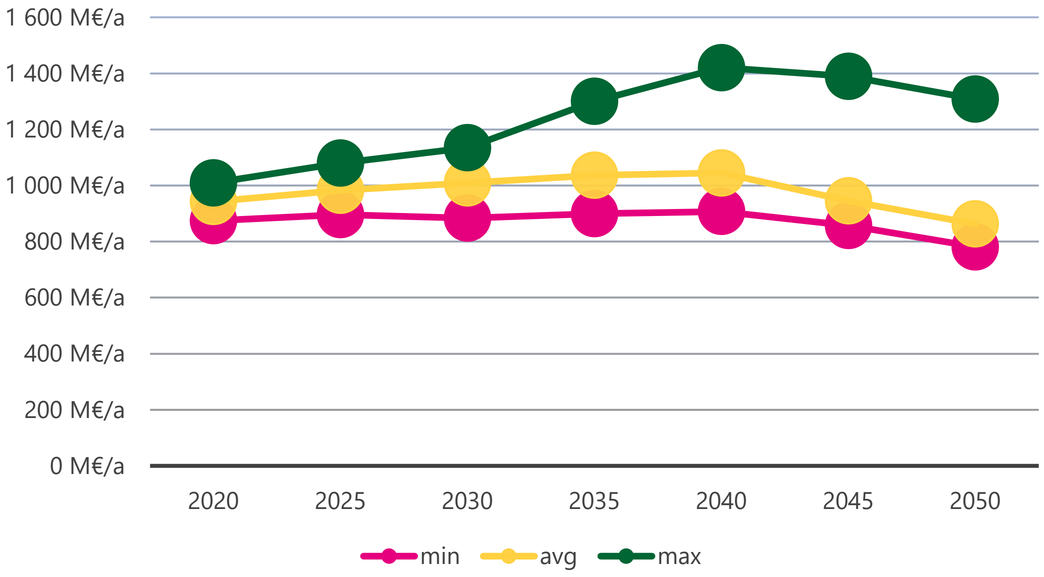

Figure 23: OPEX per year in the Conservative Pathway

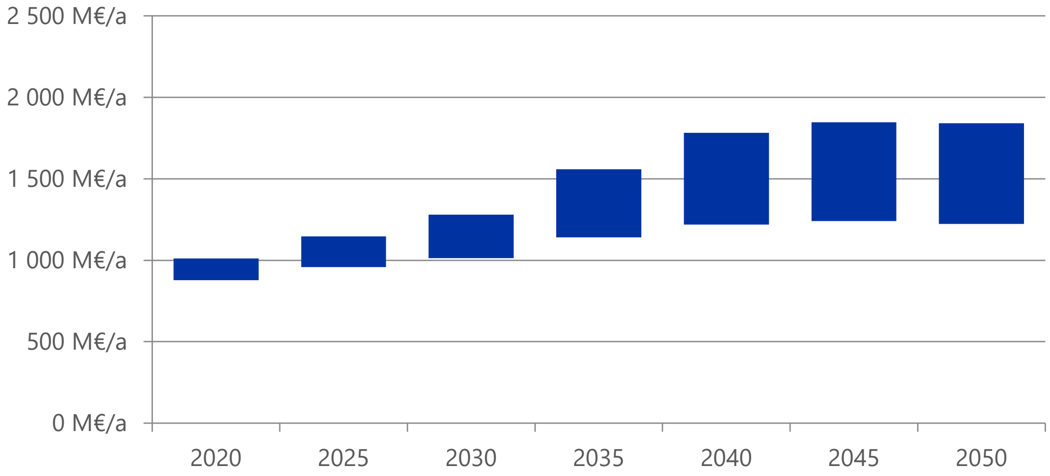

Figure 24: TCO per year in the Conservative Pathway

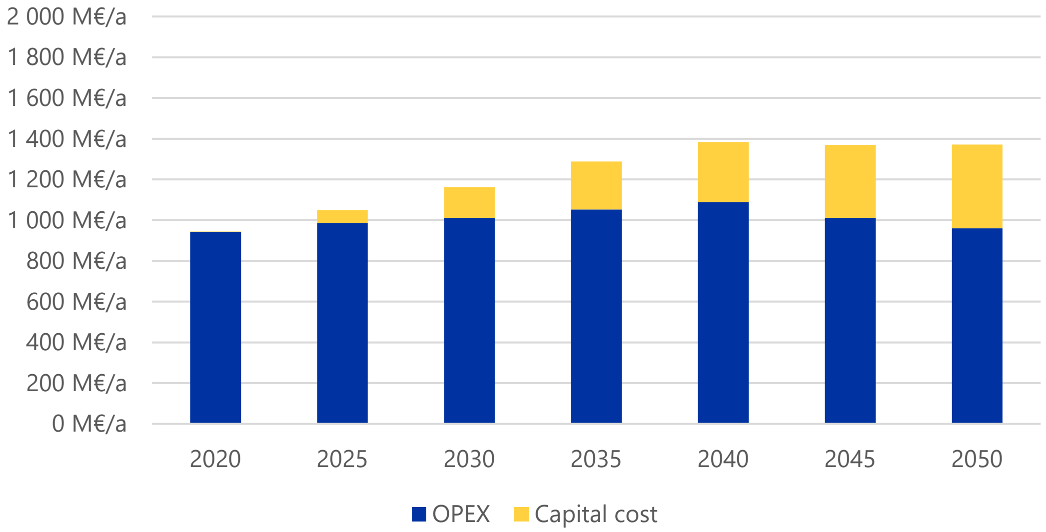

Figure 25: Capital cost and depreciation as part of the TCO for the average price scenario in the Conservative Pathway

5.4 Innovative Pathway

The last series of figures provide an overview of the CAPEX, OPEX and TCO (including share of capital costs) for the innovative pathway. The only key difference with the findings in the conservative pathway are the higher costs. The costs are higher for the CAPEX, OPEX and the overall TCO as well. This is of course due to nature of the investments, i.e. relatively more investments in more expensive technologies such as H_2 FCs and batteries.

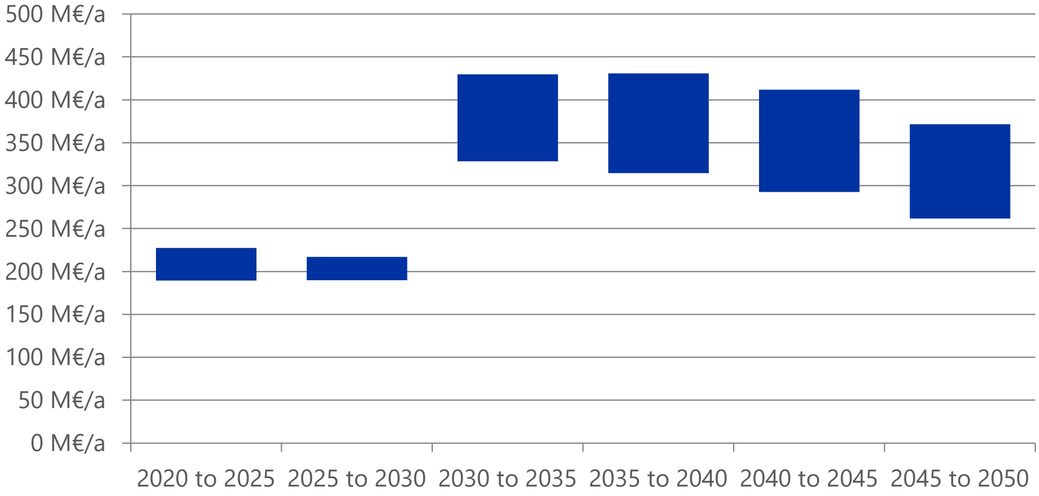

Figure 26: CAPEX per year per 5-year period in the Innovative Pathway

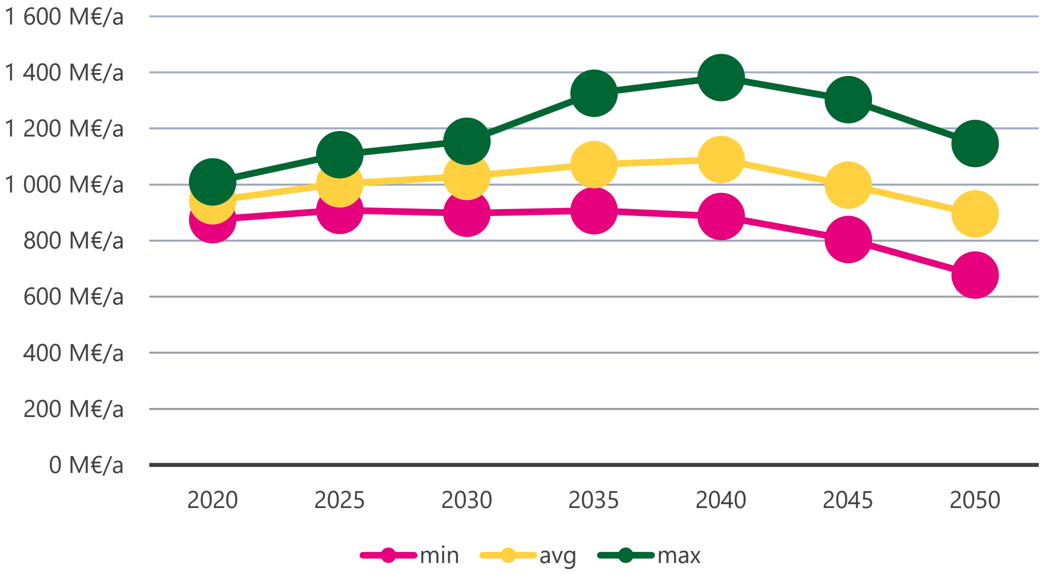

Figure 27: OPEX per year in the Innovative Pathway

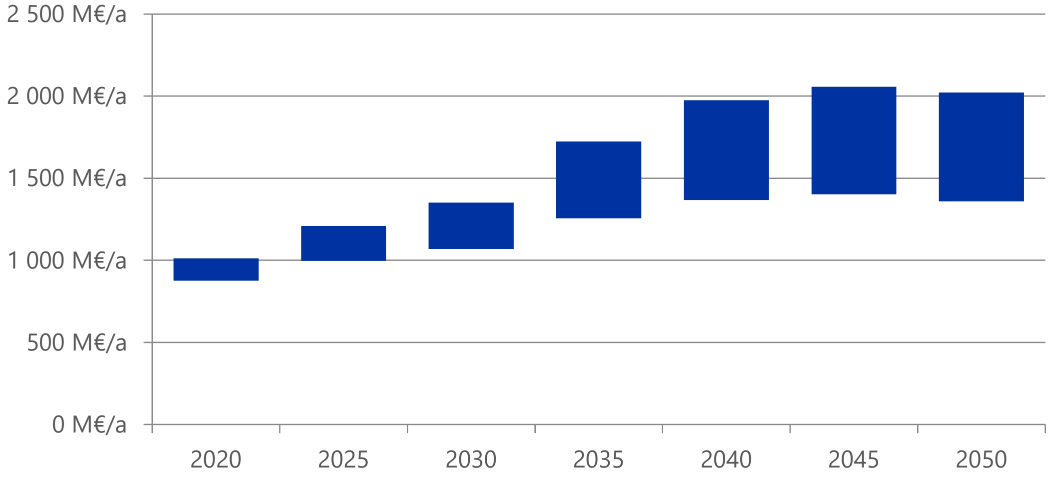

Figure 28: TCO per year in the Innovative Pathway

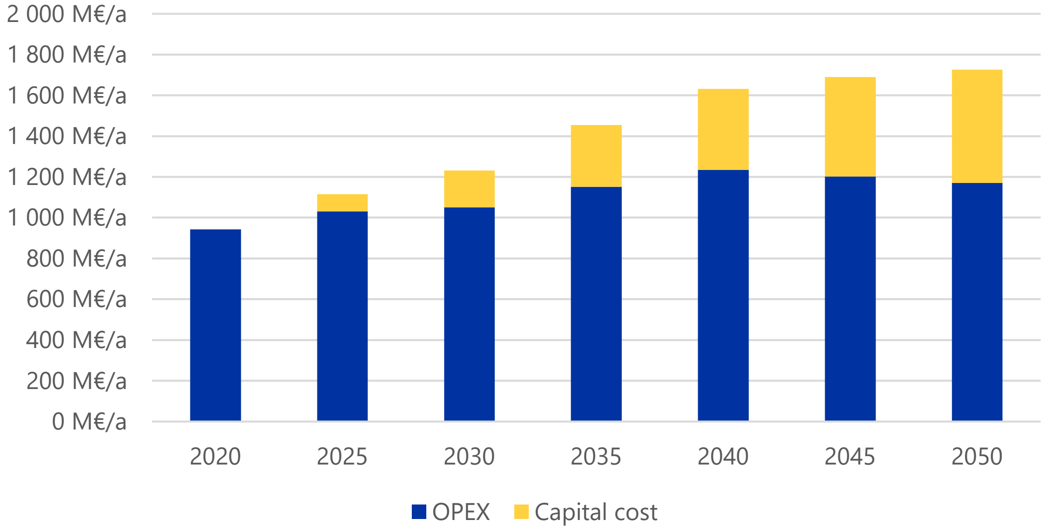

Figure 29: Capital cost and depreciation as part of the TCO in the average price scenario in the Innovative Pathway

6 Financial gap

Given the calculations in chapter 5, it is possible to carry out an analysis to determine the financial gap. In this chapter the difference in costs is made visible for the TCO, CAPEX and OPEX for the two transition pathways as compared to the BAU scenario.

This is indicative for the required financial support needed to reach the emission reduction goals, either by means of the conservative or more innovative approach.

Figure 30 illustrates the annual TCO gap between the conservative pathway and the BAU scenario indicating the bandwidth based on the price scenarios (minimum, average, maximum).

Subsequently, Figure 31 illustrates the annual TCO gap between the innovative pathway and the BAU scenario.

Figures 32 and 33 present the gap information as regards the CAPEX. Table 5, 6 and 7 provide an overall overview of the detailed figures as regards the CAPEX, OPEX and TCO.

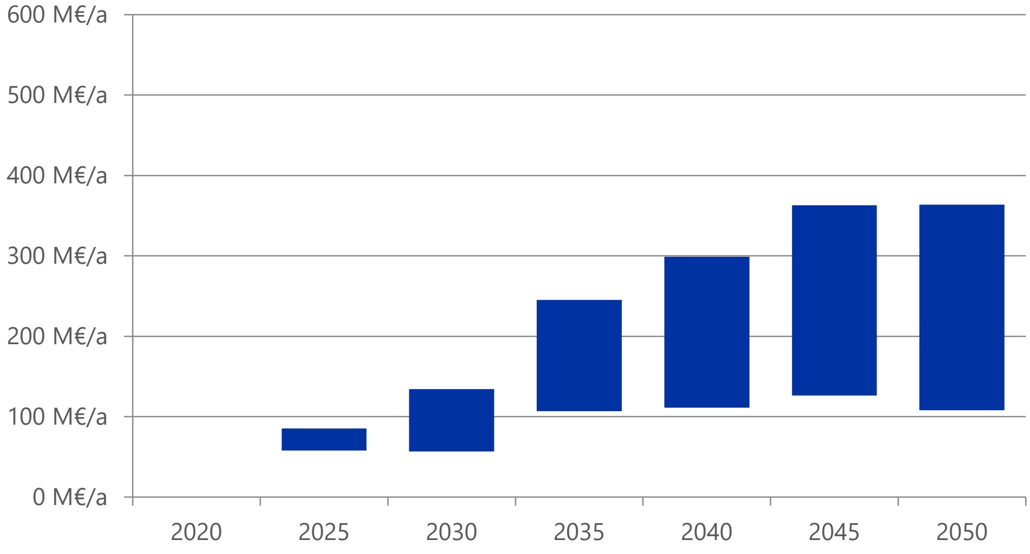

Figure 30: Annual TCO gap between Conservative Pathway and BAU

It can be seen that the TCO gap gradually increases over time for the conservative scenario reaching around 250 million euro per year in the year 2050 of additional costs compared to BAU.

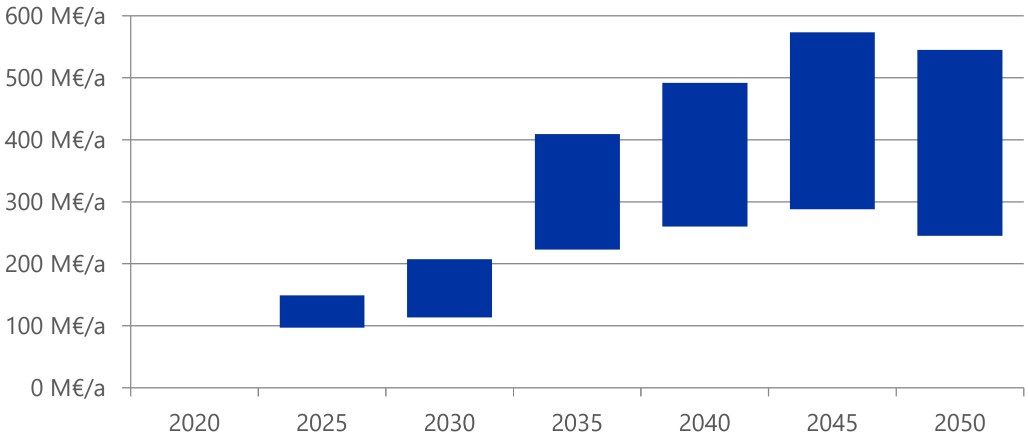

Figure 31: Annual TCO gap between Innovative Pathway and BAU

It can be seen that the TCO gap increases over time for the innovative scenario with a peak in 2045 compared to BAU. It can be seen that the TCO gap is larger for the innovative pathway compared to the conservative pathway, for the innovative pathway it is roughly around 420 million euro per year in the year 2050.

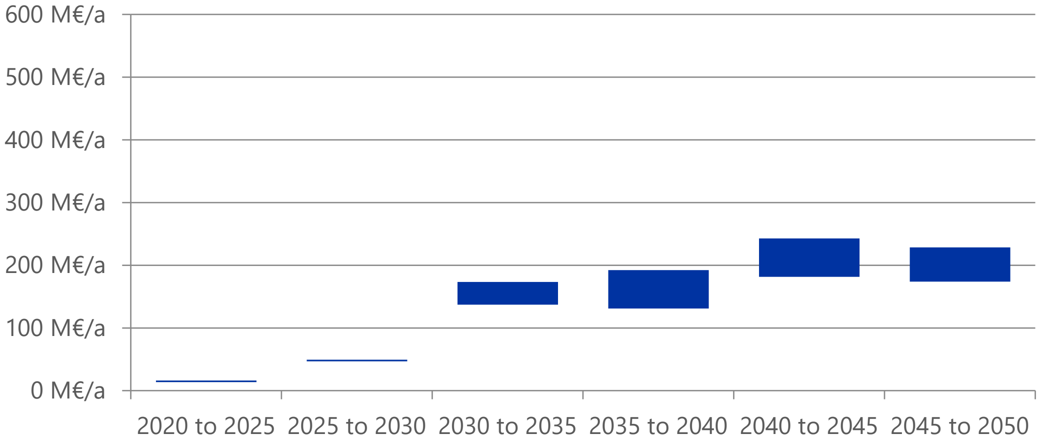

Figure 32: CAPEX gap per year per 5-year period between Conservative Pathway and BAU

The capital expenditures per year are significantly higher for the conservative pathway compared to BAU. As can be seen in particular in the period 2035-2050 the gap increases.

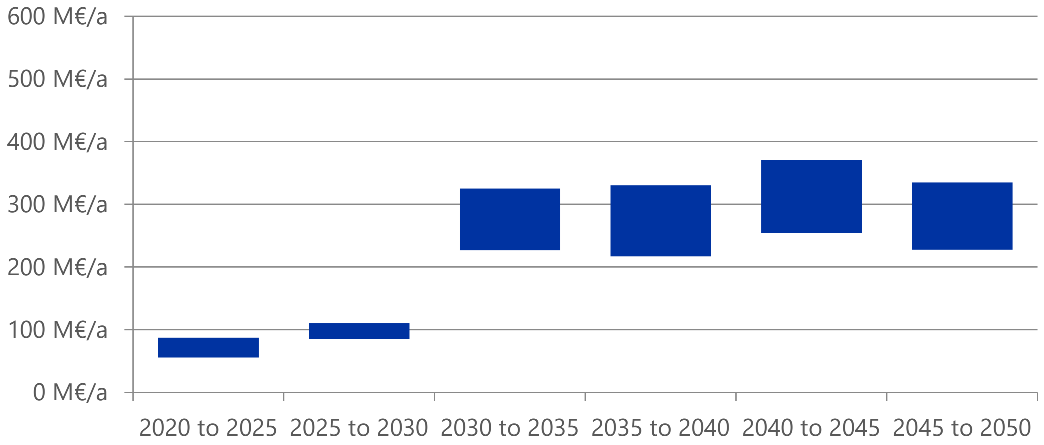

Figure 33: CAPEX gap per year per 5-year period between Innovative Pathway and BAU

The capital expenditures per year are also significantly higher for the innovative pathway compared to BAU and the gap is slightly bigger compared to the conservative pathway. For the innovative pathway, in particular the 2030 – 2050 period shows significant gaps of around 100 – 330 million euro per year, depending on the price scenario. The next table presents the direct comparison in a table and also the aggregated total for the 30 years period.

Table 7: Annual investment costs (CAPEX) in Million € in the BAU and the two pathways per year and the total accumulation over 30 years

		2020 to 2025	2025 to 2030	2030 to 2035	2035 to 2040	2040 to 2045	2045 to 2050	Total
BAU	Minimum	134	104	102	98	38	34	2,549
	Average	137	110	103	99	40	35	2,624
	Maximum	140	107	104	101	41	37	2,648
Conservative Pathway	Minimum	148	151	239	229	220	208	5,969
	Average	152	164	258	261	253	242	6,649
	Maximum	156	156	277	292	284	265	7,157
Innovative Pathway	Minimum	189	190	328	315	293	262	7,884
	Average	208	216	381	375	357	332	9,344
	Maximum	227	217	430	431	412	372	10,443

The total accumulated CAPEX (total of 30 years) gap compared to BAU for the **Conservative Pathway** is equal to approximately:

- €3.42 bln in the min. price scenario
- €4.03 bln in the avg. price scenario
- €4.51 bln in the max. price scenario

The total accumulated CAPEX (total of 30 years) gap compared to BAU in the **Innovative Pathway** is equal to approximately:

- €5.35 bln in the min. price scenario
- €6.72 bln in the avg. price scenario
- €7.80 bln in the max. price scenario

Table 8: Annual OPEX in Million € in the BAU and the two pathways per year and the total accumulation over 30 years

		2020	2025	2030	2035	2040	2045	2050	Total
BAU	Minimum	875	844	858	895	934	925	911	26,754
	Average	942	923	956	1,034	1,118	1,052	1,029	30,236
	Maximum	1,009	1,001	1,043	1,172	1,303	1,287	1,263	34,626
Conservative Pathway	Minimum	875	896	883	900	907	857	781	26,138
	Average	942	982	1,009	1,036	1,045	945	863	29,238
	Maximum	1,009	1,080	1,135	1,300	1,421	1,390	1,308	37,038
Innovative Pathway	Minimum	875	909	898	907	887	804	677	25,529
	Average	942	1,003	1,029	1,072	1,089	998	895	30,125
	Maximum	1,009	1,107	1,155	1,326	1,382	1,304	1,147	36,133

It can be seen that the OPEX for BAU has a range 26.8 - 34.6 billion euro over a 30-year period. For the conservative pathway this range is 25.3 - 35.9 billion euro. For the innovative pathway this range is 23.6 – 33.6 billion euro for the 2020-2050 time period.

Moreover, in particular the OPEX reduces for the pathways after 2035 compared to BAU, in particular for the innovative pathway. This can be linked to the relatively high share of battery electric sailing which has higher efficiency and low energy costs (electricity from grid) resulting in lower operational costs compared to diesel drive trains.

Furthermore, it needs to be remarked that it was assumed that in the two pathways there will be more attention paid to efficiency measures which also results on less fuel consumption (30% reduction in the two pathways compared to 15% impact in BAU).

Table 9: TCO in Million € in the BAU and the two pathways per year and the total accumulation over 30 years

		2020	2025	2030	2035	2040	2045	2050	Total
BAU	Minimum	877	901	956	1,033	1,108	1,115	1,115	30,443
	Average	944	981	1,059	1,174	1,296	1,246	1,238	34,026
	Maximum	1,012	1,060	1,145	1,314	1,483	1,484	1,476	38,461
Conservative Pathway	Minimum	877	959	1,012	1,139	1,219	1,241	1,223	32,873
	Average	944	1,048	1,162	1,288	1,383	1,370	1,362	36,672
	Maximum	1,012	1,145	1,279	1,559	1,782	1,847	1,840	44,845
Innovative Pathway	Minimum	877	997	1,069	1,256	1,368	1,403	1,360	35,701
	Average	944	1,101	1,231	1,455	1,631	1,689	1,708	41,827
	Maximum	1,012	1,210	1,352	1,723	1,975	2,058	2,022	48,646

The total accumulated TCO (total of 30 years) gap in the **Conservative Pathway** is approximately:

- €2.43 bln in the minimum price scenario
- €2.65 bln in the average price scenario
- €6.38 bln in the maximum price scenario

The total accumulated TCO (total of 30 years) gap in the **Innovative Pathway** is approximately:

- €5.26 bln in the minimum price scenario
- €7.80 bln in the average price scenario
- €10.19 bln in the maximum price scenario

It can be seen that at the conservative pathway is more cost effective compared to the innovative pathway. Both reach the 90% emission reduction target in 2050. The difference in the TCO gap between the pathways are

- Factor 2.2 higher at innovative pathway versus conservative pathway at the minimum price scenario
- Factor 2.9 higher at innovative pathway versus conservative pathway at the average price scenario
- Factor 1.6 higher at innovative pathway versus conservative pathway at the maximum price scenario

It can be remarked that also the conservative pathway already takes into account a significant share of H_2, MeOH fuels and FC and battery technologies.

The figures show clearly that the financial gap between the BAU and the two pathways mainly consists of higher capital costs which is the result of higher CAPEX. On the other hand, it turns out that the OPEX for the pathways is around the same level or even lower levels than OPEX for BAU on longer term. However, this is caused by the assumption of 30% energy saving between 2020-2050 in the pathways versus the 15% energy saving between 2020-2050 which is assumed in the BAU scenario.

7 No-regret investments

The decision whether or not an investment can be seen as a "no-regret investment" will depend on the viewpoint. For example, for a ship-owner the criteria will be different compared to a policymaker or an environmental NGO. Depending on the timing of an investment and the boundary conditions of the application, there are major differences regarding which measures fulfil the no-regret criterion. From the viewpoint of municipalities zero-emission applications may already today fulfil the no-regret criterion when they help to reach prescribed air quality standards. Zero-emission zones in metropolitan or protected natural areas are probably the first places where there is a business case to use technologies like hydrogen fuel cell systems or full battery-electric sailing. This will especially apply to (local) public transport, transport for public works and the transport of consumer goods. These three categories are in general more sensitive to sustainable transport, either due to societal pressure or requirements from public bodies (public procurement rules).

In normal circumstances, no-regret investments would be those investments that are worth making and would have a return on investment in any case without being certain about future developments. In the case of this study though, there are three scenarios, namely the business as usual and the two transition pathways and there are also three scenarios for the development technology and energy costs (min., avg., max.). It is therefore difficult to forecast at which (future) point in time a particular technology will meet the criterion per ship type. A key uncertainty is the level of public funding and other incentives to close the TCO gap for investments fitting into the transition pathways.

For some fleet families, some solid conclusions can be made since the technologies to be considered seem to be rather clear as there is not much difference between the conservative, the innovative pathway and the BAU scenario. For example, it can be mentioned for all pathways and scenarios that ferries and daytrip vessels are expected to use more and more batteries. In general, vessels operating locally (especially, in densely populated areas) with a limited energy demand may benefit from low energy costs for electricity from the grid used via batteries. An example for a small all-electric ferry is the "Sankta Maria II" operating between Wasserbillig and Oberbillig on the Moselle. The ferry is equipped with two lithium polymer battery packs with a total capacity of 252 kWh. Another example is seen in Amsterdam with the electric ferries of GVB for public transport. Passenger ships and especially daytrip vessels benefit from a green image, which enables operators to differentiate their services from the competition and thus attract more passengers.

Today the initial investment costs are too high in combination with the expected lifetime of the batteries to allow a return on investment. However, it is expected that the costs for marinised heavy duty batteries will go down, while energy density and lifetime will improve applicability.

Large push boats can be considered as the other extreme with their high energy demand, 24/7 operation and high utilisation of the engines. They will continue to rely on direct drives with combustion engines for several decades. Here the investment in clean and efficient combustion engines operating mechanically coupled to the propellers without electric conversion losses is considered future proof. The carbon footprint can be reduced by gradually increasing the use of compatible drop-in fuels (e.g. HVO in diesel engines or LBM in gas systems). The operational profile is well suited for exhaust gas aftertreatment to reduce air pollutant emissions.

However, electric drivetrains based on combustion engines can be a no-regret investment for new or retrofitted ships in both pathways as well as the BAU. Examples of vessels with diesel-electric drivetrains are the Sendo Liner, Sendo Mare, Sendo Nave, Borelli, Gouwenaar 2.0, Alphenaar, Den Bosch Max and Nijmegen Max as well as many cabin vessels. But **electrification will only pay off as a no-regret investment if the operational profile is suitable** and if the skipper on board of the vessel adjusts the sailing behaviour. By optimised utilisation of the system with more than one power supply the additional conversion losses can be overcompensated and the emission profile can be significantly improved. Sailing with the most suited genset(s) while others are stopped can also reduce maintenance costs and increase profitability. There is no advantage if a vessel is equipped with a diesel-electric propulsion system (e.g. three small diesel generators and an electric motor) sailing with high utilisation most of the time. On the contrary, in this case higher fuel costs and emissions are likely. The operational profile is therefore very important.

If the operational profile does not favour the installation of a diesel-electric drivetrain, a good option especially for retrofitting, is the installation of aftertreatment systems like a catalyst or a particulate filter or a direct replacement with a new Stage V or Euro VI engine (or a higher emission-standard in the future) rather than to continue the operation of engines with a lower emission standard. Especially the relatively small Euro VI engines are suitable for the combination with a diesel-electric drivetrain. This investment can also be done today.

For all investments in new drivetrains, it is important to analyse the future operational profile so that the new driveline can be optimised and designed accordingly. In many cases less power reserve compared to the existing fleet would be sufficient for safe operation. This so-called right-sizing helps to reduce investment cost, increases fuel efficiency and improves the environmental performance. Right-sizing and a modular system approach can also be seen as a no-regret investment.

For most of the fleet families and operational profiles, no-regret investments towards reaching the intermediary objective for 2035 and the final objective for 2050, will generally depend on the particular transition pathway and developments of technologies, infrastructure and costs. The conservative pathway mainly relies on clean internal combustion engines (for example the vessel Wantij with EURO VI engines) and drop-in biofuels, while the innovative pathway relies more on innovative techniques such as fuel cells (for example the demonstration cases on the vessels Emeli and Westenergie), batteries (for example the vessels Sendoliner and Invotis X) and alternative fuels like H_2 (for example the vessel Hydroville) and methanol in combustion engines. Hence, a logical investment in the conservative pathway could be the investment in clean state-of-the-art internal combustion engines which could run on both conventional as well as drop-in biofuels. Whereas the electrification (i.e. conversion or new-building with a diesel-electric drivetrain) could be a more attractive logical investment in the innovative pathway, since the integration of batteries or fuel cell systems requires the electrification of a vessel. The installation of the diesel-electric drivetrain could already today include a small battery that is sufficient for the power demand of the berthed ship. This option is also logical investment in this pathway, saving noise and even operational costs in case gensets are banned from berths and the choice is between cold ironing and the own battery storage.

A no-regret investment in battery electric-drivetrains might be possible for some specific container-liner services on short distances (e.g. inter-terminal transport routes) towards 2035. These investments need funding and the development of a reliable charging infrastructure to be futureproof. Since battery prices are expected to drop towards 2045 in the future for a short term-solution towards 2035 also the option of a pay-per use scheme without the investment in the batteries themselves might be suitable.

8 Summary, conclusions and outlook

A number of extensions and revisions have been made compared to the 1st version of the Research Question C. The following are most important:

- Development of the fleet families including number of vessels, engines types and emission performance.
- Development of the Business as Usual (BAU) scenario taking into account the available grant schemes and other assumptions, based on the current regulatory framework.
- Additional costs due to time loss and loss of payload is taken into account for alternative energy solutions.
- Cost assumptions have been updated for fuels and technologies.
- Emission performance assumptions have been refined for the internal combustion engines.
- OPEX and TCO calculations for the scenarios have been added as well as the related gap analyses.

Based on the further elaborations, the following conclusions can be made:

- The uncertainty of prices and availability of fuels and development of technologies is still quite substantial which is also reflected in the calculations. The uncertainty is especially large for the zero-emission technologies. Therefore, it is needed to regularly update the calculations and to follow closely the developments.
- The TCO gap with BAU is roughly a factor 2 higher for the innovative pathway compared to the conservative pathway (bandwidth 1.6 – 2.9). This illustrates that the conservative pathway would be most cost efficient to reach the 90% emission reduction objective for 2050 compared to 2015.
- The main economic challenges and financial gaps arise from 2030 onwards for the conservative pathway and the innovative pathway as soon as expensive zero-emission technologies are assumed to be applied at increasing growth rates (e.g. fuel cell systems and batteries). Clearly the economic challenge is the biggest for the innovative pathway.
- The aggregated TCO costs for the drivetrains for period 2020-2050 for the conservative pathway are 8% higher than BAU while for the innovative pathway it is 23% higher.

- The gap between the TCO pathway scenarios and the BAU scenario is mainly caused by the higher capital costs which is the result of higher CAPEX. The total aggregated gap for the 2020-2050 period is estimated between 2.6 and 7.7 bln euro depending on the pathway and scenario. Compared to BAU where the CAPEX is around 2.6 billion euro, this means that the increase of CAPEX is roughly 1.5 times higher for the conservative pathway and around 2.5 times higher for the innovative pathway.
- It turns out that the OPEX for the pathways is around the same level or even lower levels than OPEX for BAU on longer term (2035 - 2050). However, it shall be remarked that the 30% energy efficiency assumed for the pathways compared to 15% energy saving in BAU plays a substantial role in the calculations. The average impact on the OPEX for the conservative pathway is a 3.3% reduction compared to the OPEX for BAU scenario while for the innovative pathway the reduction is limited to 0.4%. The difference between conservative and innovative pathway is caused by higher maintenance costs in the OPEX, resulting from higher shares of battery and FC technologies.
- Further analyses of the calculations for specific technologies per fleet family showed that there is no business case for the average fleet family. There is no situation found where savings on OPEX can cover the additional capital costs. As result, in general, there is no return on investment for (near) zero-emission technologies to be expected for the ship-owner/operator compared to BAU.

9 Bibliography

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Annex I - Hypothesis and assumptions

Given all the known and unknown variables, it is quite complex to develop a comprehensive business as usual (BAU) scenario which will form the basis for the overall study on the economic and technical assessments of the greening techniques contributing to the energy transition of the IWT sector towards zero emissions. Also because of limited budget and time, simplifications were needed. Therefore, 9 main hypotheses and assumptions are formulated serving as the basis for the BAU scenario. These hypotheses are as follows:

1. **Transport demand stable for freight and slightly growing for passenger transport**

   At the moment there are no recent studies available on European level which provide a forecast of the medium- and long-term transport demand development for Inland Waterway Transport in Europe. There are no resources to do a market study to prepare quantitative scenarios for IWT on the transport demand.

   Moreover, it is uncertain what the short-term impact will be of COVID-19, if/how globalisation will further develop (e.g. global container traffic) and into what extent the European and national policies will have an impact on the competitiveness of energy intensive industries (e.g. steel production), agriculture and feedstock and into what extent there will be a shift in energy from the grid (e.g. electricity) instead of energy from fuels which are currently transported by IWT.

   It seems however likely that transport of fossil fuels such as coal, oil will decline as well as transport demand for ores and steel. It seems also likely that other market in the dry cargo market will show further increases, possible also supported by modal shift ambitions. An example is container transport which is expected to grow. Other examples are waterway upgrades, such as the Seine-Schelde connection which may trigger larger transport demand for IWT on certain corridors.

   Moreover, also alternative / sustainable fuels will need to be transported, which may require more transport demand since current fossil fuels have a higher energy intensity per ton or m^3 of fuel than alternative / sustainable fuels.

   As a result of these uncertainties and lack of reliable up-to-date studies and outlooks and budget, it was decided for freight transport to keep the overall tonkilometre performance stable for the period 2015-2050. However, a small increase is expected in the liquid cargo market (tankers) while dry cargo markets in total slightly decrease. This estimation is based on the stakeholder consultations. For the passenger transport however, a further growth of the market is expected, seen the evolution during the past decades. This was also confirmed in the Market Observation annual report 2020[24] by CCNR. Moreover, the trend of the increase of the

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[24] https://inland-navigation-market.org/?lang=en

average vessel size for the freight transportation was extrapolated based on CCNR Market Observation annual report 2020 and the Impact Assessment study by Panteia 2013[25], taking into account as well the comments and suggestions made by stakeholders on their expectations.

2. **No differentiation in costs between new or existing vessels.**

   The difference in CAPEX and OPEX for conventional and greening techniques between existing and new-build vessels will be smaller than the uncertainty of long-term cost predictions for technologies and fuels. This means that, for example, the expected cost difference in equipping either an existing vessel or new-build vessel with a H_2 FC installation will be smaller as compared to the uncertainty of long-term cost predictions for the H_2 FC installation itself. The price differences for greening techniques between existing vessels and new-build vessels are insignificant as compared to the price uncertainty of the greening techniques themselves. Therefore, the study will not take CAPEX and OPEX differences between existing and new-build vessels into account.[26]

3. **Development of the fleet broken down by fleet families.**

   The total IWT fleet consists of various types of vessels, however it is possible to define groups of comparable vessels, also called 'fleet families'. The European project PROMINENT defined a representative set of fleet families, 10 in total. Based on the CCNR Market Observation reports and the IVR database, this list of 10 fleet families can be slightly expanded with the fleet families 'Ferries' and 'Daytrip and small hotel vessels'. The 12 fleet families and corresponding number of vessels within the fleet families are illustrated in the table below. The following assumptions apply for the expected development towards 2050:

   - The fleet development in number of vessels per family will take the figures of 2015 as a starting point.
   - We assume that the transport performance expressed in tonkilometres will remain stable, while the drop in the number of small vessels will be compensated by the increase in large vessels.

   As regards the fleet development in numbers, an elaborated estimation on the trends is displayed in the next table:

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[25] https://ec.europa.eu/transport/sites/transport/files/modes/inland/studies/doc/2013-06-03-contribution-to-impact-assessment-of-measures-for-reducing-emissions-of-inland-navigation.pdf, see section 3.3.

[26] Reference can be made to the CEF funded project „Breakthrough LNG deployment in Inland Waterway Transport" which showed that cost differences for the installation (e.g. related to necessary welding and cutting activities) between retrofitting and newbuilding could amount to approximately €200,000 on average for the considered fleet families in that study. This difference is likely to be smaller for some of the zero-emission technologies that are less complex in configuration. For example, a MeOH ICE and battery-electric drive do not need a large cryogenic tank and tank connection space as LNG does.

Table 10: Fleet development

year	2015	2020	2035	2050	Change 2020-2050
Large cabin vessels	346	361	406	451	25%
Push boats < 500 kW	890	840	690	540	-36%
Push boats 500-2000 kW	520	525	540	555	6%
Push boats ≥ 2000 kW	36	36	36	36	0%
Motor cargo vessels ≥ 110 m	610	630	690	750	19%
Motor tankers ≥ 110 m	602	567	597	627	11%
Motor cargo vessels 80-109 m	1,802	1,792	1,762	1,732	-3%
Motor tankers 80-109 m	647	622	637	652	5%
Motor vessels < 80 m	4,463	3,938	2,813	1,688	-57%
Coupled convoys	140	145	160	175	21%
Ferries	103	103	103	103	0%
Day trip and small cabin vessels	2,207	2,257	2,407	2,557	13%

The exact numbers are assumed based on desk research using the following sources:

- Market observation reports by CCNR
- Contribution to impact assessment of measures for reducing emissions of inland navigation, Panteia 2013
- Rapport "Inventarisatie milieuprestaties bestaande binnenvaartvloot West-Europa", December 2015, STC-NESTRA
- PROMINENT project (deliverable D1.1 and D6.3/D6.5)

Furthermore, feedback from stakeholders is also taken into account for defining the exact numbers.

4. Approach and sources for assumptions on the renewal rate of drivetrains for BAU scenario

A renewal rate for the drivetrains (new engines and retrofitting) is assumed for each of the fleet families (12 in total) in the periods 2015-2020, 2020-2035 and 2035-2050. We take into account:

- Structure of fleet families as clarified under hypothesis number 3.
- New-building and scrapping of vessels as clarified under hypothesis number 3.
- Port of Rotterdam access restrictions (at least CCNR 2 engines) by 2025, meaning that a large share of the fleet will have CCNR 2 engines (or better).
- Grant schemes already announced and confirmed for the next years, for example:
    - Dutch scheme of 79 MEUR towards 2030 (NO_x reduction) and 15 MEUR from the Dutch Green Deal
    - German scheme for 2021 onwards
    - See also information in the deliverable for RQ F
- Available studies on the lifetime of engines and replacement rates (2015 onwards):

- Contribution to impact assessment of measures for reducing emissions of inland navigation, Panteia 2013
- Rapport “Inventarisatie milieuprestaties bestaande binnenvaartvloot West-Europa”, December 2015, STC-NESTRA

The evolution of the drivetrains in the IWT fleet is influenced by:

- New-build vessels
- Scrapped vessels
- Replacement of engines on the existing vessel or retrofitting

The new-build vessels have the Stage V engines from year 2021 onwards according to the legislation. Old vessels which are assumed to be scrapped in a time period will have old / polluting engines (e.g. unregulated engines or CCNR 1) and will therefore leave the market. The relative share of new vessels and existing refitted vessels will increase. New vessels will in general be more energy efficient than the old scrapped ones due to, e.g., reduced deadweight, new more efficient engines, improved hull forms, optimised arrangement of propellers, ducts, tunnels and rudders. On the other hand, existing vessels will be refitted with new engines or after-treatment techniques. Equipping an existing vessel with new engines may involve right-sizing which will increase efficiency and reduce emissions. Furthermore, with after-treatment techniques the combustion process of engines is optimised for efficiency rather than air pollutants. As a result, the efficiency effects are resulting in less energy needed which results in savings of fuel and therefore emissions. The average emission profile (grams per kWh) improves as emissions are getting lower per kWh.

Data for the engine renewal is based primarily on the PROMINENT project[27] and the STC-NESTRA/EICB/REBEL study[28] which gives the estimations on the average lifetime of an engine per fleet segment. Furthermore, views were received from consulted stakeholder and information was received from engine suppliers on the number of CCNR 2 engines installed in the years 2015-2020. It shall be remarked that the number of engine replacements showed increases during the past years, as can also be seen in Table 11.

Table 11: Engine renewals

Fleet families	2015-2020 New CCNR2 installed	2015-2020 unregulated left the market	2015-2020 Engine replacement existing vessels (to CCNR2)
Large cabin vessels	65	50	50
Push boats < 500 kW	5	75	75
Push boats 500-2000 kW	10	45	40
Push boats ≥ 2000 kW	1	5	20

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[27] https://www.prominent-iwt.eu/

[28] https://zoek.officielebekendmakingen.nl/blg-775460.pdf

Motor cargo vessels ≥ 110 m	14	50	20
Motor tankers ≥ 110 m	20	135	20
Motor cargo vessels 80-109 m	10	60	480
Motor tankers 80-109 m	11	80	210
Motor vessels < 80 m	5	550	850
Coupled convoys	5	20	50
Ferries	3	15	20
Day trip and small cabin vessels	50	200	100

Ship owners decided to invest in order to avoid uncertainty and expected higher costs for NRMM Stage V engines and to be compliant with the Port of Rotterdam access restriction from 2025 onwards. In addition, also the announced grant schemes were taken into account, which is expected to contribute to an 80% reduction of the NO_x reduction of a substantial share of the fleet and will support availability and installation of Stage V engines for the market.

Moreover, for daytrip vessels and ferries a significant share of battery-electric drivetrains is assumed in the BAU scenario due to the pressure from clients and local governments.

It is remarked that in the BAU scenario the share of LNG is limited to the current vessels and the announced 40 new-build LNG propelled motor tankers with gas-electric drivetrains and additional diesel generator set for backup power[29]. Further expansion of LNG or LBM market share will depend on new financial instruments and incentives.

Figure 34 below shows the development for the average engine and technology distribution for the fleet.

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[29] https://www.maritimebyholland.com/news/concordia-damen-orders-120-stage-v-generator-sets-from-man-rollo/

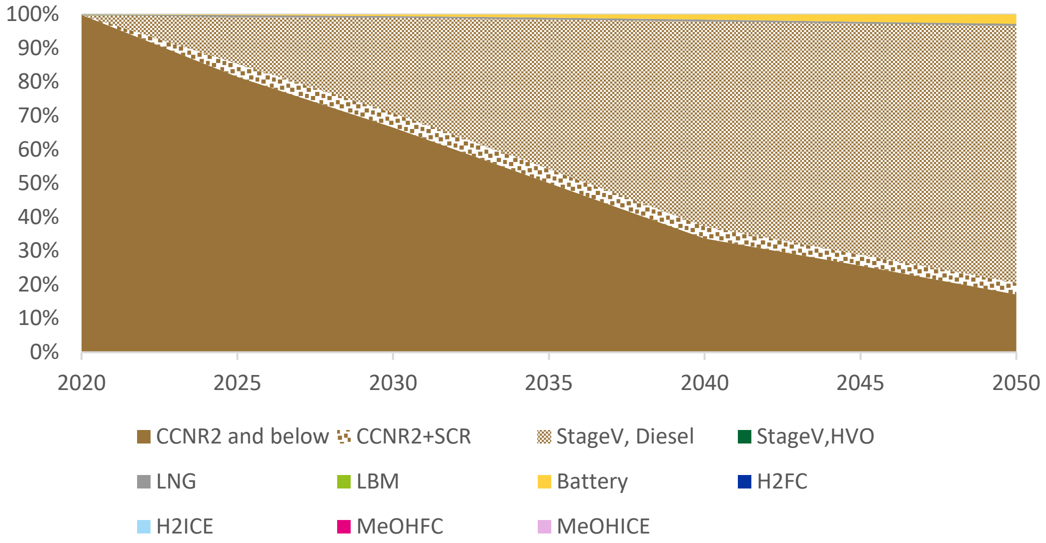

Figure 34: Development of engine and technology distribution in the fleet

It can be seen that by 2050 a very large part of CCNR 2 and older engines are replaced or scrapped. The share of CCNR 2 and older engines in 2050 is expected to be around 17%, in addition around 3% of the fleet will be equipped with a CCNR 2 engine with SCR as result of funding schemes[30] promoting the retrofit with SCR technology. The share of Stage V diesel engines is expected to grow up to 47% in 2035 and 76% in 2050 as result of new-build vessels and engine replacements of existing vessels. Shares of LNG and battery electric navigation are not significant, seen from the total viewpoint of the fleet as a whole. This is different for the share in specific fleet families. For example, it is expected that the share of full battery electric drivetrains will be around 10% for the fleet family "day trip and small cabin vessels" and 17% for the fleet family "ferries" in 2050, see also Table 12 which presents the breakdown for each fleet family in rounded percentage values.

Table 12: Development of the distribution of engines and technologies in the fleet

2020	**CCNR 2 and below**	**CCNR 2 + SCR**	**Stage V, Diesel**	**LNG**	**Full battery electric**
Large cabin vessels	100%	0%	0%	0%	0%
Push boats < 500 kW	100%	0%	0%	0%	0%
Push boats 500-2000 kW	100%	0%	0%	0%	0%

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[30] Enabled by the 79 M€ subsidy scheme by Dutch government (2021-2030) to support installation of SCR to drastically reduce NO_x emissions.

Push boats ≥ 2000 kW	100%	0%	0%	0%	0%
Motor cargo vessels ≥ 110 m	100%	0%	0%	0%	0%
Motor tankers ≥ 110 m	98%	0%	0%	2%	0%
Motor cargo vessels 80-109 m	100%	0%	0%	0%	0%
Motor tankers 80-109 m	100%	0%	0%	0%	0%
Motor vessels < 80 m	100%	0%	0%	0%	0%
Coupled convoys	99%	0%	0%	1%	0%
Ferries	99%	0%	0%	1%	0%
Day trip and small cabin vessels	100%	0%	0%	0%	0%
All vessels	*100%*	*0%*	*0%*	*0%*	*0%*
2035	**CCNR 2 and below**	**CCNR 2 + SCR**	**Stage V, Diesel**	**LNG**	**Full battery electric**
Large cabin vessels	26%	3%	71%	0%	0%
Push boats < 500 kW	64%	1%	35%	0%	0%
Push boats 500-2000 kW	46%	2%	52%	0%	0%
Push boats ≥ 2000 kW	0%	0%	100%	0%	0%
Motor cargo vessels ≥ 110m	33%	10%	57%	0%	0%
Motor tankers ≥ 110m	9%	12%	70%	9%	0%
Motor cargo vessels 80-109 m	62%	6%	32%	0%	0%
Motor tankers 80-109 m	42%	12%	42%	0%	0%
Motor vessels < 80 m	69%	2%	29%	0%	0%
Coupled convoys	13%	13%	73%	1%	0%
Ferries	15%	4%	69%	1%	11%
Day trip and small cabin vessels	42%	0%	54%	0%	4%
All vessels	*47%*	*5%*	*47%*	*1%*	*1%*
2050	**CCNR 2 and below**	**CCNR 2 + SCR**	**Stage V, Diesel**	**LNG**	**Full battery electric**

Large cabin vessels	0%	0%	100%	0%	0%
Push boats < 500 kW	29%	2%	69%	0%	0%
Push boats 500-2000 kW	12%	2%	86%	0%	0%
Push boats ≥ 2000 kW	0%	0%	100%	0%	0%
Motor cargo vessels ≥ 110 m	2%	9%	88%	0%	0%
Motor tankers ≥ 110 m	0%	0%	92%	8%	0%
Motor cargo vessels 80-109 m	44%	6%	50%	0%	0%
Motor tankers 80-109 m	17%	15%	68%	0%	0%
Motor vessels < 80 m	31%	3%	66%	0%	0%
Coupled convoys	0%	0%	99%	1%	0%
Ferries	0%	0%	83%	1%	17%
Day trip and small cabin vessels	2%	0%	88%	0%	10%
All vessels	*17%*	*3%*	*76%*	*1%*	*3%*

It can be seen from both Figure 34 and Table 12 that there is no shift towards a wide spread of technologies in large shares. But it should be considered that the increased use of engines with higher emission standards takes place as illustrated in the figure and table. Furthermore, a slight increase in electric driven vessels is expected in the ferries and daytrip and small cabin vessel segments.

There will also be a slight overall increase in the use of biodiesel by the whole fleet as result of diesel blends consisting of biodiesel and conventional diesel provided by the fuel suppliers. Starting with 0% in 2015 this share expands to the maximum 7% (maximum according to EN590) in 2050.

5. Emission performance levels for internal combustion engines

It is expected that a certain part of the fleet can reach the NRMM Stage V emission limits (and beyond the limits) by own means (own financial resources/bank financing) and confirmed grant schemes. There are four types which can be distinguished in the Stage V solutions:

- IWA/IWP > 300 kW: 1.8 g NO_x and 0.015 g PM per kWh
- IWA/IWP < 300 kW: 2.1 g NO_x and 0.1 g PM per kWh
- NRE engines 56 < P < 560 kW: 0.4 g NO_x and 0.015 g PM per kWh
- EURO VI marinised truck engines: 0.46 g NO_x and 0.01 g PM per kWh

For each fleet family the choice of Stage V engine solution will depend on the installed power per engine. For the fleet segment with larger vessels and large power, it is expected that the vast majority will select the IWA/IWP > 300 kW engine. Small vessels with smaller engine power may choose for alternative engines like EURO VI marinised truck engines. Little is known yet as regards the difference in maintenance costs and lifetime between, for example engines in the category IWA/IWP > 300 kW as compared to EURO VI marinised truck engines or NRE engines. Therefore, for simplicity, the costs for the various types of engines are assumed to be equal.

6. Efficiency increase leads to reduction of energy demand

Increasing the efficiency of the logistics chain leads to a reduction in emissions per unit transported. As digitalisation progresses, this optimisation also takes place in the conservative BAU scenario, without inland navigation itself striving for a technological leap, but rather benefiting from the development of its environment. Moreover, a new drive train for both existing and new vessel can have two positive effects: A reduction in emissions (for example, if the engine complies with a higher emission standard) and an increase in efficiency (for example, if the drive train is better adapted to the ship's sailing profile).

Hence, it is assumed that the energy consumption of the entire fleet will in total reduce by 15% for the BAU scenario. The underlying reasons can be summarised as follows:

- Right sizing with less overpowering increases efficiency and reduces the installed power.
- Newer engines with exhaust gas after-treatment allow more efficient engine control compared to CCNR II engines.
- Better utilisation of vessels based on logistics optimisation increases efficiency.
- Improved hydrodynamics of new vessels and the growing number of larger vessels (ongoing long-term trend[31]) reduce the energy consumption for the same transport performance.
- Increasing operational costs, smart navigation tools (eventually including autonomous ships), better education and awareness of energy efficient navigation lead to more efficient ship operation.

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[31] The increasing share of relatively large vessels and reducing share of relatively small vessels is an ongoing long-term trend. Sources such as the CCNR market observation reports (e.g. https://inland-navigation-market.org/wp-content/uploads/2019/11/ccnr_rapport_naiades_ii_Multimodality_Report_Final_en_compressed.pdf) and the Contribution to impact assessment of measures for reducing emissions of inland navigation can be consulted for this purpose (https://ec.europa.eu/transport/sites/transport/files/modes/inland/studies/doc/2013-06-03-contribution-to-impact-assessment-of-measures-for-reducing-emissions-of-inland-navigation.pdf).

7. BAU scenario addresses existing legislation only

It needs to be remarked that for the Business as Usual scenario only the existing legislative framework and existing incentives and drivers have been taken into account. For that reason, the BAU scenario includes the assumption that there will be no CO_2 taxation. This assumption is consistent with the assumptions for answering to research questions G and H on the possible contribution by the sector and the legal elements in view of Act of Mannheim and Polluter Pays Principle. A significant tax on CO_2e emissions would inevitably lead to a long-term advantage for technologies with little or no CO_2e emissions. This would then be in contradiction with the findings of the research questions G and H indicating severe legal barriers and possibly reverse modal shift effects in case there is a CO_2e tax. An earmarked contribution by the sector, linked to fuel consumption and differentiated to the emission performance of the vessel would be seen already as an intervention measure in view of the gap to close to reach the two transition pathway scenarios.

In addition, setting up major financial instruments or new grant schemes have also not been taken into account. Also, other possible future instruments such as labelling systems and/or energy efficiency indices have not been taken into account. Indeed, the details of such instruments are not foreseeable at the time of conducting this study. However, it is important to bear in mind, given the latest European developments, that such instruments might be implemented in the long term. The same applies to the consideration relating to a possible extension of European emissions trading schemes to inland navigation.

Assumptions as regards the economics are presented in chapter 5 in which the TCO for the BAU scenario is presented, taking into account the prices of the Stage V engines, batteries, LNG equipment and the prices of the other fuels and energy taken into account in the BAU scenario.

For the fuel price scenario of fossil diesel, we will follow the average crude oil price scenario towards 2050 based on current policies.

8. Biofuels are seen as carbon neutral.

According to IPCC methodology and RED II directive biofuels are seen as climate neutral from tank-to-wake perspective (see also chapter 4). As result, the CO_2 emission which is calculated for IWT is lower in case a biofuel is used. As there is at this moment no binding decision on mandatory blending of biofuels for IWT under the RED II directive, it was assumed that the biofuels will not be part of a mandatory scheme. For the share of biofuel, the current limit under EN590 is a maximum of 7% of biofuel. Moreover, some operators voluntary use biofuels, such as ‘ChangeTL’, a blend of 80% GTL and 20% FAME.

In the BAU scenario it is assumed that the share of biofuels gradually increases, starting from 0% in 2015 to reaching a share of 7% in 2050 for the diesel used in IWT in Europe.

9. Specification of emission performance figures

The following figures for the air pollutants were applied based on the emission standards of the engine to estimate the emissions of the fleet:

Table 13; Basic assumptions for the fleet emission calculations TTW (Tank-To-Wake)

	gram per kWh	
	NO_x	PM
Battery electric vessels	0	0
LNG propelled vessels	1.6	0.015
# vessels with Stage V engines (incl. refit)	1.525	0.035
# vessels with SCR	1.525	0.2
# vessels with CCNR 2 engines	6	0.2
# vessels with CCNR 1 engines	9.2	0.54
# vessels with unregulated engines	10	0.54

Note: this table only includes the techniques/fuels considered in BAU

The emissions for battery electric vessels are assumed to be zero from a TTW perspective.

For LNG the emission performance is based on gas-electric propulsion as recently measured in practice on the vessel ‘Werkendam’ (mono fuel, gas-electric LNG propulsion system) in the CEF LNG breakthrough project[32]. The three gas engines on board emit on average 1.6 NO_x g/kWh and 0.016 PM g/kWh. It is expected that PM emissions can be reduced by 0.001 g/kWh in order to make the engine Stage V compliant, especially in view of the fact that 40 new motor tankers will be built with a similar LNG configuration on board.

For Stage V type approved engines, a representative mix is assumed consisting of:

- 25% Euro VI and NRE engines < 560 kW
- 50% Stage V IWA/IWP engines > 300 kW
- 25% Stage V IWA/IWP engines < 300 kW

The results of this mix for the emissions are presented in Table 1. For vessels with SCR it is assumed that CCNR 2 engines will be equipped with SCR installations making it possible to bring down NO_x emissions and align it to the NO_x limits in Stage V. The PM emissions are kept equal to CCNR 2 diesel engines without after-treatment systems.

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[32] https://lngbinnenvaart.eu/wp-content/uploads/2020/02/Pilot-test-report-Werkendam-external.pdf

The CO_2 calculation was directly based on the fuel consumption of the fleet family segment. We took the following values for fossil fuels:

- CO_2e emission: 3.13 gram per gram fuel and density of diesel 835 kg/m^3
- CO_2e emission: 2.614 kg per m^3 diesel fuel[33]
- CO_2e emission of LNG: 2.352 kg per m^3 diesel fuel (equivalent), which is a 10% reduction compared to diesel, taking into account methane slip[34].

In case of biofuels such as HVO and LBM, the CO_2 emissions are considered zero on tank-to-wake approach, considering the IPCC and RED 2 methodologies (see chapter 5).

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[33] There are multiple sources for these standard values, two of them are:

- P.144 of the book Lecture Notes in Management Science Vol. 6 (https://books.google.nl/books?id=6VLYDwAAQBAJ&pg=PA144&lpg=PA144&dq=2.61kg+co2+per+liter+diesel&source=bl&ots=pwv7bvW-pC&sig=ACfU3U2iMVFyCA0GQFo6moAr7FxG6JoNLQ&hl=nl&sa=X&ved=2ahUKEwintZvg5a3uAhV1wQIHHawuCLYQ6AEwBnoECAoQAg#v=onepage&q=2.61kg%20co2%20per%20liter%20diesel&f=false)
- https://ecoscore.be/fr/info/ecoscore/co2?path=info%2Fecoscore%2Fco2

[34] The A-factor in NRMM Stage V concerns the limit value of methane gas emitted by gas engines. In case A would be 0, the CO_2e saving would be 20% for a gas engine compared to diesel engine (with the same net power output on the shaft). With the monofuel gas solution, the one considered in this analysis, the A-factor is equal to 3, given the average emission values of the used example case of the vessel Werkendam. This means a 10% reduction of CO_2e emission with LNG compared to diesel.

Annex II – Detailed tables

Table 14: Fuel 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

Table 15: Costs 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

Table 16: Installation costs per technique and fleet family. The maintenance costs are expressed in % of the investment.

	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 m^3)	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

	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
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%
Capital Costs and Depreciation												
Interest rate	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%
Depreciation (years)	20	20	20	20	20	20	20	20	20	20	20	20

Note: the annual maintenance costs are calculated by taking a percentage of the CAPEX. The maintenance costs of FC systems and batteries also take into account the renewal of membranes and battery cells respectively, seen the short lifetime compared to ICE.

* The “SCR base” refers to the minimum necessary components and the installation of the SCR system, regardless of its size. The “SCR per installed kW” cost depends on the size of the necessary components in relation to the installed power.

Table 17: Share of technologies per fleet family in the conservative pathway in 2035

Fleet families	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
CCNR 2 and below with Diesel	0%	37%	18%	0%	5%	0%	34%	13%	40%	0%	0%	2%
CCNR 2 + SCR with Diesel	0%	1%	2%	0%	10%	0%	6%	16%	2%	0%	0%	0%
Stage V with Diesel	67%	35%	52%	75%	52%	58%	32%	42%	29%	67%	50%	54%
Stage V with 100% HVO	24%	25%	27%	24%	23%	23%	25%	25%	26%	24%	21%	25%
LNG	1%	0%	0%	0%	5%	10%	0%	0%	0%	5%	1%	0%
LBM	0%	0%	0%	2%	3%	9%	0%	0%	0%	3%	0%	0%
Battery	0%	1%	0%	0%	0%	0%	1%	1%	1%	1%	24%	12%
H_2 FC	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	1%	5%
H_2 ICE	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%
MeOH FC	5%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	1%
MeOH ICE	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	1%	0%

Table 18: Share of technologies per fleet family in the conservative pathway in 2050

Fleet families	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
CCNR 2 and below with Diesel	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CCNR2 + SCR with Diesel	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Stage V with Diesel	10%	20%	15%	40%	15%	20%	10%	5%	5%	15%	5%	0%
Stage V with 100% HVO	40%	55%	75%	40%	35%	30%	50%	55%	64%	42%	10%	50%
LNG	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LBM	0%	0%	0%	20%	35%	40%	0%	0%	0%	33%	5%	0%
Battery	5%	10%	5%	0%	5%	0%	15%	10%	10%	10%	40%	25%
H_2 FC	0%	10%	5%	0%	5%	5%	5%	5%	5%	0%	10%	5%
H_2 ICE	25%	0%	0%	0%	0%	0%	5%	5%	0%	0%	15%	5%
MeOH FC	5%	5%	0%	0%	0%	0%	10%	15%	8%	0%	5%	10%
MeOH ICE	0%	0%	0%	0%	5%	5%	5%	5%	8%	0%	10%	5%

Table 19: Share of technologies per fleet family in the Innovative Pathway in 2035

Fleet families	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
CCNR 2 and below with Diesel	0%	36%	20%	0%	0%	0%	34%	14%	42%	0%	0%	0%
CCNR 2 + SCR with Diesel	0%	1%	2%	0%	5%	0%	6%	16%	2%	0%	0%	0%
Stage V with Diesel	66%	40%	62%	80%	57%	62%	32%	42%	34%	48%	50%	46%
Stage V with 100% HVO	10%	10%	5%	13%	10%	20%	10%	10%	10%	21%	10%	20%
LNG	0%	0%	0%	0%	5%	5%	0%	0%	0%	5%	1%	0%
LBM	0%	0%	0%	6%	12%	7%	0%	0%	0%	6%	0%	0%
Battery	4%	9%	6%	0%	7%	1%	13%	12%	7%	11%	36%	21%
H_2 FC	7%	0%	1%	0%	2%	1%	1%	1%	2%	5%	1%	6%
H_2 ICE	0%	1%	1%	0%	0%	0%	1%	2%	2%	1%	1%	5%
MeOH FC	12%	0%	0%	0%	0%	2%	0%	1%	0%	0%	0%	1%
MeOH ICE	0%	2%	2%	0%	1%	1%	1%	1%	1%	2%	1%	1%

Table 20: Share of technologies per fleet family in the Innovative Pathway in 2050

Fleet families	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
CCNR 2 and below with Diesel	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
CCNR 2 + SCR with Diesel	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Stage V with Diesel	0%	10%	30%	50%	15%	15%	15%	10%	20%	20%	0%	0%
Stage V with 100% HVO	5%	5%	5%	35%	5%	5%	5%	5%	5%	15%	0%	0%
LNG	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
LBM	0%	0%	0%	15%	20%	20%	0%	0%	0%	15%	0%	0%
Battery	40%	40%	10%	0%	20%	10%	30%	25%	20%	10%	70%	65%
H_2 FC	25%	5%	10%	0%	20%	15%	15%	15%	20%	5%	10%	10%
H_2 ICE	5%	15%	15%	0%	5%	5%	15%	20%	20%	10%	10%	5%
MeOH FC	20%	0%	5%	0%	5%	20%	5%	15%	5%	5%	0%	10%
MeOH ICE	5%	25%	25%	0%	10%	10%	15%	10%	10%	20%	10%	10%

Ministry of Infrastructure and Water Management

CCNR
CENTRAL COMMISSION FOR THE NAVIGATION OF THE RHINE

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Throughout the project there were exchanges with the CCNR, the steering Committee composed of representatives of CCNR member States and a stakeholder group consisting of :

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Danube Commission
Mosel Commission
European Investment Bank (EIB)
European Investment Advisory Hub (EIAH)

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