D1.2 Report on Suitability of Identified Technical Solutions

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

GRANT AGREEMENT NO.	101096809
DURATION OF THE PROJECT	42 months
DELIVERABLE NUMBER	D1.2
DELIVERABLE LEADER	OST
STATUS	Final
SUBMISSION DATE	20-12-2024
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List of Abbreviations

BAU	Business As Usual
CAPEX	CAPital EXpenditure (investment costs)
CCNR	Central Commission for the Navigation of the Rhine
CH3OH	Chemical formula for methanol
CNG	Compressed Natural Gas
CO2	Carbon dioxide emissions (CO2e: carbon dioxide equivalent emissions)
CSRD	Corporate Sustainability Reporting Directive
DAC	Direct Air Capture
EU	European Union
EUR	Euro
FAME	Fatty Acid Methyl Esters
GHG	Greenhouse Gas
H2	Chemical formula for hydrogen
HVO	Hydrotreated Vegetable Oil
IWT	Inland Waterway Transportation
kWh	Kilowatt-hour (energy equal to 3.6 MJ)
LCA	Life Cycle Assessment
LNG	Liquified Natural Gas
MENA	Middle East and North Africa
MJ	Megajoule (energy equal to 1/3.6 kWh)
NOx	Nitrogen Oxide emissions
OPEX	OPerational EXpenditures
PM	Particulate Matters (PM10: PM with a diameter of 10 micrometres or less)
PV	Photovoltaics
TCO	Total Cost of Ownership
TEN-T	Trans European Transport Network
TRL	Technology Readiness Level (9 levels)
TTW	Tank-to-Wake
WTT	Well-to-Tank
WTW	Well-to-Wake

Release Approval

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Executive Summary

The aim of the Innovation Action SYNERGETICS is the green transformation of the European Inland and Coastal shipping using retrofit solutions. In the first Work Package "WP1: Exploration" techno-economic opportunities for the implementation of alternative energy carriers and propulsion systems are explored. The focus of this Deliverable "D1.2: Report on suitability of identified technical solutions" is the prospective assessment of emissions and costs of such greening options as well as the identification of viable business models ("Task 1.1: Business models and infrastructure for alternative energy carriers"). The results will be further used in the Work Packages "WP4: Integration" and "WP5: Acceleration".

To reduce greenhouse gas emissions as well as nitrogen oxide (NOx) and particulate matter (PM10) emissions, the use of fossil diesel must be replaced by fully renewable and additional alternative energy carriers. Promising options for retrofitting are the direct use of electricity (battery-electric), e-hydrogen and e-methanol. Bio-based energy carriers would also lead to emission reductions. Yet, their sustainable capacities are strongly limited by nature itself. Hence, they are likely only to play a minor role in the greening efforts of the European coastal and inland shipping. The electricity-based energy carriers, however, can be scaled up if decisive action is taken to expand the production of renewable electricity (wind onshore, wind offshore and photovoltaics).

In this report the emissions as well as the costs of several energy carrier supply paths are assessed from a Well-to-Wake perspective using a comprehensive, modular Well-to-Tank model as well as pre-processed Tank-to-Wake data for the years 2020 (status quo), 2035 and 2050. The greenhouse gas emissions of the electricity-based energy carriers are 20-380 gCO2e(fossil)/kWh for the status quo. Thus, the global warming potential can be reduced by up to 95% (compared to fossil diesel) if the supply paths are well-chosen. Nonetheless, as there will not be zero emissions for any energy carrier, the use of energy should be avoided where possible.

The absence of carbons in the propulsion system is a major advantage of battery-electric and e-hydrogen paths. However, infrastructural changes and on-board storages tend to be more challenging compared to e-methanol. The main greenhouse gas emission hotspots along the supply chain are the energy production, the electrolysis, the methanol synthesis as well as the direct air capture. In addition, energy storages are highly relevant for battery-electric paths. Tank-to-Wake trade-offs (e.g., loss of payload) will be investigated in-depth in further works of SYNERGETICS. For e-hydrogen and e-methanol the NOx emissions are roughly halved whereas the PM10 emissions increase by a factor of three to twenty. Both NOx and PM10 emissions are strongly reduced for battery-electric paths (over 95%, respectively about 60%). The current costs are higher for all energy carriers, ranging from 0.24 to 0.61 EUR/kWh (fossil diesel: 0.22 EUR/kWh).

From a business perspective, one major challenge is how to finance the transition towards low-emission propulsion systems. Ship owners in the traditional business set-up incur significant CAPEX through retrofitting solutions, most often not fully covered through bank loans or other fundings (e.g. subsidies through various policy instruments). Additionally, vessel owners face insecurities regarding OPEX for retrofitting solutions not only regarding the development of fuel prices but also in the context of operational aspects. Emerging and fluid policy developments on EU and national level pose an opportunity and risk at the same time: While ETS2 (opt-in) and RED-III have the potential to internalise environmental costs and to provide long-term stability from the policy side, their mechanisms are not fully in place yet. New business models have the potential to mitigate financing gaps in the current environment. Promising approaches include business models involving new stakeholders like energy providers or intermediaries (e.g. pay-per-use or insetting). Thereby, a part of the financial risk is shifted away from traditional small-scale ship-owners. However, going forward, more detailed information on costs (CAPEX and OPEX) are required to evaluate (future) advantages of green retrofitting solutions.

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1 Introduction

1.1 Initial Situation

Currently, fossil diesel represents close to 100% of the energy carriers used for inland and coastal shipping in Europe, mainly due to existing infrastructure for large scale production, storage, transport, fuelling/bunkering and on-board handling of (fossil) diesel. Also, today's pricing of fossil diesel, with tax exemptions for inland and maritime transport as well as available, largely fully developed technologies and components including spare parts and professionals for operation and maintenance make the use of (fossil) diesel convenient and cost effective from an end-user perspective. However, environmental impacts are not or only to a very small extent considered in the pricing of fossil diesel. Lack of internalisation of external costs as well as a very limited legal framework to limit greenhouse gas and air pollutant emissions, result in a limited extent of shipping decarbonisation/defossilisation and reduction of air pollutant emissions, despite the rapid development of alternative energy carriers and technologies.

Only a comparably small number of new vessels related to the total existing fleet are taken into operation each year due to long lifetimes of vessels and their engines. This requires a focus on existing inland vessels and coastal ships. A large scale retrofit of the fleet would effectively accelerate the greening transformation and reduction of emissions on short term. However, there is a wide variety of ship types with different power demands and different required volume of energy to be carried on board. Alternative energy carriers require more space on board and/or more frequent bunkering or recharging. The bunkering and recharging infrastructure for such alternative energy carriers is absent or scarce, and the future price levels of alternative energy is uncertain. Most measures are associated with considerable investments and higher operational costs. In addition, the existing regulatory and funding framework still does not provide an adequate support, especially in inland navigation and seagoing vessels below 5 000 GT (gross tonnage). Moreover, clients of coastal and inland transport are generally not willing yet to pay a premium for a low-emission transport (Dahlke-Wallat et al. 2024).

1.2 Motivation and Objectives

The overall objectives regarding climate change mitigation as well as the reduction of harmful air pollutant emissions are clear. Following the agreements of the Intergovernmental Panel on Climate Change (IPCC), global warming needs to be mitigated (Lee and Romero 2023). Moreover, in particular in ports and at waterways in or along urban areas and in or near sensitive NATURA2000 areas the air pollutant emissions such as nitrogen dioxide emissions (NOx) and particulate matter emissions (PM) shall be minimised (Rijksoverheid 2024).

More specifically, the European Green Deal and the European Commissions' Sustainable and Smart Mobility Strategy (SSMS) provide more specific motivation and objectives for transport. The European Green Deal marks that transport accounts for a quarter of the climate change emissions of the European Union (EU), and still growing. To achieve climate neutrality, a 90% reduction in transport emissions is needed by 2050. Road, rail, aviation, and waterborne transport including inland waterway transportation (IWT) will all have to contribute to this reduction (European Commission 09/12/2020). Furthermore, an element of reducing climate change emissions is the modal shift ambition. The European Commission is emphasising with regards to the transportation sector that "substantial part of the 75% of inland freight carried today by road should shift onto rail and inland waterways" (Jacobs 2022). A milestone defined in the SSMS on shifting more activity towards more sustainable transport modes is "Transport by inland waterways and short sea shipping will increase by 25% by 2030 and by 50% by 2050" (European Commission 09/12/2020).

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For inland navigation a specific policy document "NAIADES III" was published in 2021. It focuses on two core objectives (European Commission 24/06/2021): Shifting more freight transport to inland waterways (1) and setting the sector on an irreversible path to zero-emissions (2). Under the header "Transitioning to zero-emission inland waterway transport" (section 2.2) it is stated that "Despite its strong environmental record compared to other transport modes, it is nonetheless crucial that inland waterway transport quickly embarks on a pathway to zero greenhouse gas emissions by 2050, if it is to remain competitive and sustainable".

More specific targets for Inland Waterway Transport and seagoing vessels can be derived from the latest updates to the EU Taxonomy (European Union 21/11/2023). It aims for zero direct (tailpipe) carbon dioxide (CO2) emissions. However, if achieving zero direct CO2 emissions is technologically and economically not feasible, the EU Taxonomy refers to a methodology for calculating CO2e/MJ values based on the FuelEU Maritime methodology. If it is technologically and economically not feasible for vessels to achieve zero direct (tailpipe) CO2 emissions, the criteria from the EU Taxonomy Regulation, effective from 2025 onwards for vessels, are displayed in the Table 1 in comparison to the fossil diesel baseline. Furthermore, seagoing vessels will also need to show that their Energy Efficiency Existing Ship Index (EEXI) is 10% better compared to the baseline.

Table 1: Criteria from the EU Taxonomy Regulation both for inland and seagoing vessels, in comparison to the fossil diesel baseline (European Union 21/11/2023).

*only valid for inland vessels	**2025-2029**	**2030-2034**	**2035-2039**	**2040-2044**	**2045-2049**	**2050**
Greenhouse gas emissions in [gCO2e/MJ] for inland and seagoing vessels	76.4	61.1	45.8	30.6	15.3	0.0*
Emission reduction compared to fossil diesel	-20%	-36%	-52%	-68%	-84%	-100%

Regarding air pollutant emissions, it is defined that engines in inland vessels need to comply with emission limits outlined in Annex II to Regulation (EU) 2016/1628 (including vessels meeting those limits without type-approved solutions such as through after-treatment). Seagoing vessels need to comply with the IMO MARPOL convention regarding the sulphur emissions and NOx emissions (European Union 16/09/2016).

Similar to FuelEU Maritime and, to some extent, the EU Taxonomy, the Renewable Energy Directive revision (RED-III) implementation can follow a Well-to-Wake approach based on the CO2e-emissions in g/MJ. In case the Member State follows this Well-to-Wake approach, the reduction target for transport to be achieved on national level shall be 14.5% by the year 2030. This concerns a relative CO2e-reduction in g/MJ of energy supplied to the transport market. However, also another approach is possible for implementing RED-III on member state level. This second approach focuses on the share of renewable/biofuels in the total fuel mix, which must be at least 29% in 2030. Additionally, multipliers can be taken into account for certain types of energy. Moreover, it does not impose any limit on the total energy consumption (European Union 01/10/2023).

Furthermore, also within Europe there are more specific goals and objectives defined. The most elaborated roadmap on energy transition and emission reduction for (inland) vessels was published by the Central Commission for Navigation on the Rhine (CCNR), representing Germany, Switzerland, France, Belgium and The Netherlands. It gives an elaboration of the emission goals as agreed by these states in the "Mannheim Declaration" (CCNR 2018). Therefore, it is relevant to recall the objectives stated in

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the Mannheim declaration which was signed and adopted by the Rhine countries in October 2018. The aim was to develop a roadmap with three main emission reduction goals:

- 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 (at least 90% reduction)

The CCNR roadmap was published in March 2022 and presents as assessment of the possible energy carriers and technologies, "transition pathways", to reach these objectives, an assessment of the associated capital expenditures and operational costs and the implementation plan. The implementation plan consists of regulatory, voluntary and financial measures (CCNR 2022).

Regarding the seagoing vessels a clear focus by policy makers can be seen on the larger vessels, which are above 5 000 GT. For these vessels there is already regulation in place to monitor and verify the emissions, the Monitoring, Reporting and Verification (MRV). Based on this MRV the FuelEUMartime will be also implemented, and these vessels will also become part of the EU Emissions Trading System (ETS). This means that these vessels will have to use an increasing share of renewable energy and at the same time they will have to purchase emission rights to be allowed to emit CO2 emissions. The CO2 costs for society will thus be internalised into some extent. Moreover, the emission rights will be capped, and the volume auctioned each year does decrease over time, resulting in a steady decline on the overall emissions under the ETS scope (European Commission 2024b). It needs to be noted that such measures are not (yet) in place for smaller seagoing vessels, below 5 000 GT, which are mostly in the scope of SYNERGETICS since SYNERGETICS does focus on the coastal vessels. However, there is a range of measures applying to much smaller ships as well. MARPOL regulations for energy efficiency, for example, apply to vessels of 400 GT and above.

To unlock the potential for environmental impact reductions by means of retrofit and to enable its acceleration in inland and coastal navigation, a core aim of the SYNERGETICS project is to demonstrate highly promising and mature retrofit technologies. These will rely on renewable energy carriers for high Technology Readiness Level (TRL) retrofit solutions, i.e. renewable electricity (plus batteries) for direct electricity-based propulsion concepts or renewable hydrogen or renewable methanol, both for the use in internal combustion engines. SYNERGETICS Work Package WP2 describes the demonstrations in more detail.

Alternative (renewable) energy carriers should lead to a direct reduction of environmental impacts, identifiable and measurable in the so-called Tank-to-Wake (TTW) part of the value chain of the energy carriers. These environmental impacts when using energy carriers are relevant and regulated since they occur locally or geographically close to the activity, i.e. using the energy carriers on the ship for propulsion and/or auxiliary units. However, solutions for an accelerated and effective decrease of greenhouse gas emissions must be investigated and assessed taking broader system boundaries into account. Economic aspects must be combined with technical parameters, and system integration aspects on local, regional, national and transnational level should be considered. This requires a Well-to-Wake analysis (WTW), including for example indirect emissions of producing and providing energy carriers and technology as well as their techno-economic potentials in concise value chains. Thus, also renewable energy carriers have environmental impacts in the upstream supply chain, the so-called Well-To-Tank (WTT) part of the value chain. These are relevant since a large amount of energy is needed and suitable scales of production, storage, transport, and fuelling/bunkering of the energy carriers must be considered.

Renewable energy carriers are likely to have higher costs (and therefore higher prices) for the end users. If reduced environmental impacts are to be combined with economic competitiveness, operators need new business models to finance the energy transition. Moreover, also a favourable legal framework

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is needed to internalise the external costs of emissions and to put limits on the emission levels. Therefore, implementation strategies must be investigated, e.g. existing and new business models and best practices in other (mobility) markets. Part of this is the necessity that suitable infrastructure for new energy sources needs to be built up at great expense. This needs to be combined with policy scenario assessments and recommendations. For the latter, SYNERGETICS Deliverable D1.3 provides a picture on the state of play of the scenarios. In SYNERGETICS Work Package WP5 recommendations to policy makers will be identified and discussed.

1.3 Deliverable D1.2 within SYNERGETICS

The mission of SYNERGETICS Work Package WP1 ("Exploration") is to explore the techno-economic possibilities for implementation of alternative propulsion solutions in the waterborne transport, considering also technical measures and business models applied in other industrial (transport) sectors.

Deliverable D1.1 identifies technical solutions, including other sectors, that are promising for use in waterborne transport. Deliverable D1.3 presents a collection and reflection of transition scenarios up to 2050 in line with the relevant strategies. In this context, Deliverable D1.2 (this report) provides a techno-economic assessment of feasible renewable energy carriers (Well-to-Tank and Tank-to-Wake) including production and availability as well as different generic supply paths for the total amount of energy needed for Inland Waterway Transport in Europe. It also identifies business models and funding options to round up the economic perspectives of alternative energy carriers. By this, Deliverable D1.2 concludes Task T1.1 of Work Package WP1 ("Exploration") within SYNERGETICS.

1.4 Structure of Deliverable

In Chapter 2 feasible alternative energy carriers (both electricity-based as well as bio-based) are identified based on a set of criteria. Furthermore, sustainability measures for the inland and coastal shipping are discussed from a systemic perspective. In Chapter 3 a techno-economic analysis of the identified energy carriers is carried out. It focusses on the Well-to-Tank part which is assessed by a comprehensive model. The overall emissions and costs (Well-to-Wake perspective) are assessed too, though with a lower level of detail. Additionally, a rough overview of further impacts is given. In Chapter 4 sustainable business models are discussed in detail. In Chapter 5 the main insights are summarised.

The authors would like to thank all SYNERGETICS partners for their valuable inputs and feedback. Special thanks go to Martin Quispel (SPB/EICB), Niels Kreukniet (SPB/EICB), Benjamin Friedhoff (DST), Igor Bačkalov (DST), Friederike Dahlke-Wallat (DST), Alex Grasman (MARIN) and Simone Bründl (OST).

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2 Identification of Feasible Alternative Energy Carriers

2.1 Relevant Criteria

2.1.1 Sustainable Energy Sources

Alternative energy carriers are only suitable for substituting fossil diesel and for meeting the environmental goals of the European Union if they are fully sustainable. This means, energy carriers must be produced from fully renewable and additional sources within Europe, in North Africa or in the Middle East (EUMENA). The geographical limitation to EUMENA is based on the capacity (see Chapter 2.1.2) and the circumstance that the environmental benefit of biomass usage decreases with an increasing transport distance (Liebich et al. 2021). Hence, electricity from Europe (wind onshore and wind offshore) as well as from the MENA region (photovoltaics) is considered, whereas biomass is limited to Europe. By setting these boundary conditions a fair comparison between the different supply paths is possible without justifying an "allowed percentage" of non-sustainable sources in the overall energy mix.

Fully renewable electricity sources are wind power, solar power, hydroelectric power, marine energy and geothermal energy. In case of bioenergy, the biomass sources must have a low indirect land use change impact (ILUC), and they must be useable after 2030 according to the renewable energy directive (RED II/III). All other energy sources like nuclear power (uranium is a limited resource), liquefied natural gas or grid electricity are excluded since they are not fully renewable (IRENA 2024).

Furthermore, energy sources must be additional to minimise the risk of environmental burden shifting. For example: If renewable electricity is diverted from the existing power sector to a "sustainable" power-to-X-plant it must be assumed that the resulting deficit will be compensated by the cheapest marginal unit of electricity, which usually are non-renewable energy sources like coal or natural gas (Carvalho et al. 2023). Thus, the indirect emissions of these "renewable" energy carriers may even exceed the emission reduction of substituting fossil diesel.

2.1.2 Capacity

Energy sources as well as energy carriers are only included if they have a relevant capacity today and/or in the future within the defined geographical boundaries (see Chapter 2.1.1). The theoretical maximum capacity of electricity from renewable sources is (almost) unlimited whereas renewable biomass is limited by nature itself (e.g., limited wood area). Yet, the costs for using these renewable electricity and biomass sources are directly linked with their demand, i.e. the higher the demand, the higher the costs (Braun et al. 2022). Thus, the capacity is not just limited to "natural" boundaries but also to financial boundaries. Indeed, renewable electricity is supposed to be limited by increasing costs of expanding the existing infrastructure.

The capacity of renewable energy carriers is further limited by the competition between sectors. Meaning, even if the maximum capacity of a certain energy carrier would meet the total energy demand of the European inland and coastal shipping, this may not be a likely scenario. For example, the aviation sector must become climate neutral as well but the technical options for substituting fossil kerosene are even more limited than substituting fossil diesel in the shipping sector. Thus, the aviation sector may politically be prioritised in the future (IRENA 2022).

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2.1.3 Further Criteria

In addition to the above-mentioned criteria (sustainability, additionality and capacity), the technological readiness level (TRL) and selected experiences of the inland and coastal shipping from the recent past are taken into account as well for identifying feasible alternative energy carriers.

2.2 Electricity-Based Energy Carriers

Wind power (both onshore as well as offshore) and solar power are the only electricity sources which meet the defined criteria (see Chapter 2.1). Hydroelectric power, ocean energy and geothermal energy would be sustainable, but their additional capacities are thought to be strongly limited.

Renewable electricity can either be used directly (battery-electric shipping) or as a basis for electricity-based energy carriers like e-hydrogen. Generally, electricity can be transported easily over long distances (high energy density) whereas affordable storage options (both short-term and long-term) are currently limited.

The renewable electricity production in EUMENA is summarised in Table 2. The current European electricity demand is 3 500-4 000 TWh/a. It includes both renewable as well as non-renewable electricity sources and it is supposed to increase in the future (IEA 2024a; Fraile et al. 2021).

Table 2: Renewable electricity production in [TWh/a] for wind onshore and offshore in Europe as well as for photovoltaics in MENA (Middle East and North Africa).

Year	Wind onshore	Wind offshore	Photovoltaics	Sources
2020	401	88	19	IRENA 2024
2035	940	580	-	EMBER 2024 ("Stated Policy" scenario)
	-	-	75 000	Braun et al. 2022 (potential for 2030 for Middle East with LCOE <32 EUR/MWh)
2050	2 400	1 200	-	EMBER 2024 ("Stated Policy" scenario)
	2 200	1 200	-	Fraile et al. 2021 (EU-27 only)
	-	-	70 000	Braun et al. 2022 (potential for 2050 for Middle East with LCOE <22 EUR/MWh)

2.2.1 Battery-Electric

Battery-electric vessels are considered in SYNERGETICS due to a couple of reasons: They are outlined in the application, there are demonstrators (Work Package WP3), there are even a few vessels in commercial operation (ZES 2024), and the capacity of their energy sources is "not" limited. Moreover, in Work Package WP2, insights in ongoing demonstrations are given. The effects of this alternative energy carrier to the operation (e.g., weight or charging time) are not part of this report.

Basically, it is possible to produce electricity from on-board photovoltaic panels. The Dutch company "WATTLAB", for example, commercially sells aluminium hatches with integrated solar modules (WATTLAB 2024). However, the electricity demand of the propulsion system exceeds the production capacity by about a factor of ten. Thus, these photovoltaic panels can be used to substitute the on-board diesel generator but not the main engine.

2.2.2 E-Hydrogen

Hydrogen powered vessels are considered in SYNERGETICS due to a couple of reasons: They are outlined in the application, there are demonstrators (Work Package WP3, using hydrogen produced from other processes), and the capacity of their energy sources is "not" limited. The effects of this alternative energy carrier to the operation (e.g., weight) are not part of this report.

2.2.3 E-Methanol

Methanol powered vessels are considered in SYNERGETICS due to a couple of reasons: They are outlined in the application, there are demonstrators (Work Package WP3, using methanol produced from other processes), and the capacity of their energy sources is "not" limited. The effects of this alternative energy carrier to the operation (e.g., weight) are not part of this report.

2.2.4 Not Considered (Electricity-Based Energy Carriers)

Fuel cells are disregarded in general due to comparably high costs for large-scale and high-power operation in mobility applications. Consequently, a path to supply e-ammonia is not included due to comparably low TRL (if used for direct combustion, since fuel cells are not considered) and open issues regarding the safety as well as regulative aspects of operating inland and coastal vessels with ammonia (Dahlke-Wallat et al. 2024).

Renewable methane (e-methane and bio-methane) is not considered. Over the past 15 years, several ships in the European inland shipping industry were converted to liquified or compressed natural gas (LNG/CNG). An increasing number of these retrofitted ships are operated with diesel again these days. This is possible since they are mostly dual fuel engines. In some cases, the gas engine was even removed again. Several drawbacks in using LNG/CNG for inland and coastal shipping were reported by experts and project partners:

- Cost and availability of fossil methane (LNG/CNG): Methane was more expensive than diesel (even as a fossil alternative with slightly improved environmental impact compared to fossil diesel, but especially when considering renewable methane) and the prices were not stable at all. Furthermore, it had limited availability (especially renewable LNG) which was exacerbated by geopolitical turmoil. Finally, the advantage of existing transport infrastructure for methane could hardly be used for shipping (ships had to be supplied and refuelled via LNG transport by lorry).
- Lock-in effect: The switch to renewable methane was partly motivated with the advantage that a blending of fossil LNG/CNG could be used for a transition phase. However, it was criticised that a switch from diesel to methane is likely to result in fossil methane being used for (too) long instead of consequently switching to renewable alternatives. This gave a bad image to the use of LNG/CNG in inland shipping.
- Technical (methane slip): Methane emissions occur in the upstream supply chain (production and transportation), which have a relevant negative impact even at low quantities due to the very high global warming potential (GWP100 of 28 and a GWP20 of 84). Methane emissions also occur during the operation of ship engines. High speed engines, as commonly used in inland shipping, have a relatively high methane slip (Schuller et al. 2021). Further development steps would be necessary to avoid emissions altogether or to reduce them to an acceptable level in the overall balance. Direct methane emissions are difficult to measure, record and control and therefore represent a risk that remains even when using renewable methane.

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- Competition with other utilisation paths: Natural gas is currently used as an energy source in various sectors. In some of these (mostly in industry, but also in the heating of buildings), a change in technology is only possible to a limited extent or it is even more difficult than in the transport sector. For this reason, renewable methane should not be used primarily in the transport sector, especially as there is often a need to liquefy the methane to increase its energy density. Instead, those utilisation paths should be given preference where methane is difficult to replace with another energy source and where the supply of methane is established and techno-economically attractive (e.g. due to already existing supply infrastructure).
- Limited holding time of the tanks due to boil-off. This means the vessels need to sail all the time, or at least consume power.

Radojčić et al. (2021) provide an overview on other options of so-called drop-in fuels, e.g. via the so-called Gas-to-Liquid route using the Fischer-Tropsch synthesis. Also, hydrotreated vegetable oils (HVO) "should not be mistaken with Biodiesel […]. Biodiesel is a chemically fatty acid methyl ester (FAME) and could cause trouble in long-term storage and being used as a fuel substitute in a conventional engine. Nevertheless, today this is the most important BTL [biomass to liquid] fuel used as a 7% blend with fossil diesel (B7). Increasing the blends of FAME is a greater challenge than for HVO and not covered by usual test fuels." Based on this assessment and since the Gas-to-Liquid (GTL) route has a lower overall efficiency compared to the routes analysed, GTL and FAME are not considered in detail. Additionally, GTL and FAME may result in higher NOx emissions. Due to requirements and restrictions in the Innovation Action call text (HORIZON-CL5-2022-D5-01-04), E-Diesel using the Fischer-Tropsch synthesis (which is not going beyond a simple exchange of fuels through minor technical adaptations) as well as retrofit options using hydrogen fuel cells are not investigated within the scope of this report (Task 1.2 in Work Package WP1).

To conclude, this report provides techno-economic possibilities for implementation of alternative propulsion solutions in the waterborne transport for three relevant groups of energy carriers based on the supply path assessment: diesel-like fuels (HVO and methanol, representing the group of hydrocarbons), hydrogen and the direct use of electricity for propulsion, with energy storage via batteries. However, other solutions and variations are being investigated (outside the scope of this report) and may play significant roles in the energy transition of the transport sector in the future.

2.3 Bio-Based Energy Carriers

Bio-based energy carriers ("biofuels") are liquid or gaseous transport fuels, such as biodiesel and bio-methanol, which are produced from biomass. They serve as renewable alternatives to fossil fuels helping to reduce greenhouse gas emissions as well as dependencies on exporting countries of oil and gas. Biofuels can be obtained by biochemical, thermo-chemical or oleochemical routes. Relevant biomass production sectors for renewable energy are agriculture, forestry, and waste. Advanced biofuels, i.e. biofuels produced sustainably in accordance with the criteria of the European Union, are based on the production from raw materials in accordance with RED-II Annex IX Parts A and B.

As biofuels rely on limited biomass sources (see Chapter 2.1) the maximum possible capacity needs to be estimated first. Biofuels are only suitable for substituting fossil diesel for the European coastal and inland shipping if enough capacities are available today and/or in the future.

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Legal framework

Part of the implementation of the EU's strategy is the switch to advanced biofuels produced from sustainable feedstock. In June 2023, the European Commission issued new regulations (Renewable Energy Directive RED-II/III) to determine the proportion of biofuels and biogas in mixed fuels (European Union 21/12/2018, 01/10/2023). The directive sets targets for the share of renewable energy in the transport sector. The EU member states are also obliged to impose obligations on fuel suppliers to achieve these targets. In addition, the sustainability criteria for bioenergy are strengthened through different provisions. These provisions include negative direct impacts that the production of biofuels can have due to indirect land use changes (ILUC). To tackle the problem of indirect land use change, limits are set for biofuels, bioliquids and biomass fuels with a high ILUC risk. For the period from the end of 2023, it is stipulated that these fuels with a high ILUC risk must be gradually reduced to zero by 2030. The Delegated Regulation on indirect land-use change (European Union 27/06/2022) sets out criteria for the certification of biofuels, bioliquids and fuels from biomass with a low ILUC risk, which are listed in Annex IX Part A and B of the RED-II. Many of the substances mentioned are waste and residues from agricultural and forestry processes, e.g. straw, low-value wood products such as bark waste and branches, material containing lignocellulose (part A) or used cooking oils (part B, use is limited to 1.7% due risks associated with sustainability (e.g. palm oil) and fraud, which would be exacerbated by unlimited consumption).

Biomass potential in Europe

The technical biomass potential for the years 2020 to 2050, which falls under Annex IX of RED-II/III, is estimated to be around 1 700 TWh/a (see Figure 1). In this medium availability scenario, shares of non-energy use of biomass (competing biomass use) are already deducted (Ruiz et al. 2015).

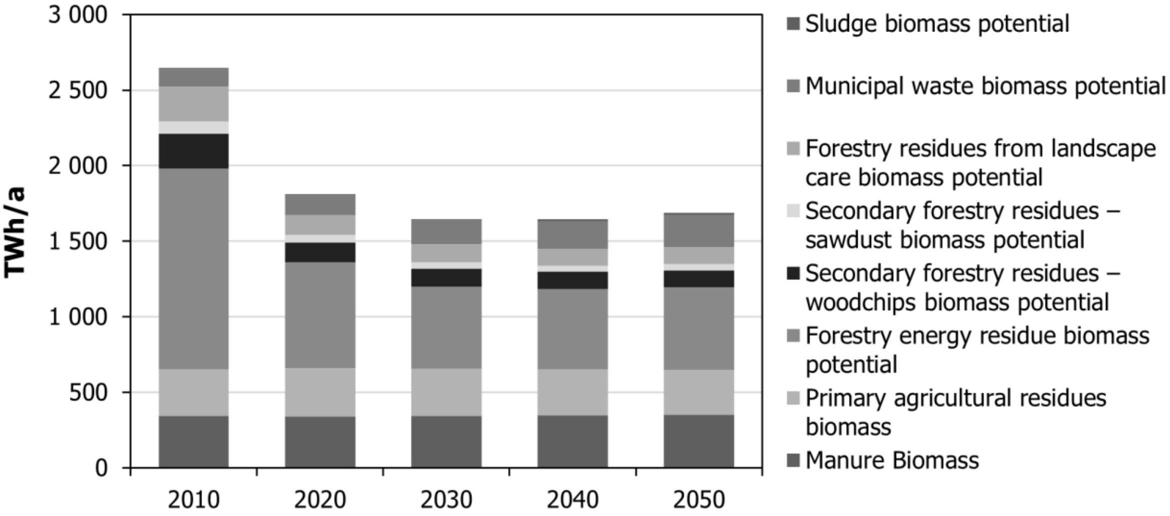

Figure 1: Biomass potentials in Europe (36 countries, medium scenario) (Ruiz et al. 2015).

The current production of biofuels covers 4-5% of the final energy consumption in the EU's transport sector (Figure 2). If the total technical biomass potential could be converted into biofuels, a maximum of 18% of the final energy demand of the EU's transport sector could be covered with biofuels (assumed conversion rate: 35%). In other words, the biomass capacity is strongly limited by itself, i.e. it can only substitute a small share of fossil diesel.

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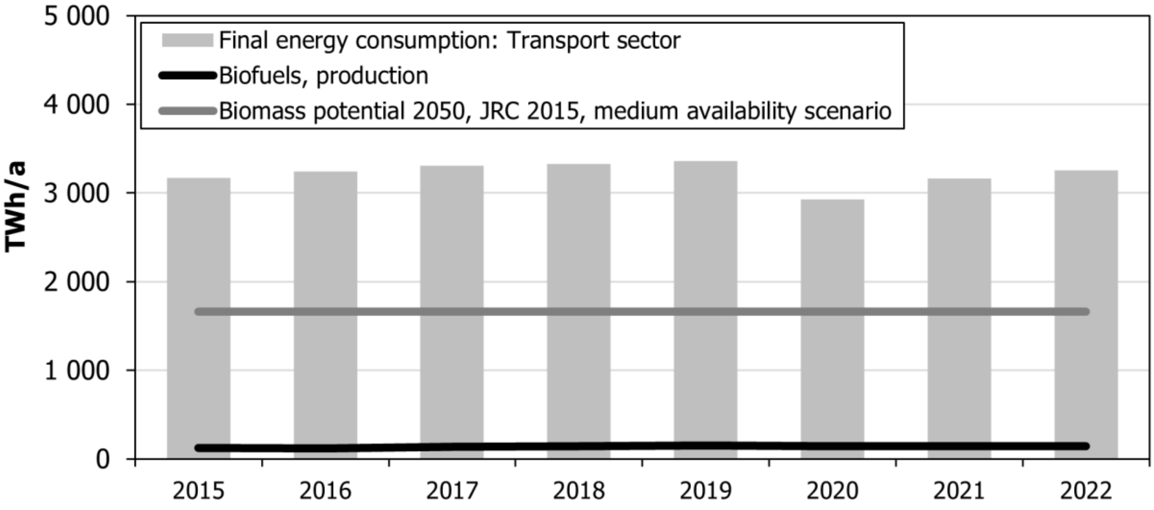

Figure 2: Final energy consumption in the European Union (27 countries) and technical biomass potential 2050 (Ruiz et al. 2015).

In this report, the following assumptions are made to determine the quantities of the technically utilisable biomass potential that could be used for European coastal and inland shipping:

- All biofuels are produced centralised in Rotterdam.
- The biomass used to produce these biofuels is not transported further than 500 km as longer transport routes are neither sensible from an ecological nor from an economical perspective.

Figure 3 shows the technical biomass potential in Europe in a spatial representation and broken down into the 500 km radius around Rotterdam: The maximum possible biomass potential is 137 TWh/a (not to be mistaken with the biofuel potential).

Figure 3: Residual biomass potential in Europe (36 countries) and residual biomass potential in the 500 km region around Rotterdam in the year 2050.

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Biofuels

The different types of biomasses (dry, wet or liquid biomass, or different composition of biomass) are suitable for the production of different types of fuel (e.g. biodiesel, gaseous biofuels). In order to be able to utilise biofuel alternatives in the short to medium term, the targeted production technologies must already be sufficiently mature, i.e. the TRL should be above 7 of a maximum of 9 levels (DIN DIN EN 16603-11:2020-02). There are three types of biofuels from sustainable biomass feedstocks which fulfil these criteria in accordance with RED-II/III Annex IX (Motola et al. 2023; Laursen et al. 2022): methanol from biomass (or bio-methanol), hydrotreated vegetable oils (HVO) and biomethane.

Bio-methanol (directly comparable with e-methanol) and HVO (currently great hype/hope) are assessed in SYNERGETICS. In accordance with the criteria in Chapter 2.1 a couple of assumptions are made:

- All biomass is from Europe, and it must be sustainable (low ILUC, usable after 2030) (European Union 21/12/2018, 27/06/2022, 01/10/2023).
- There is a focus on biomass with high availability. Residues from forestry and agriculture (especially straw) have the highest potential for sustainable biomass production (Ruiz et al. 2015; Hamelin et al. 2019).
- The production methods must have a high TRL: gasification of biomass, synthesis of bio-methanol, hydrotreatment of used cooking oils and production of HVO (Motola et al. 2023).

2.3.1 Methanol from Biomass

Methanol is an important raw material in the chemical industry, and it can be used as a fuel. A limited amount of methanol can be injected with the marine diesel so that the propulsion systems can continue to be operated with only minor conversions. If pure methanol is used as fuel, modifications to the machines are necessary. Methanol can be produced from a wide range of biomass feedstocks (for example agricultural residues like straw, lignocellulosic biomass like forestry residues or biogas) through gasification of biomass and a synthesis of the resulting syngas to methanol (Laursen et al. 2022). The maximum possible bio-methanol production with a conversion rate of 35% is 48 TWh/a, as depicted in Figure 4 (500 km radius around Rotterdam). For comparison: the current methanol market (2023) in the chemical industry in Europe is 62 TWh/a (ChemAnalyst 2024). Thus, the demand for (renewable) methanol is already larger today than the maximum possible production capacity.

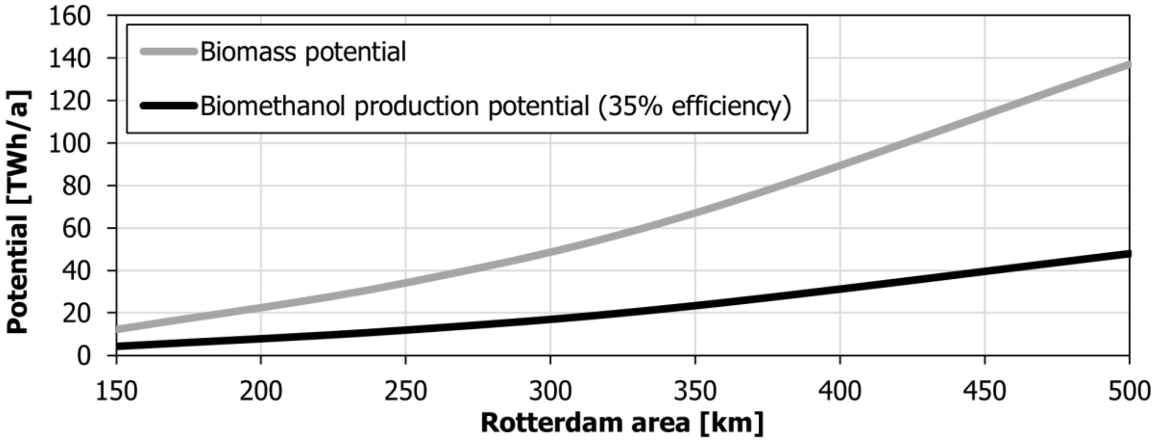

Figure 4: Estimation of the residual biomass for the year 2050 in the medium scenario (Ruiz et al. 2015) and potential of bio-methanol production in the 500 km region around Rotterdam.

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The capacity of existing and planned plants for "green methanol" in Europe until 2029 (The Methanol Institute 2024) could only cover around a third of the current demand for methanol (see Table 3). The chemical industry is currently the largest consumer of methanol. It can be assumed that the demand in the chemical industry for sustainable raw materials such as methanol will increase in the future and that potentially interested parties, such as the shipping industry, will compete for these resources. Thus, due to the limited biomass capacity it is unlikely that the European coastal and inland shipping can rely to a large extend on bio-methanol.

Table 3: Production plants for methanol from biomass and residual waste (RW) in the European Union (EU). The methanol production in the EU is shown for comparison. Abbreviations: oper: operational, feas: feasibility, eng: engineering, RW: residual waste.

Plant, location	**Status**	**Startup year**	**Capacity [kt/a]**	**Energy [TWh/a]**	**Feedstock**	**Owner, country**
Biomethanol, Ludwigshafen	oper	2018	17	0.1	biomethane	BASF, DE
Liquid Forest, Monsteras	oper	2020	5	0.0	black liquor	Sodra, S
Tjelbergodden Biomethanol	oper	2023	48	0.3	biomethane	Equinor, NO
Veolia biomethanol, Aanekoski	feas	2024	12	0.1	black liquor	Veolia, FI
Advanced Methanol Amsterdam	eng	2025	88	0.5	RW + biomass	Gidara Energy, NL
Waste-to-Methanol & H2, Empoli	eng	2025	125	0.7	RW	Alia Servizi Ambientali, I
Renewable Methanol, Mangualde	eng	2026	80	0.4	biomass + H2	Capwatt, PT
Project AIR, Stenungssund	eng	2026	200	1.1	biomethane	Perstorp, S
Sannazzaro Circular Methanol & H2	feas	2026	94	0.5	RW	Eni, I
Zero Residues-I, Zaragoza	feas	2026	661	3.7	RW	Urbaser et al., ES
Green2X, Vordingborg	eng	2027	280	1.5	biomethane	Green2x, S
Advanced Methanol Rotterdam	eng	2027	90	0.5	RW + biomass	Gidara Energy, NL
Livorno, Livorno	eng	2027	115	0.6	RW	Eni, I
DeltaNor-DeltaTorr, Delfzijl	feas	2027	220	1.2	biomass	Perpetual Next, NL
Baltanor, Vagari	feas	2027	220	1.2	biomass	Perpetual Next, EE
GasifHy-II, Delfzijl	feas	2027	450	2.5	RW + biomass	OCI Global, NL
ETA Manfredonia, Manfredonia	feas	2027	140	0.8	RW	Energie Tecnologie Amb., I
Gela, Gela	feas	2027	185	1.0	RW	Asja Ambiente, I
Boson Energy Tjorn-I, Tjorn	feas	2027	15	0.1	RW	Boson Energy, S
Pontedera, Pontedera	feas	2027	125	0.7	RW	Alia Servizi Ambientali, I
Ecoplanta MRS, El Morell	feas	2028	237	1.3	RW + H2	Repsol, ES
Glocal Green, Øjer	feas	2028	150	0.8	biomass + H2	Glocal Green, NO
Varmlands Methanol, Hagfors	feas	2028	100	0.6	biomass	Varmlands Methanol, NO
Power2X Estonia, Pärnu	feas	2028	500	2.8	biomass + H2	Power2X, EE
Total, operational and planned			**4 157**	**23.0**		
Methanol market Europe, EU 2023			11 300	62.5		(ChemAnalyst 2024)

2.3.2 Hydrotreated Vegetable Oils (HVO)

Vegetable oils can be converted into fuels through a catalytic reaction with hydrogen (hydrotreatment). The reaction conditions can be adjusted so that the fuels produced are comparable to conventional diesel. Used cooking oils (UCO) and biowaste are suitable raw materials for this process. The production processes are mature and there are already numerous production facilities in Europe. HVO can be used as a drop in fuel for diesel combustion engines.

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According to RED II Annex IX (European Union 21/12/2018), UCO are also considered sustainable raw materials to produce fuels under certain conditions. They are already widely used today to produce diesel for aviation and land transport. Figure 5 shows the production capacities of all production plants in Europe in 2020. The column next to it shows the range of available UCO within the European Union and United Kingdom for 2030. More HVO is already being produced from UCO than there is feedstock available. This "overconsumption" is only possible by importing large quantities of UCO to the EU. It can be concluded that the quantities of HVO produced in with UCO of EU's origin cannot be increased any further. Moreover, it is unlikely that the European coastal and inland shipping can rely to a large extend on HVO. Yet, as there is a great hope/hype in HVO as a replacement for fossil fuels, UCO is considered in this report as a possible feedstock for producing sustainable biofuels.

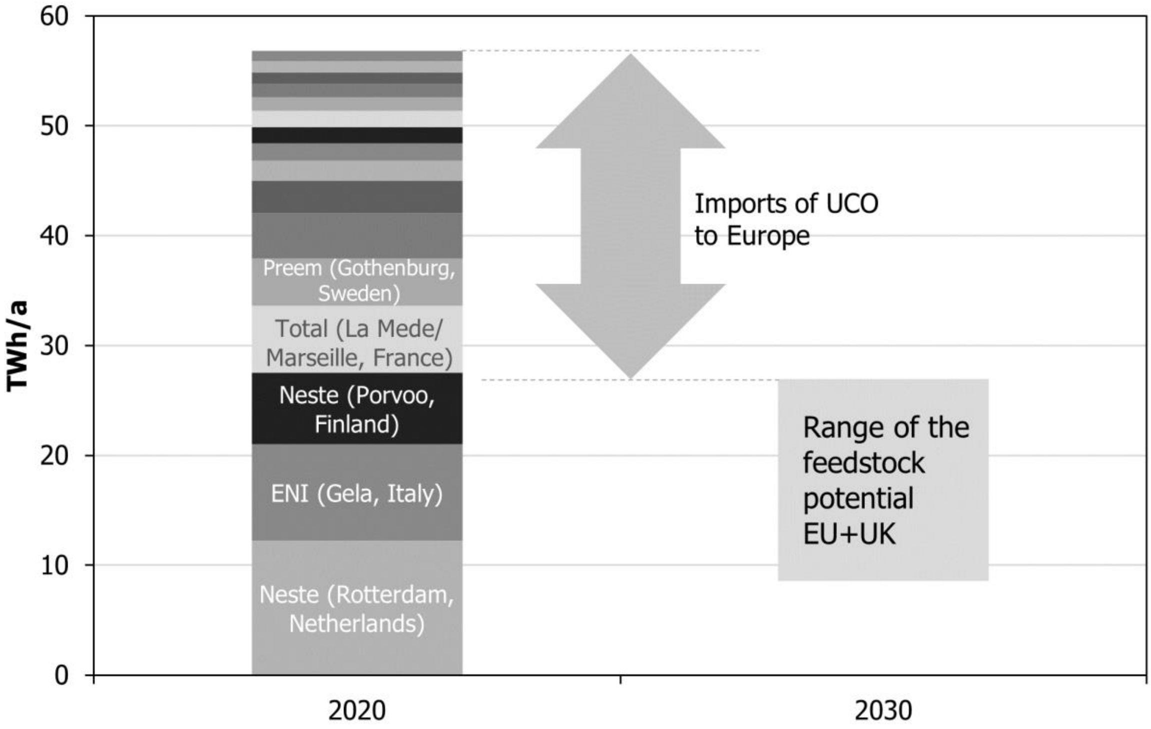

Figure 5: Production capacities of UCO-HVO 2020 in Europe (Statista 2024) and estimated range of UCO feedstock potential in the European Union and United Kingdom for 2030 (van Grinsven et al. 2020).

2.3.3 Not Considered (Bio-Based Energy Carriers)

Biomethane

Biomethane (CH4) can be produced by fermentation of organic materials with subsequent separation of methane from the raw biogas mixture produced or gasification of biomass, purification to synthesis gas, methanisation and drying or hydrothermal gasification of organic materials with subsequent separation of methane, water and residues. In compressed (CBM) or liquefied form (LBM), biomethane represents an option for operating inland cargo ships with renewable energy sources. However, the current restraints of use are described in Chapter 2.2.4.

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Black liquor

Black liquor is produced in the paper industry as a by-product of cellulose production from wood after the sulphate process. After separation of the pulp, water, dissolved lignin and chemicals remain. Nowadays, black liquor is processed at the sites of the mostly larger production facilities in the paper industry: Chemicals are separated and reused, residues are incinerated to provide heat and electricity.

In principle, black liquor can be used to produce renewable fuels. For this purpose, lignin would have to be separated and further processed. Black liquor to fuel BL2F is a Horizon 2020 project that will use black liquor as raw material to produce biofuels (BL2F 2024). From the point of view of the paper industry, there are two reasons against such use: First, lignins are high-quality phenolic macromolecules that should be utilised as a raw material in the chemical industry, e.g. as a biopolymer material. Second, the paper industry would have to replace black liquor with other renewable energy sources for the supply of heat and electricity. Existing and planned plants for bio-methanol production from black liquor in Europe are "Liquid Forest Monsteras" (Sweden, capacity 5 250 t/a using black liquor, start-up 2020) and "Veolia bio-methanol" (Finland, capacity 12 000 t/a, start-up planned in 2024) (The Methanol Institute 2024). Figure 6 shows that the black liquor produced in the EU is already almost completely consumed (no consumer specifications are given).

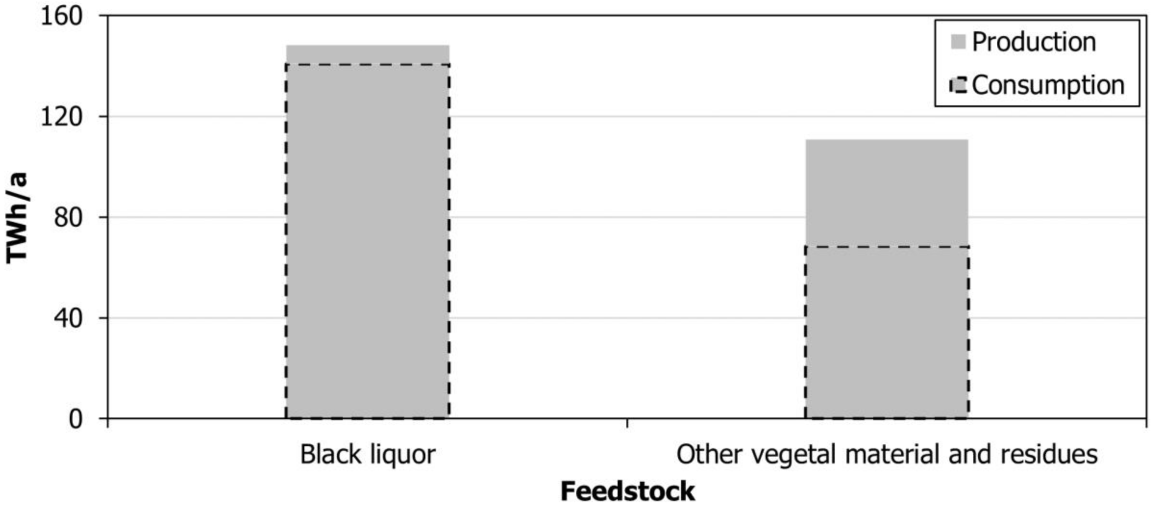

Figure 6: Usage of energy sources black liquor and other vegetal material and residues in the European Union (27 countries) in 2020 (Food and Agriculture Organization of the United Nations 2024).

In this report, black liquor is not considered as a feedstock to produce biofuels because lignins are valuable raw materials that should preferably be used as materials. In addition, black liquor is already used in the paper industry to generate heat and electricity. Shifting this by-product to the production of biofuels would have to be ecologically and economically more favourable than using alternative energy sources to replace black liquor.

Glycerine

Crude glycerine is a by-product of biodiesel production. It can be used as raw material to produce methanol and as such it can be re-used in biodiesel production, for example. Glycerine is also a valuable raw material for the chemical industry, where there is an increasing demand (Fortune Business Insights 2024). Thus, glycerine is not in focus for the use as a raw material for the production of energy carriers.

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2.4 Systemic Optimisation

The overall goal of SYNERGETICS is to improve the environmental performance of inland and coastal shipping with a focus on the existing fleets and retrofitting measures. In a broader context, this also contributes to the implementation of the European Green Deal and the Sustainable and Smart Mobility Strategy. There, shipping is expected to make a significant contribution to climate change mitigation. However, the excellent energy efficiency in transporting large quantities of goods over long distances alone is not enough. While intercontinental maritime transport is almost without alternative for large quantities of goods, intracontinental inland navigation and coastal shipping compete with rail and road transport. This competitive situation leads to considerable cost pressure, but also to competition to further improve sustainability through continued efficiency optimisation and decarbonisation/defossilisation.

A holistic optimisation of the transport sector should not be limited to single transport modes or vehicles as described in Allekotte et al. (2021):

- **Avoid** (1st priority): Reduce the overall amount of freight which needs to be transported
- **Shift** (2nd priority): Use environmentally friendlier modes of transport
- **Improve** (3rd priority): Reduce the environmental burdens of existing ships (or vehicles)

Where freight transport cannot be avoided, also modal shift options should be considered. Lorries benefit from their flexibility and the extensive road infrastructure for door-to-door services. Rail freight transport has a similar energy efficiency as shipping and benefits from an energy mix with a growing share of renewable energies due to the large proportion of electrified railway lines. Shipping, in addition to energy efficiency, has significant reserve capacity on most waterways.

The "Handbook on the external costs of transport" published by CE Delft (van Essen et al. 2019) provides the external costs of heavy goods vehicles, rail and inland waterway transport (IWT) in the EU28 as shown in Table 4. This list summarises the advantages and disadvantages of the different modes of transport in a very compact form. Accordingly, freight transport by rail and waterway should not be considered in competing roles but should contribute jointly to the social challenge. Depending on the transport task, shipping, for example, can take over transport services from rail in optimised logistics and thus free up additional capacity to avoid road transport on suitable routes.

Table 4: Average external costs of freight transport in the EU28 (van Essen et al. 2019).

Costs in [EUR-cent/tkm]	**Heavy goods vehicles**	**Rail**	**Inland shipping**	**Maritime shipping**	**Transport avoided**
Accidents	1.3	0.1	0.1	0.0	0.0
Air Pollution	0.8	0.2	1.3	0.4	0.0
Climate	0.5	0.1	0.3	0.2	0.0
Noise	0.5	0.6	na	na	0.0
Congestion	0.8	0.0	0.0	na	0.0
Well-to-Tank	0.2	0.2	0.1	0.1	0.0
Habitat Damage	0.2	0.2	0.2	na	0.0
Total	4.2	1.4	1.9	0.7	0.0

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3 Techno-Economic Analysis of Energy Carriers

3.1 Environmental Impact Indicators and System Boundaries

There are various environmental indicators for assessing the impact of freight transport: primary energy consumption, greenhouse gas emissions, nitrogen oxide emissions, sulphur dioxide emissions, particulate matter emissions, non-methane volatile organic compound emissions, land use, noise pollution, etc. (Allekotte et al. 2020; Anthes et al. 2022) In SYNERGETICS the following indicators are used:

- Greenhouse gas emissions in [gCO2e] (global warming potential / climate change)
- Nitrogen oxide emissions in [gNOx] (acidification, eutrophication, human toxicity, ecotoxicity)
- Particulate matter emissions in [gPM10] (human toxicity, summer smog)
- Costs in [EUR] as additional, non-environmental information

These indicators are stated per unit of energy supplied to the engine […/kWh]. If, for example, 1 kWh of diesel (heating value) is supplied to the engine, 266 gCO2e are emitted directly (Tank-to-Wake perspective). These specific emissions are independent of the efficiency of the propulsion system. Yet, if the specific emissions and costs of different energy carriers are compared directly to each other, these efficiencies must be considered. In case of an average diesel engine with an efficiency of 38%, the specific direct emissions "increase" (due to heat losses) to 701 gCO2e/kWh(kinetic).

The negative environmental impact of greenhouse gas emissions is independent of the locations of the emission sources. The greenhouse gas emissions of a remote methanol synthesis plant are equally bad as the corresponding emissions of a vessel which is anchoring in a densely populated area. However, nitrogen oxide and particulate matter emissions primarily have a negative impact on their direct surrounding. Thus, the negative environmental impact in the latter case increases the closer the emission source is situated to urban infrastructure and/or sensitive nature areas (e.g. Natura 2000).

The four most commonly used system boundaries for assessing the environmental impacts of transportation are illustrated in Figure 7. In SYNERGETICS a Well-to-Wake perspective is chosen as a full life cycle assessment was out of scope. Thus, the environmental impacts of the energy supply as well as the operation are considered (including storages). However, environmental impacts from infrastructure (ports, locks, waterways, etc.) and vessels (excluding storages) are not taken into account. Also, end-of-life is disregarded for all components in the modelling. The energy supply is modelled in detail (see Chapter 3.2) whereas existing data is used for the operation (see Chapter 3.3).

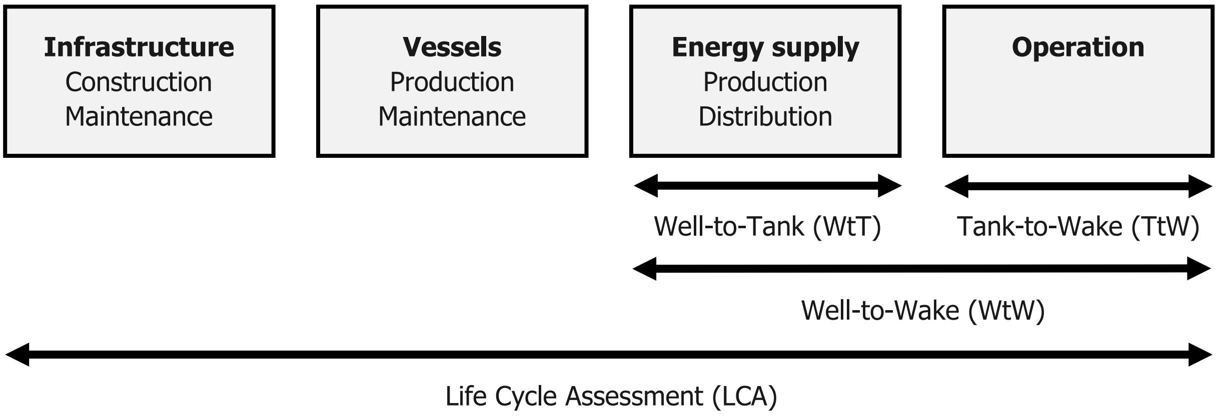

Figure 7: System boundaries of different assessment options.

In accordance with the "Mannheim Declaration" (CCNR 2023b) there are three reference years used in SYNERGETICS.

- **2020:** These results represent the status quo
- **2035:** These results represent a near-term future perspective
- **2050:** These results represent a long-term future perspective

In addition to these reference years, there are three scenarios modelled for all single paths:

- **Best guess:** Results based on most-likely raw data and assumptions
- **Low:** Lower end of result bandwidth based on "optimistic" raw data and assumptions
- **High:** Upper end of result bandwidth based on "pessimistic" raw data and assumptions

This report focuses on the years 2020 and 2050 as well as the best guess scenario.

3.2 Well-to-Tank: Modelling of Emissions and Costs

3.2.1 Modular Modelling and Basic Assumptions

All costs and emissions are calculated using a modular model (see Figure 8). Thus, all process steps along the supply paths are modelled individually and compiled afterwards. Detailed information on the individual modules is presented in the subsequent chapters as well as in the appendix. The Well-to-Tank perspective includes all process steps until the energy carrier is on the vessel (either as a fuel in a tank or as electricity in a battery container). By using this modular approach, it can be taken into account that process losses are more relevant the further down the supply chain they are situated.

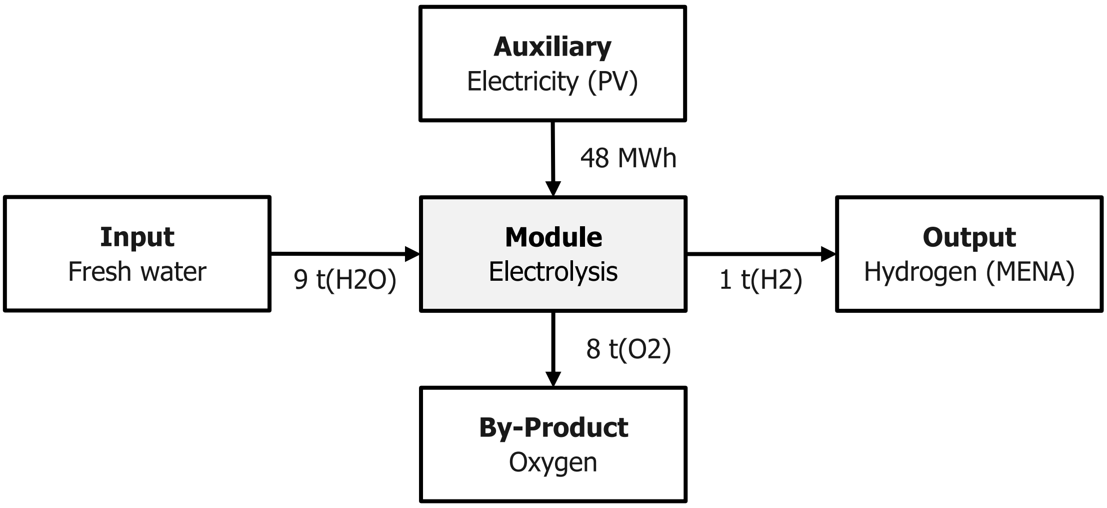

Figure 8: Modular model design: simplified example of the module "electrolysis". All Flows are stated per output.

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Several assumptions and simplifications had to be introduced to allow a fair comparison of the various supply paths for certain renewable energy carriers:

- Electrolysers, synthesis plants, etc. are only operating as much hours as the assumed full load hours of their corresponding power source (example of photovoltaics: about 1 700 h/a). This assumption allows to ensure the exclusive usage of fully renewable energy sources. Consequently, the total emissions tend to be higher when compared to alternative operational concepts of electrolysers. Such alternative concepts may be favoured by industry due to lower costs. Yet, the emissions increase strongly since non-renewable energy sources will then be used.
- All energy is transported to Rotterdam where the fuelling/charging takes place. Rotterdam is chosen as a reference harbour as it has the highest cargo handling within Europe (CCNR 2023a). A decentralised usage of the energy carriers is assessed as a What-If-Scenario in Chapter 3.6.2.
- By-products such as oxygen in the electrolysis process are neither considered for emission calculation (reductions by substitution of alternative production) nor for cost calculation (reduction by sale of by-products) due to the high level of speculation.
- Heat is used in closed loops within single process steps, but not between different process steps. Therefore, heat as a by-product is lost whereas additional heat is produced using electricity (1 kWh electricity = 1 kWh heat).
- In order to provide a neutral cost basis for political decisions costs are used (not prices). Thus, price effects such as taxes, subsidies or penalties are not covered.
- The annuity method is applied for the cost calculation. An interest rate of 7% is assumed in the best guess scenario.

The model input (raw data) is primarily based on the highly comprehensive SYSEET study by the German Federal Environment Agency which was first published in German in 2020 and then translated to English in 2021 (Liebich et al. 2021). Using one main source allows to have a high consistency in the raw data. The reference years are adjusted without adjusting the corresponding data (2015→2020, 2030→2035, 2050→2050). Yet, several raw data had to be added and/or updated for the usage in the model. For example, there is no data on fuelling/charging and the storage of energy carriers in the SYSEET study.

In Table 5 the assumptions for the bandwidth modelling (low and high scenario) are summarised.

Table 5: Modelling assumptions for the low and the high scenario for the years 2020, 2035 and 2050.

Module	Low scenario	High scenario
Wind offshore	Emissions: GEMIS v5.1 (IINAS 2023)	Emissions: +10%/+20%/+30%
Wind onshore	CAPEX, OPEX: -10%/-20%/-30%	CAPEX, OPEX: +10%/+20%/+30%
Photovoltaics	Interest rate: 4%/4%/4%	Interest rate: 10%/10%/10%
Electrolysis	Efficiency: -2%/-4%/-6%	Efficiency: +2%/+4%/+6%
Methanol synthesis	Emissions: -10%/-20%/-30%	Emissions: +10%/+20%/+30%
	CAPEX, OPEX: -10%/-20%/-30%	CAPEX, OPEX: +10%/+20%/+30%
	Interest rate: 4%/4%/4%	Interest rate: 10%/10%/10%
Other modules	Identical to best guess scenario	Identical to best guess scenario

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3.2.2 Electricity and Biomass Sources

Three electricity sources are considered in the Well-to-Tank analysis in general:

- Wind onshore from Europe
- Wind offshore form Europe
- Photovoltaics from MENA

This selection is based on the high electricity production potential per area for these regions. More specifically, a hypothetical onshore wind park in Germany (location with high wind potential), a hypothetical offshore wind park in Germany (North Sea) as well as a hypothetical photovoltaic system in Morrocco are modelled. They are located 500 km apart from Rotterdam (wind parks), respectively 3 000 km (photovoltaics). There are no combinations of electricity sources modelled, i.e., all single paths rely on just one electricity source.

The emissions in the best guess scenario for the year 2020 are based on comprehensive life cycle data from the German Environmental Agency (Lauf et al. 2023; Hengstler et al. 2021). "Auxiliary" components such as the cabling to the grid connection point are included proportionally. The extracted data can be seen representative for Europe as well as MENA since the supply chain emissions are outweighing the direct emissions by far. Thus, emissions are coupled to the emission intensity of the energy system in the production country (particularly China). The costs are based on a comprehensive German study (Schick et al. 2018). The values for the EU-mix are based on Icha et al. (2023) and Soler et al. (2022). The most relevant emission and cost parameters as well as the assumed full load hours are summarised in Table 6.

Table 6: Emissions, costs and full load hours for the electricity sources in the best guess scenario for the years 2020, 2035 and 2050. (Lauf et al. 2023; Hengstler et al. 2021; Schick et al. 2018; Icha et al. 2023; Soler et al. 2022; Liebich et al. 2021; IINAS 2023).

*-15% | **-50%	**Wind onshore**	**Wind offshore**	**Photovoltaics**	**EU-mix**
Greenhouse gas emissions [gCO2e/kWh]	17.7 *15.1 **8.9	9.7 *8.2 **4.8	56.6 *48.1 **28.3	498.0 254.0 67.0
Nitrogen oxide emissions [gNOx/kWh]	0.04 *0.03 **0.02	0.03 *0.02 **0.01	0.08 *0.07 **0.04	0.37 0.19 0.05
Particulate matter emissions [gPM10/kWh]	0.01 *0.01 **0.01	0.01 *0.01 **0.00	0.03 *0.03 **0.02	0.01 0.01 0.00
Costs [EUR/kWh]	0.055 0.047 0.040	0.103 0.083 0.071	0.037 0.029 0.023	0.100 0.100 0.100
Full load hours [h/a]	3 200 3 650 4 100	3 900 3 950 4 000	1 700 1 700 1 700	() () ()

The modelled biomass sources are residual forest wood (RFW) and straw for bio-methanol, respectively used cooking oils and biowaste (UCO+BW) for hydrotreated vegetable oil (HVO). The assumed average collection distances to the methanol synthesis plant are 500 km for RFW and 150 km for straw. UCO+BW is transported 1 000 km to the hydrotreatment plant on average. The following literature sources are used for modelling the biomass sources: Liebich et al. (2021), Anthes et al. (2022) and Brown et al. (2020).

3.2.3 Water Treatment and Carbon Dioxide Sources

There are several process steps in the supply chains of the assessed energy carriers which need larger quantities of treated water. This can either be sourced from seawater or from freshwater (groundwater and surface water). As freshwater resources are limited both in Europe as well as in MENA (Kuzma et al. 2023), only desalinated seawater is used. Reverse osmosis is chosen for all paths since it is the most common used desalination method (Liebich et al. 2021).

For producing e-methanol carbon dioxide (CO2) is needed. To assure net zero CO2 emissions from the on-board combustion only direct air capture (DAC) is used where CO2 from the atmosphere is harvested. Therefore, point sources like cement plants or municipal solid waste treatment plants are not considered. Although emissions and costs are expected to decrease in the future, this process step will remain emission and cost intensive, amongst others due to the adsorption fleece (Biemann et al. 2024; Liebich et al. 2021).

The following literature sources are used for modelling the water treatment and the carbon dioxide sources: Liebich et al. (2021), IINAS (2023) and Fasihi et al. (2019).

3.2.4 Electrolysis, Methanol Synthesis and Hydrotreatment

The most mature method to produce renewable hydrogen is water electrolysis. Pretreated water is split into hydrogen and oxygen using renewable electricity. It can be done by three main methods: alkaline electrolysis (AEL), proton exchange membrane electrolysis (PEM) and solid oxide electrolysis (SOEC). AEL is chosen since it is the most common method today as well as it is less expensive than PEM and SOEC (Gielen et al. 2021; Liebich et al. 2021). Since in this report hydrogen is either further processed or used for internal combustion engines and not for fuel cells, the purity of hydrogen produced by AEL is sufficient.

The main inputs for producing e-methanol are hydrogen, carbon dioxide, water as well as renewable electricity. Methanol from biomass consists of slightly different inputs: biomass, water as well as renewable electricity for the gasification. Both processes include three main steps: synthesis gas generation, methanol syntheses and a separation unit. It must be noted that they are technically different, i.e., a synthesis plant either produces e-methanol or methanol from biomass (Gielen et al. 2021; Liebich et al. 2021).

Hydrotreated vegetable oil (HVO) is produced using pretreated used cooking oils and biowaste (UCO), hydrogen, water and renewable electricity (Khandelwal and van Dril 2020).

The following literature sources are used for modelling the electrolysis, the methanol synthesis as well as the hydrotreatment: Liebich et al. (2021), Harmsen and t' Hart (2021), IINAS (2023), Kreidelmeyer et al. (2020), Kramer et al. (2021), Khandelwal and van Dril (2020) and Brown et al. (2020).

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3.2.5 Transport of Energy Carriers

Electricity is transported via the existing grid (direct current transmission cable overground). Costs and emissions of expanding the electricity grid due to the additional usage by the inland and coastal shipping are neglected. Hydrogen, methanol and HVO are transported by vessels, lorries or pipelines. Again, a shared use is assumed, i.e., process and infrastructure emissions and costs are neglected. Moreover, vessels and lorries are assumed to exclusively use diesel for their engines both today and in the future; this very conservative assumption can be used since these transport emissions and costs are neglectable in the overall picture anyway. Hydrogen is assumed to be liquified for the transport via vessels. The existing gas grid can be retrofitted to the transport hydrogen (van Rossum et al. 2022).

The following literature sources are used for modelling the transport of energy carriers: Liebich et al. (2021), Bundesnetzagentur (2022), Hank et al. (2020), Kreidelmeyer et al. (2023), FfE (2022), Anthes et al. (2022), Al-Breiki and Bicer (2020), Riemer et al. (2022) and Mendelevitch et al. (2023).

3.2.6 Charging and Fuelling Stations

Charging and fuelling stations for the energy carriers are modelled considering operational energy losses as well as auxiliary energy demands for the operation. Process and infrastructure emissions are neglected. There are no opportunity costs considered for the additional charging and fuelling time.

The following literature sources are used for modelling the charging and fuelling stations: Röck et al. (2020), Kramer et al. (2021), Frank et al. (2021), Al-Breiki and Bicer (2020), Jöhrens et al. (2022) and Röck et al. (2020).

3.2.7 Onshore Energy Storage (Short-Term)

To cope with the fluctuating renewable electricity supply, short-term onshore energy storages are modelled. For all supply paths the average daily energy demand of the European inland waterway transportation (IWT) fleet is used for dimensioning the storages, calculated for the respective technologies. The same assumptions are used for electricity from photovoltaics (MENA) and onshore/offshore wind (Europe) although their supply profiles differ from each other. A more detailed assessment of short-term storages (hours, days, weeks), long-term storages (seasonal) and synergies with other energy consumers (e.g. chemical industry) are not part of this report. For a better comparability of the different supply paths all short-term storages are assumed to be located in Rotterdam. On-board storages are part of the Tank-to-Wake part and thus, they are described in more detail in Chapter 3.3.2.

In 2015 the annual energy demand of the IWT was 6.2 TWh(diesel)/a (Dahlke-Wallat et al. 2021). Using the efficiencies of the different propulsion systems (see Table 8), hypothetical annual energy demands can be calculated for alternative energy carriers. These values are then divided by 365 days per year to calculate the average daily energy demands, i.e. the dimensioning values for the short-term energy storages. The storage capacities range from 7.2 GWh in case of storing electricity to 17.0 GWh in case of all other energy carriers. The different short-term storage technologies for the analysed energy carriers as well as further modelling assumptions are presented in the subsequent paragraphs.

Electricity storage ("batteries")

Electricity storage ("batteries") and charging facilities are needed to operate ships electrically. Kistner et al. (2024) assess potentials and limitations of battery electric propulsion systems for different types of vessels and transport capacities. They also provide an overview of today's common battery types with capacities, costs, and operating parameters. Regarding greenhouse gas emissions, this report

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refers to Transport & Environment (2023), NHOA Energy (2024), Dai et al. (2019) and Crenna et al. (2021). The scale of greenhouse gas emissions depends more on the frequency of charging processes than on the choice of cell technology. Lithium-nickel-manganese-cobalt-oxide (NMC) cells are considered as the most widely used technology for marine applications today. Hence, NMC cells are used for modelling. Other cell types are lithium-iron-phosphate (LFP) and lithium-titanium-oxide (LTO) cells.

The battery lifetime depends amongst others on the type of battery cell and the number of charging cycles as battery cells degrade over time. Depending on the cell type, the charging capacities of the battery at the end of its service life are in the range of 80%. They can then be further used for other application with lower requirements. The battery storage units can either be housed in containers (especially for mobile applications) or in fixed battery stations. The following components are generally required: battery cells, converter, transformer, control unit, cooling and ventilation, safety equipment such as fire alarm system and additional equipment. In addition to the electricity that is stored, electricity is also required to operate the auxiliary equipment.

The daily average energy demand for electric sailing determines the capacity of onshore batteries which serve as short-term energy storage. The charging times are expected to be higher compared to all other technology paths for alternative energy carriers (not represented in the modelling). The modelling includes the degradation of the battery as well as the main operational aspects (charging and discharging, cooling, control etc.). However, it excludes the preparation of the site (buildings, grid connection, etc.) as well as grid service operations. Based on Röck et al. (2020) an overall loss factor of 7% of the energy output related to the energy input of the battery is applied. For the capacity chosen, roughly one full cycle per day can be assumed on average, leading to a match of reaching the maximum number of cycles within the lifetime of the battery (20 years).

To cover representative costs for utility-scale NMC batteries, several papers and studies are reviewed. Detailed and well-founded descriptions for battery CAPEX and OPEX which include various relevant parameters are provided by Ramasamy et al. (2022) as well as Cole and Karmakar (2023). Based on the analysis of a 240 MWh battery for utility-scale battery storage by using the NREL Calculator (NREL 2024) the following input data is used in this report: CAPEX [EUR/kWh(battery capacity)] of 446 (2020), 281 (2035) and 219 (2050) and OPEX [% of CAPEX] of 2.5%.

Hydrogen storage

According to Hren et al. (2023) hydrogen can be stored by multiple technologies that can mainly be divided into physical and chemical storages. For chemical hydrogen storages, Zhang et al. (2024) describe several challenges related to complex material synthesis, handling, slow kinetics of hydrogen uptake and release, and the lower maturity of chemical storage technologies. Therefore, the assessment of short-term hydrogen storage in this report focusses on physical hydrogen storage technology. This can again be divided in the storage of gaseous compressed hydrogen or cryogenic cooled liquefied or compressed hydrogen (Hren et al. 2023). With respect to the substantial energy demand for liquefaction or compression at cryogenic temperatures and the evaporative losses when applying cryogenic storage technologies (Zhang et al. 2024; Ye and Lu 2023), only gaseous hydrogen compression storage are considered as short-term storage option. Compressed gaseous hydrogen can be stored in hydrogen cylinders or in caverns. Suitable caverns are not available in Rotterdam and are therefore neglected.

Hydrogen cylinders as storages are a well-established and practical method for stationary purposes (Usman 2022). Tanks for storage of compressed gaseous hydrogen are classified in four different types, each being applicable to different conditions (Hassan et al. 2021). The pressure applied ranges from low pressures of up to 50 bar (Bionaz et al. 2022) to high pressures of up to 1 000 bar (Hassan et al. 2021). Pressure variations cause changes of the volumetric hydrogen density, the required volume of the tank and the required materials. Tank type I is especially suitable for stationary applications with

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low pressures (Hassan et al. 2021) and less costly than the other tank types (Guerra et al. 2021; Mucci et al. 2023). Stolten and Emonts (2016) describe that the concept of spherical tanks commonly used for natural gas storage in the range of about 30 tons of storage capacity could also be used for storing hydrogen if suitable materials (stainless steel) are applied. Type I hydrogen storages are regarded as established and available technologies and therefore classified as TRL 9 (Klinger et al. 2024).

To assess the emissions of hydrogen onshore storages, the following assumptions are made:

- Data for physical hydrogen storage, gaseous/compressed, Tank Type I is used, i.e. a storage concept consisting of metal only. As material, stainless-steel Type 304 (chromium steel 18/8) is assumed with material specific greenhouse gas emissions of 4.1 kg CO2e/kg(steel) (KBOB 2024).
- The total capacity of the short-term hydrogen storage is assumed to be the daily average energy demand for hydrogen-based vessels with internal combustion engines.
- No underground storage concepts are considered due to restrictions in port areas. For larger hydrogen storage capacities, spherical storage containments are assumed due to lower specific costs per energy content compared with cylindrical storage containments.
- Based on Stolten and Emonts (2016) specific emissions and costs are calculated for a spherical hydrogen storage with a working capacity of 24.6 tons of hydrogen at low pressure (less than 20 bar), an inner diameter of 39.5 m, a wall thickness of 34 mm (stainless steel type 304) and a material surcharge for steel of 25% for valves, structural components, etc., leading to a rounded total mass of 1 700 tons. This material demand is used for calculating the emissions. In order to consider the environmental impact of all other materials an additional surcharge of 100% is applied.
- The total emissions are then converted to specific values per kWh of hydrogen finally delivered to the vessels with an estimated lifetime of the on-shore storages of 50 years and an extrapolation of the number of on-shore storages needed to cover the average daily energy demand.
- Compressors are needed to charge the hydrogen storages. The energy demand of the compressor depends on the applied pressure. For compression to less than 50 bar, an electricity demand of 0.6 kWh(electricity)/kg(hydrogen) is assumed (Linde 2022) which corresponds to about 2% of the lower heating value of hydrogen.
- Hydrogen losses from compressors and storage units are assumed to be 0.1% (Kramer et al. 2021).
- The modelling includes the main operational aspects (i.e. charging with compressors), but it excludes the preparation of the site (buildings, ground preparation, security installations such as ex-zones and barriers/fences, etc.).

The cost assessment is primarily based on Clean Hydrogen Joint Undertaking (2022): For aboveground storage, KPI 5 in Annex 3 presents state-of-the-art and future capital costs including all necessary components to operate the storage system. van Leeuwen and Zauner (2018) are listing many references analysing the OPEX of large-scale hydrogen storages. Summarising, an OPEX of 1% of the initial CAPEX appears to be a good assumption. As on-land storages for the hydrogen path would have to be in port areas, underground storage options are neglected.

Methanol storage

Since the production of methanol with renewable electricity and/or biomass input is fluctuating, short-term onshore storages are needed for methanol as well. The daily demand is assessed from the annual methanol supply needed to operate the whole European IWT fleet on renewable methanol.

Unlike hydrogen methanol can be stored as liquid at atmospheric pressure. Therefore, an overground cylindrical storage tank with a volume of 4 000 m3, a diameter of 16 m, a height of 20 m, a wall thickness of 18 mm and a lifetime of 50 years is modelled. The same material as for hydrogen is chosen

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(stainless steel 304 (Ortiz Cebolla et al. 2022)) and a material surcharge for piping, fittings, racks, etc. of 50% is applied. With the amount of energy calculated as daily demand, the 4 000 m3 storage is too large. Therefore, the storage volume is reduced to the share needed (about 80%). The emissions are calculated using the same method as for the hydrogen storage (emissions for stainless stell, plus 100% surcharge).

For the costs (CAPEX and OPEX) of large-scale methanol storage tanks no reliable sources are found. Therefore, the cost estimations are based on a commercial offer for a methanol tank with a volume of 100 000 litres. Since in the overall results this leads to neglectable additional costs, it is not necessary to consider lower specific costs of larger units.

HVO (diesel) storage

For HVO (diesel) storages, the same method as for methanol storages is applied. There is only one difference: A smaller share (about 45%) of the 4 000 m3 storage is needed due to the higher energy density of HVO compared to methanol.

For the costs (CAPEX and OPEX) of large-scale HVO and/or diesel storage tanks no reliable sources are found. Therefore, the cost estimations are based on a commercial offer for a diesel tank with a volume of 100 000 litres. Since in the overall results this leads to neglectable additional costs, it is not necessary to consider lower specific costs of larger units.

3.2.8 Selection of Supply Paths

There would be hundreds of supply paths which could be modelled due to the modular setup. However, not all of them are feasible and/or advisable. Twenty-six fully renewable supply paths are chosen (see Table 7). They are categorised by a two-digit system ("path-ID"):

- The first digit represents the energy carrier:
  1: diesel, 2: electricity, 3: e-hydrogen, 4: e-methanol, 5: bio-methanol, 6: HVO
- The second digit is a sequent number for path variations

There are eight best guess supply paths (marked with an asterisk in Table 7) which can be interpreted like this:

- 2020: "If the inland and coastal shipping was powered by renewable energies today, the following emissions and cost would have occurred."
- 2035/2050: "If the inland and coastal shipping will be powered by renewable energies in the near-term and/or long-term future, the following emissions and costs will occur."

Several assumptions are used to identify the eight best guess supply paths:

- Wind onshore is preferred over wind offshore since it has higher annual electricity production capacities, both today as well as in the future.
- Decentralised electrolyses and methanol syntheses are chosen due to limited space at Rotterdam (or any other fuelling location).
- Hydrogen transport by vessels is chosen for today (2020) and the near-term future (2035) whereas transport via pipeline is chosen for the long-term future (2050).
- Methanol transported by vessels is preferred over lorries as vessels have higher transport capacities.

Be aware that the costs of the reference path (diesel) cannot be compared directly as SYNERGETICS uses costs whereas in most literature prices are stated for diesel.

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Table 7: Selection of single supply paths (UCO: Used Cooking Oils). Best guess paths are marked with an asterisk.

Path	Energy source	Decentralised process	Energy carrier and mode of transport	Centralised process
21	wind offshore	-	electricity / grid	-
22*	wind onshore	-	electricity / grid	-
23*	photovoltaics	-	electricity / grid	-
31	wind offshore	-	electricity / grid	electrolysis
32	wind offshore	electrolysis	hydrogen / vessel	-
33	wind offshore	electrolysis	hydrogen / pipeline	-
34	wind onshore	-	electricity / grid	electrolysis
35*	wind onshore	electrolysis	hydrogen / vessel	-
36(*)	wind onshore	electrolysis	hydrogen / pipeline	-
37	photovoltaics	-	electricity / grid	electrolysis
38*	photovoltaics	electrolysis	hydrogen / vessel	-
39(*)	photovoltaics	electrolysis	hydrogen / pipeline	-
41	wind offshore	-	electricity / grid	methanol synthesis
42	wind offshore	methanol synthesis	methanol / vessel	-
43	wind offshore	methanol synthesis	methanol / lorry	-
44	wind onshore	-	electricity / grid	methanol synthesis
45*	wind onshore	methanol synthesis	methanol / vessel	-
46	wind onshore	methanol synthesis	methanol / lorry	-
47	photovoltaics	-	electricity / grid	methanol synthesis
48*	photovoltaics	methanol synthesis	methanol / vessel	-
51*	residual forest wood	methanol synthesis	methanol / vessel	-
52	residual forest wood	methanol synthesis	methanol / lorry	-
53	straw	methanol synthesis	methanol / vessel	-
54	straw	methanol synthesis	methanol / lorry	-
61*	UCO and biowaste	hydrotreatment	HVO / vessel	-
62	UCO and biowaste	hydrotreatment	HVO / lorry	-

3.2.9 Allocation of Emissions and Costs

Emissions and costs are allocated to their corresponding module which is illustrated in Figure 9. Emissions and costs from the energy production (e.g., wind offshore) are allocated to the module where the energy is actually used. Meaning, if there was no energy used along the supply chain, all emissions and costs would be allocated to the energy production. In reality, however, there are always some losses (e.g., electricity grid) and auxiliary energy demands (e.g., electrolysis) along the supply chain.

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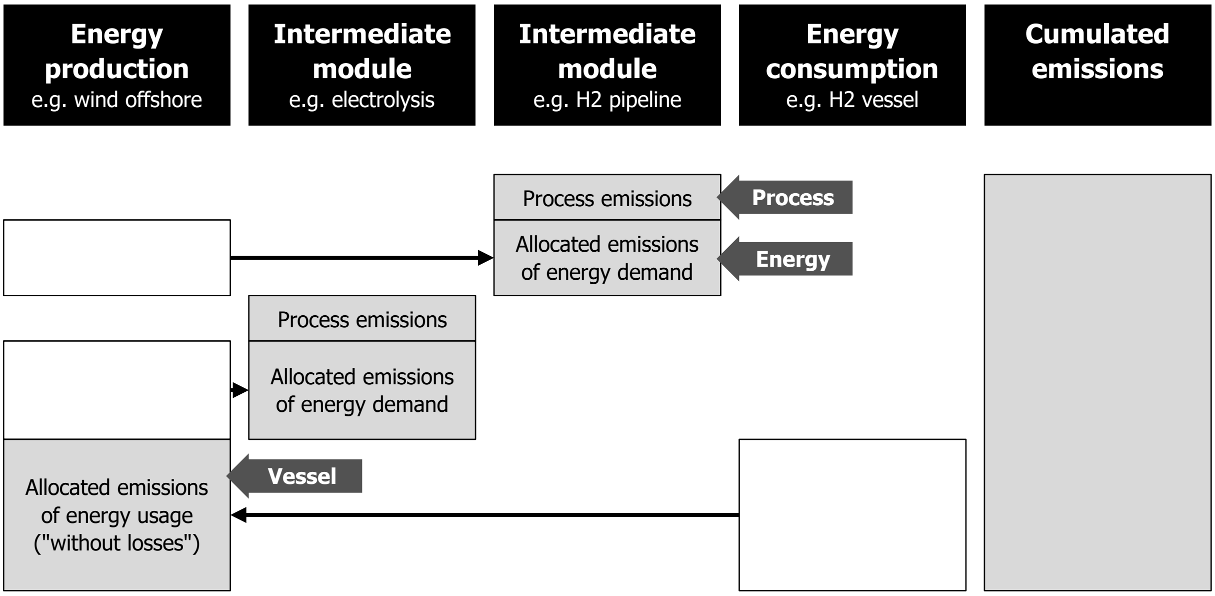

Figure 9: Allocation of emissions. Costs are allocated using the same method. The terms "Process", "Energy" and "Vessel" (dark grey arrows) are used for the hotspot analysis.

3.2.10 Reference Path (Diesel)

As reference, fossil diesel from the Middle East is used (path-ID: 11). It has the following Well-to-Tank-emissions: 84 gCO2e/kWh, 0.1 gNOx/kWh and 0.003 gPM10/kWh (Allekotte et al. 2024; Allekotte et al. 2020). The efficiency of the propulsion system (38%) is not included in these emission values. Thus, the effective emissions will be about three times as high. Costs are taken from Soler et al. (2022).

3.3 Tank-to-Wake: Data on Emissions and Costs

3.3.1 Propulsion System

Tank-to-Wake emissions and costs strongly depend on multiple factors such as vessel types or load profiles. A detailed assessment of these aspects is outside the scope of this report but will be done in Work Packages WP4 and WP5. Nevertheless, the chosen methodology allows a fair comparison of the different energy carriers.

Average emissions and costs from a Tank-to-Wake perspective are summarised in Table 8. Although no bandwidths are displayed, these values vary between different vessel types, load profiles, etc. The CAPEX does not include the costs for a corresponding fuel tank or battery container since they are reflected in Chapter 3.3.2. It is assumed that the efficiency of the propulsion system remains constant until 2050. Efficiency improvements tend to be "compensated" by the additional energy demand for the exhaust gas aftertreatment.

Dahlke-Wallat et al. (2021) gives an overview on the future development of the energy efficiency in inland navigation: "It is assumed that the energy consumption of the entire fleet will in total reduce by 15% for the BAU [business as usual] 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

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pathways, besides a fund it is likely that additional accompanying measures are implemented to promote fuel efficiency and lowering of carbon footprint of IWT."

There are no operational fossil greenhouse gas emissions for any of the energy carriers. The emitted greenhouse gas emissions have either been captured before or they are of biogenic origin.

Table 8: Emissions and costs from a Tank-to-Wake perspective for the year 2020, all values are rounded. Sources: DST, MARIN, SPB/EICB as well as literature (Allekotte et al. 2024; Allekotte et al. 2020; Dahlke-Wallat et al. 2021; Kortsari et al. 2020; Ryste 2019).

	Diesel	**Electricity**	**Hydrogen**	**Methanol**	**HVO**
Efficiency of the propulsion system	38%	90%	38%	38%	38%
Greenhouse gas emissions [gCO2e/kWh***]	266	no emissions	no emissions	net zero	net zero
Nitrogen oxide emissions [gNOx/kWh***]	*3.91	0.00	**1.53	**1.53	**1.53
Particulate matter emissions [gPM10/kWh***]	*0.08	0.00	**0.04	**0.04	**0.04
Costs [EUR/kWh***]	0.02	0.07	0.07	0.05	0.02

*fleet average | **EU emission limits (European Union 16/09/2016; Dahlke-Wallat et al. 2021): 25% Euro VI marinised lorry and NRE engines 56 kW < P < 560 kW, 50% Stage V IWA/IWP engines > 300 kW, 25% Stage V IWA/IWP engines < 300 kW | ***heating value

The Tank-to-Wake costs are based on the most common European inland vessel ("motor vessel 80-109 m"). The following parameters are assumed equal for all energy carriers: power: 700 kW, running hours: 6 000 h/a, lifetime: 20 a, interest rate: 7%, OPEX: 10% of CAPEX. The CAPEX differ between the energy carriers and are depicted in Table 9.

Table 9: CAPEX assumptions for the retrofit of the most common European inland vessel (values used and bandwidths). Sources: DST, MARIN and SPB/EICB.

	Diesel	**Electricity**	**Hydrogen**	**Methanol**	**HVO**
CAPEX engine [EUR/kW]	600 (450-750)	150 (100-150)	750 (600-900)	750 (600-900)	600 (450-750)
CAPEX installation [EUR]	40 000 (30 000-40 000)	1 500 000 (1 000 000-1 900 000)	950 000 (700 000-1 200 000)	650 000 (500 000-800 000)	40 000 (30 000-40 000)

3.3.2 On-board Energy Storage

The total annual energy demand for the propulsion system must be stored on-board the vessel before use. Hence, suitable on-board storage options must be installed. Theoretically, a surcharge could even be included since on-board energy storage capacities are usually higher than the effectively used

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amount of energy per charging (fuelling) and discharging cycle. For some paths, the additional environmental impacts and costs will depend on the sizing of the on-board storage, balancing space requirements, additional weight and other aspects with the required range of sailing with one filling of the on-board storage. In this report, it is assumed that the data calculated for the on-board storage options are scalable to the total annual energy needed. Yet, they are based on concrete technical options as described below for the different technology paths. In Table 10 the emissions and costs of on-board storages are depicted for the year 2020. Emissions are caused at the production of the storages (materials and processing) and add to the overall emissions of the technology path. For the assessment of the share in the value chain, they are divided by the total energy supplied to the engine (i.e., kWh does not refer to the capacity of the storage in this case).

Table 10: Emissions and costs of on-board storages for the year 2020, all values are rounded. Sources: DST, MARIN, SPB/EICB as well as literature (see main text body).

	Diesel	Electricity	Hydrogen	Methanol	HVO
Greenhouse gas emissions [gCO2e/kWh]	0	28	7	0	0
Nitrogen oxide emissions [gNOx/kWh]	0.00	0.04	0.02	0.00	0.00
Particulate matter emissions [gPM10/kWh]	0.00	0.02	0.06	0.00	0.00
Costs [EUR/kWh]	0.00	0.17	0.01	0.00	0.00

Batteries

There are two main use concepts for electricity-powered vessels with their individual advantages and disadvantages: (1) Vessels with permanently installed on-board batteries. These batteries are charged on-board using onshore charging stations while the vessel is anchoring at a port. This concept is used for modelling. (2) Vessels with standardised, exchangeable battery containers. These battery containers are charged independently of the vessels and swapped when a vessel is anchoring at a port. The charging times are significantly reduced applying this concept. However, it requires more storage redundances, i.e. a higher number of battery containers fully charged on land. Under certain conditions these might be used for grid stabilisation services which would mitigate the additional costs and emissions. Since this is a complex topic, it is not integrated in the modelling.

Different publications for smaller batteries (e.g., cars or trains) present a greenhouse gas intensity of 60-110 kgCO2e/kWh battery capacity (Transport & Environment 2023). However, most studies include or exclude different parts of the battery system or were made for specific boundary conditions. In this report, on-board batteries are modelled with the same specific emissions and costs as onshore batteries (see Chapter 3.2.7). This should be a good approximation: On the one hand, the specific emissions and costs of smaller battery installations are underestimated (scaling). On the other hand, onshore storages include some technical parts (e.g. transformers and rectifiers) which are not needed in on-board batteries since they are covered by the upstream components and modelling modules. The lifetime of on-board batteries is assumed to be 10 years due to the higher number of charging cycles (onshore batteries: 20 years).

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The calculated emissions and costs are summarised in Table 10. The costs for on-board batteries are assessed as those for short-term battery storage on land (see Chapter 3.2.7) since they are more likely to be in a similar order of magnitude of utility-scale battery systems than those for cars.

Hydrogen tanks

The compression for on-board storage is covered in the fuelling module (see Chapter 3.2.6). Shin and Ha (2023) present an overview on available on-board hydrogen storages and types. For this analysis, on-board storages are assessed with Tank Type IV concepts (mainly consisting of carbon fibres and epoxy resin, plus HDPE) at 700 bar as these currently seem to be the ones considered for the upscaling of application in lorries.

Comprehensive data and calculations are presented in Weiszflog and Abbas (2022). Based on their life cycle assessment results for Type IV storages with a capacity of 80 kg of hydrogen, the greenhouse gas emissions per kWh of hydrogen are transferred directly. The particulate matter emissions and the nitrogen oxide emissions are extrapolated since data is missing, respectively it is not directly transferrable. To be consistent with the assumptions in other parts of this report, the use phase and end-of-life are neglected. For the on-board hydrogen storage system a number of 700 bar tanks for 80 kg of hydrogen (about 1 500 kg) are assumed, a frame (about 1 100 kg) and balance of plant components (about 100 kg). Hydrogen losses of 5% are assumed. Although currently for the small number of existing hydrogen systems on board of inland vessels 350 and 500 bar systems are used, it might be expected that for larger energy demand (long-haul lorries, trains etc.) in mobility applications the 700 bar Type IV storages will become standard for the up-scaling and thus they are used as reference in this report. Especially for the costs, the expectations of the number of produced units are largely influencing the projections.

The calculated emissions and costs are summarised in Table 10. The cost assessment is primarily based on Clean Hydrogen Joint Undertaking (2022): KPI 7 in Annex 4 presents state-of-the-art and future capital costs for compressed hydrogen storage tank including necessary components and assuming a production of 200 000 units per year in 2030. Unlike the low-pressure on-land aboveground storage, the assumed lifetime is shorter (10 instead of 50 years) and the OPEX is higher (4% instead of 1%) which leads to a higher contribution to the overall costs in the full path assessment.

Methanol and HVO tanks

The specific emissions are assessed based on the material demand for standard tank units of 4 000 m3 (stainless steel) as calculated for the onshore storages. Naturally, the on-board storage of a vessel is smaller and thus has a higher specific material demand. However, in retrofit most of the existing on-board tanks might be further used, at least for several years or even decades. Therefore, the same specific emissions and costs are used as for onshore storages. Since the contribution to the overall results is marginal, no in-depth analysis is necessary.

The calculated emissions and costs are summarised in Table 10. Since also the contribution of costs of on-board storages to the overall path results are marginal, the same cost assumptions as for the on-land storage are applied.

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3.4 Electricity-Based Energy Carriers

3.4.1 Well-to-Tank: Results and Discussion

Emissions and costs for the year 2020 (status quo)

The global warming potential varies between 20 gCO2e/kWh and 378 gCO2e/kWh for the year 2020 in the best guess scenario (see Figure 10). The hydrogen (31-36) and battery-electric paths (21-22) using electricity from wind offshore/onshore have the lowest greenhouse gas emissions. The supply paths with electricity from photovoltaics (23,37-39,47-48) have higher emissions compared to their corresponding supply paths with electricity from wind offshore/onshore. This difference is primarily caused by the higher emissions of photovoltaics. The six times longer transport distance plays a subordinated role. The supply paths with electricity from wind offshore (21,31-33,41-43) have slightly lower emissions than those from wind onshore (22,34-36,44-46). On average offshore turbines are larger than onshore turbines. Hence, they are more efficient and have lower emissions. Also, they have higher full load hours due to better wind profiles. Generally, the more energy conversation steps are included in a supply chain, the higher are the greenhouse gas emissions (electric < hydrogen < methanol). However, as onshore storages for the battery-electric paths (21-23) are very emission-intense, the corresponding hydrogen paths (31-39) have lower overall Well-to-Tank greenhouse gas emissions.

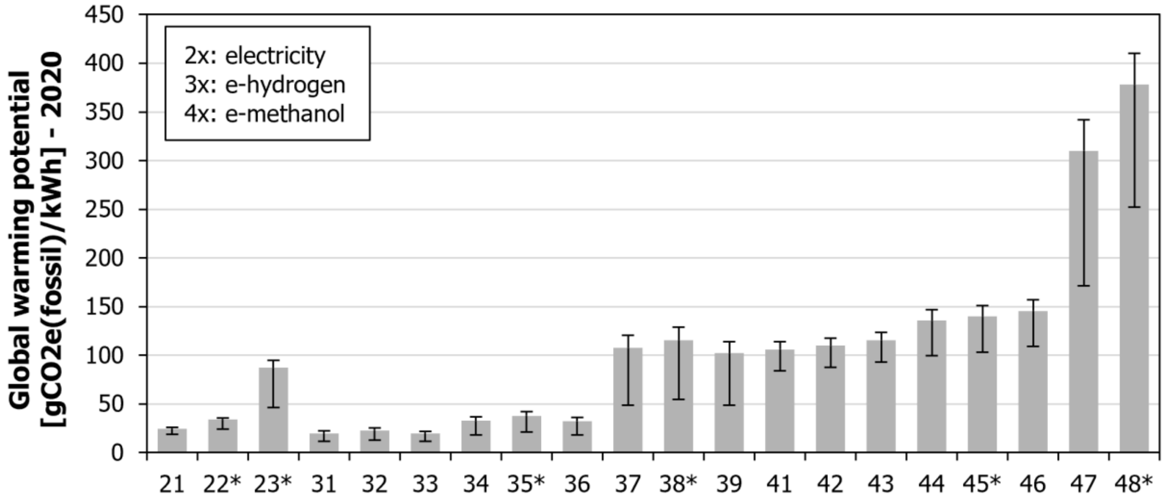

Figure 10: Global warming potential in [gCO2e(fossil)/kWh] for the year 2020 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

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The nitrogen oxide emissions vary between 0.05 gNOx/kWh and 0.46 gNOx/kWh for the year 2020 in the best guess scenario (see Figure 11). They show basically the same characteristics as the global warming potential (see explanations above). Yet, despite the emission-intense onshore storages the battery-electric paths have the lowest overall Well-to-Tank nitrogen oxide emissions.

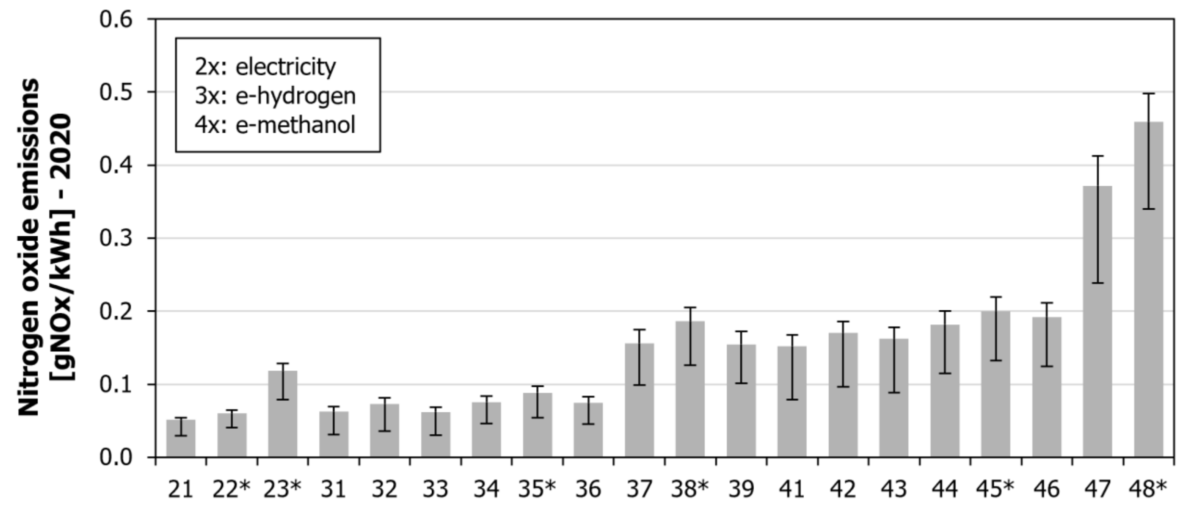

Figure 11: Nitrogen oxide emissions in [gNOx/kWh] for the year 2020 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

The particulate matter emissions vary between 0.02 gPM10/kWh and 1.55 gPM10/kWh for the year 2020 in the best guess scenario (see Figure 12). The electrolysis as well as the methanol syntheses are the modules with the highest emissions along the supply chain. Thus, the battery-electric paths have the lowest overall Well-to-Tank particulate matter emissions. The plant emissions in MENA are about twice as high as those in Europe.

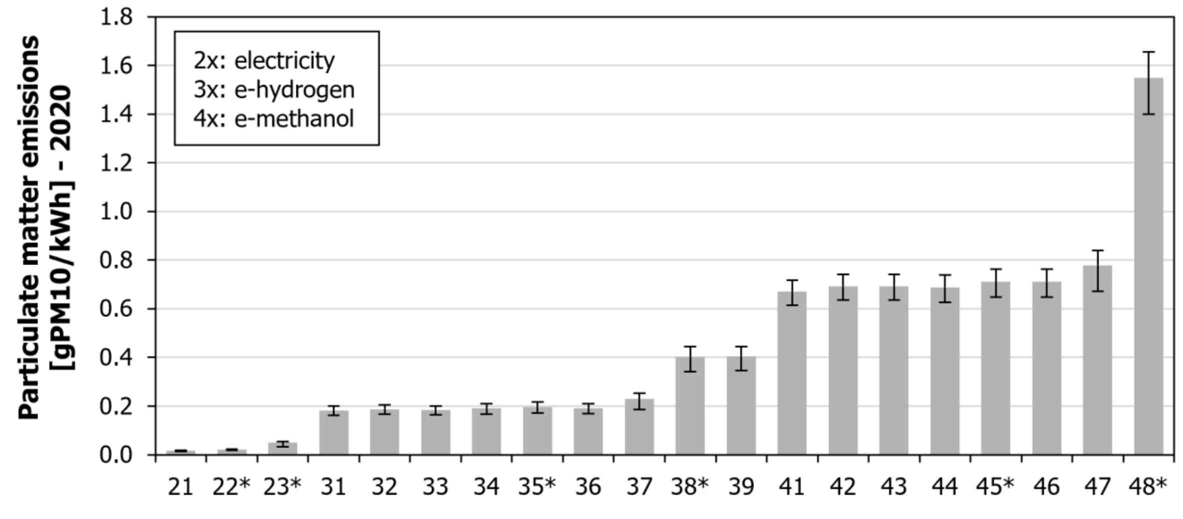

Figure 12: Particulate matter emissions in [gPM10/kWh] for the year 2020 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

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The costs vary between 0.17 EUR/kWh and 0.56 EUR/kWh in the year 2020 for the best guess scenario (see Figure 13). The supply paths from wind onshore (22,34-36,44-46) have the lowest costs, followed by those from photovoltaics (23,37-39,47-48). Hydrogen supply paths (31-39) have the lowest costs.

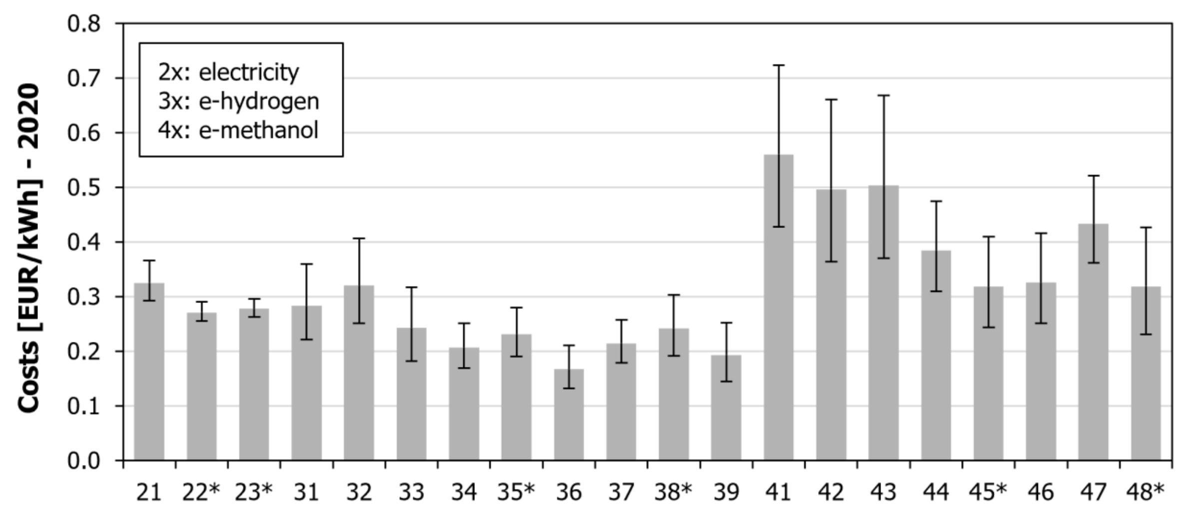

Figure 13: Costs in [EUR/kWh] for the year 2020 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

The Well-to-Tank path energy efficiencies vary between 24% and 88% for the year 2020 in the best guess scenario (see Figure 14). The efficiencies decrease with the number of energy conversation steps and the overall path complexity (electric > hydrogen > methanol). The battery-electric paths from Europe (21-22) have less transmissions losses compared to the path from MENA (23) and thus, they are more efficient. The hydrogen paths including a decentralised electrolysis coupled with hydrogen transport by vessel (32,35,38) are the most efficient hydrogen paths. The efficiencies of the methanol paths are very similar, except for the one where electricity is transported first to Rotterdam (47).

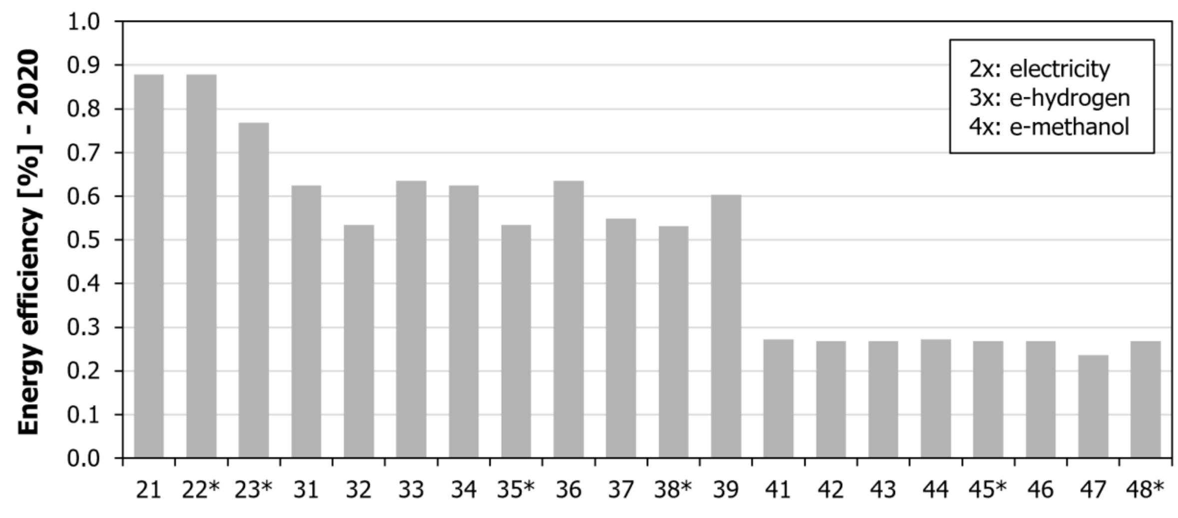

Figure 14: Energy efficiency in [%] for the year 2020 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7. Bandwidths are not displayed.

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Emissions and costs for the year 2050 (long-term future perspective)

The global warming potential varies between 9 gCO2e/kWh and 159 gCO2e/kWh for the year 2050 in the best guess scenario as displayed Figure 15. The same effects are applicable as described for the year 2020 (see above).

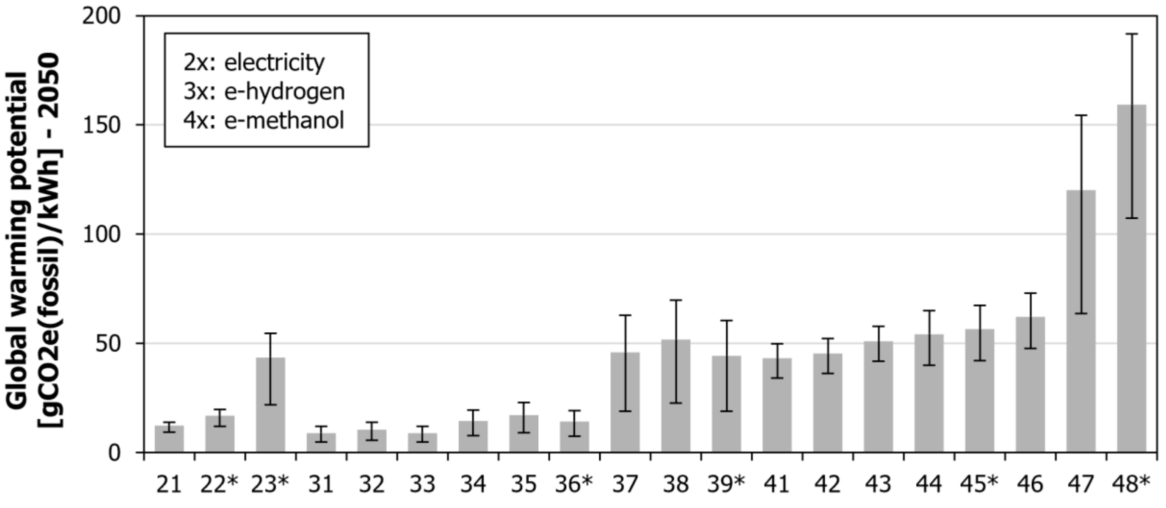

Figure 15: Global warming potential in [gCO2e(fossil)/kWh] for the year 2050 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

The nitrogen oxide emissions vary between 0.03 gNOx/kWh and 0.28 gNOx/kWh for the year 2050 in the best guess scenario as displayed in Figure 16. The same effects are applicable as described for the year 2020 (see above).

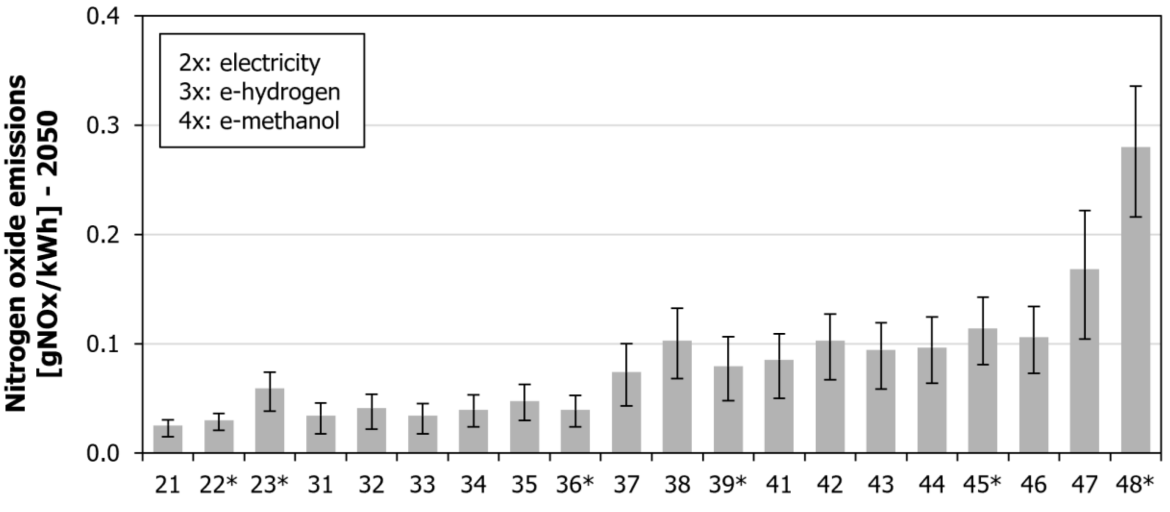

Figure 16: Nitrogen oxide emissions in [gNOx/kWh] for the year 2050 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

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The particulate matter emissions vary between 0.01 gPM10/kWh and 0.90 gPM10/kWh for the year 2050 in the best guess scenario as displayed in Figure 17. The same effects are applicable as described for the year 2020 (see above).

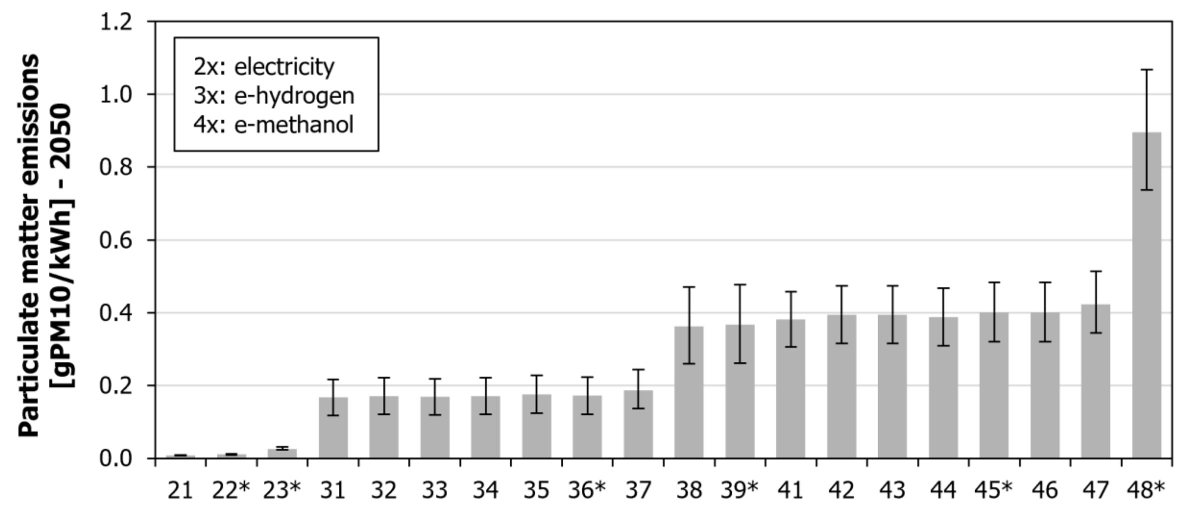

Figure 17: Particulate matter emissions in [gPM10/kWh] for the year 2050 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

The costs vary between 0.10 EUR/kWh and 0.34 EUR/kWh for the year 2050 in the best guess scenario as displayed in Figure 18. Generally, the same effects are applicable as described for the year 2020 (see above). Yet, the costs for the battery-electric path from MENA (23) may fall below the one of wind onshore (22).

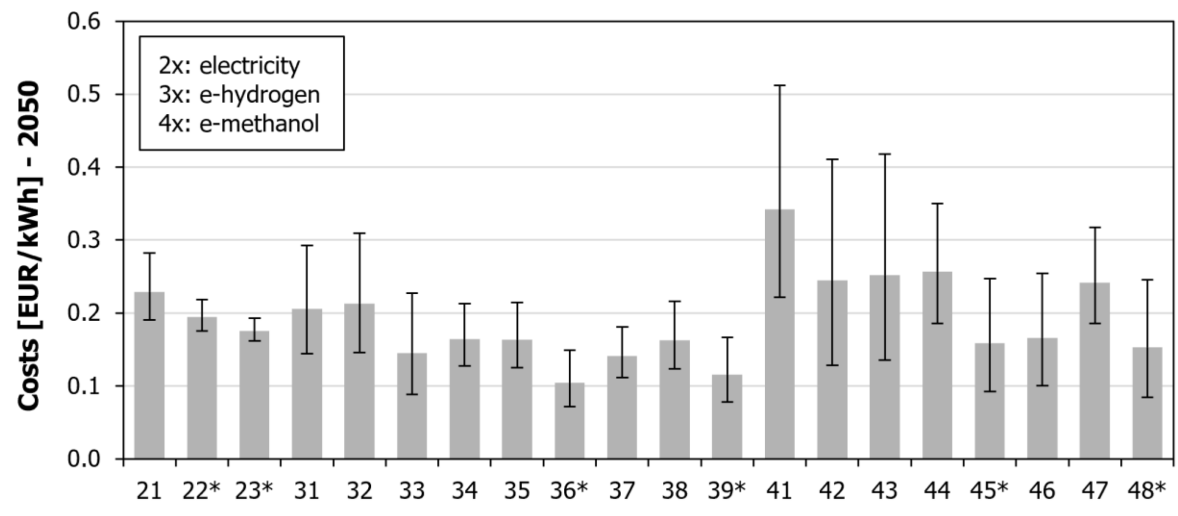

Figure 18: Costs in [EUR/kWh] for the year 2050 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7.

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The energy efficiencies vary between 31% and 88% for the year 2050 in the best guess scenario as displayed in Figure 19. The same effects are applicable as described for the year 2020 (see above).

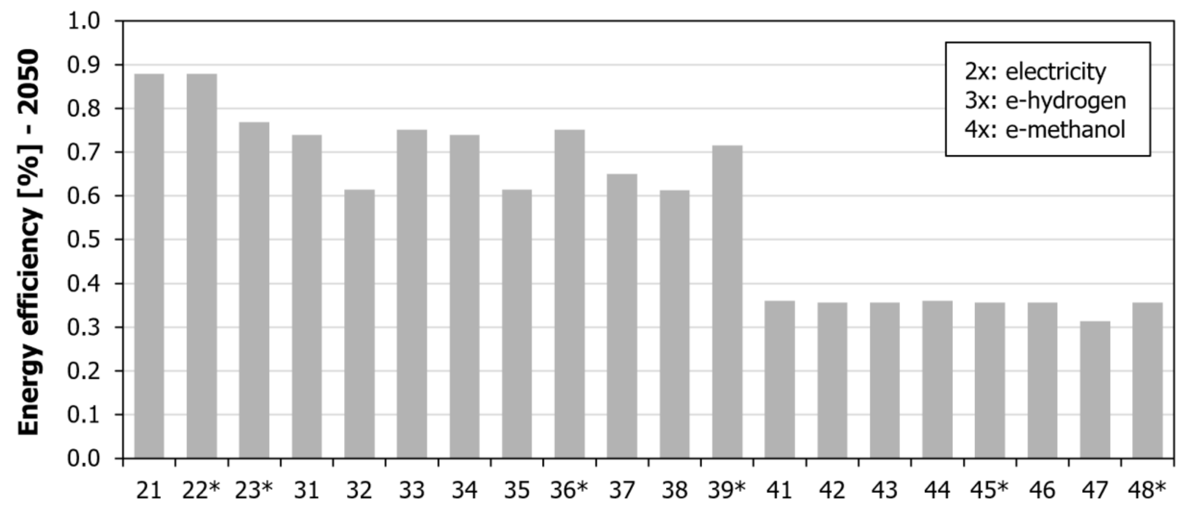

Figure 19: Energy efficiency in [%] for the year 2050 from a Well-to-Tank perspective. Best guess paths are marked with an asterisk. Path description: see Table 7. Bandwidths are not displayed.

Development of emissions and costs until the year 2050

The global warming potential and the costs are expected to decrease significantly until the year 2050 as displayed in Figure 20. The majority of supply paths are expected to have a global warming potential of below or close to 50 gCO2e(fossil)/kWh in the year 2050, except for the methanol paths with electricity from PV in MENA (47 and 48). The costs are expected to decrease to about 0.1-0.25 EUR/kWh.

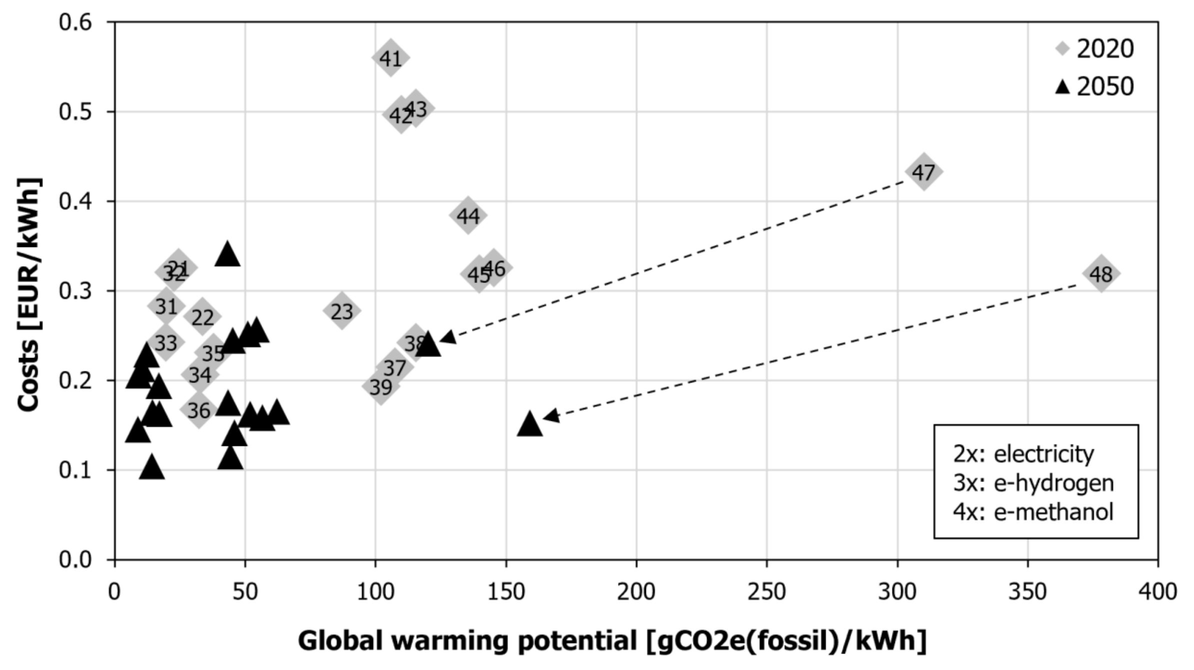

Figure 20: Global warming potential and costs for the years 2020 (grey diamonds, including path-ID) and 2050 (black triangles) from a Well-to-Tank perspective in the best guess scenario.

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Hotspot analysis of the global warming potential

The energy production (WOx, PVM) as well as the onshore storages (STA) are dominating the battery-electric paths (21-23) regarding the global warming potential in the best guess scenario for the year 2020 as displayed in Figure 21. The electrolysis (ELx) is almost as relevant as the energy production for the hydrogen paths (31-39). The direct air capture plants (DAx) and the methanol synthesis (MSx) are dominating the methanol paths (41-48) whereas the electrolysis and the energy production become less relevant in relative terms. The absolute global warming potentials of the same supply paths are shown in Figure 22.

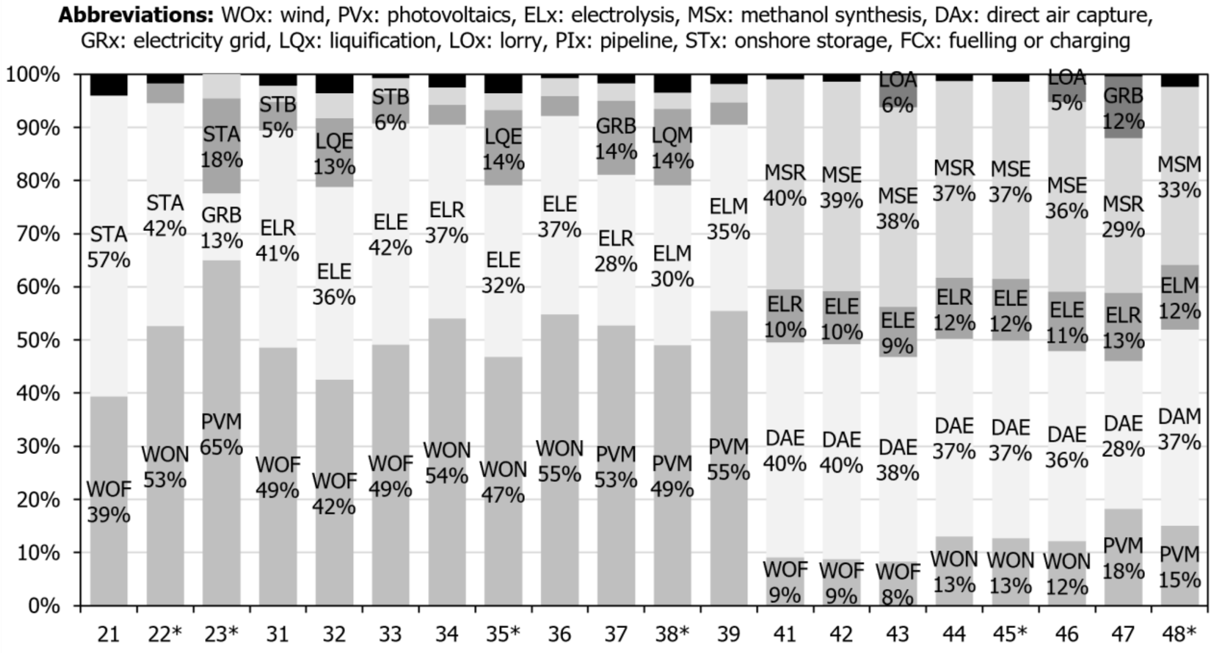

Figure 21: Hotspot analysis of global warming potential for the year 2020 in the best guess scenario regarding individual modules (relative values). Path description: see Table 7.

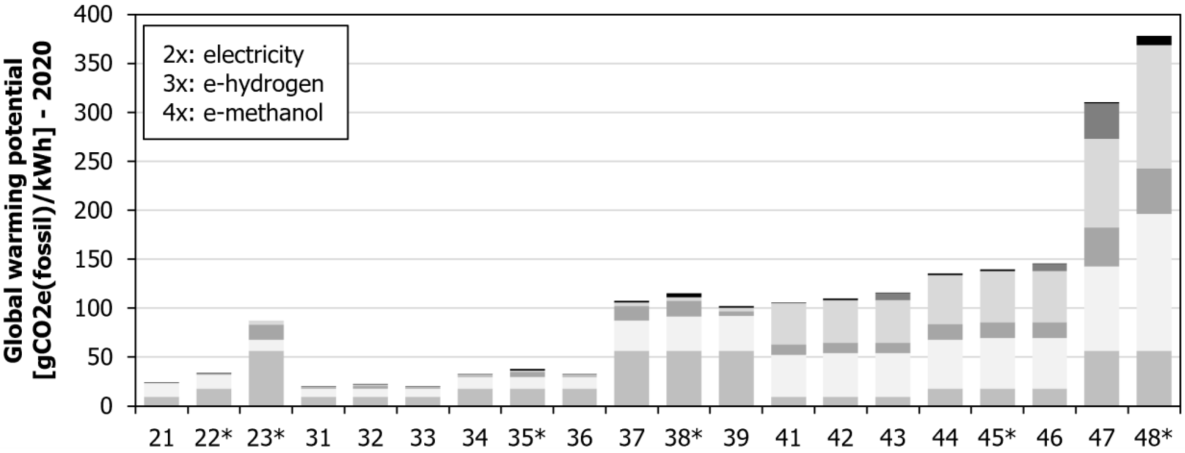

Figure 22: Hotspot analysis of global warming potential for the year 2020 in the best guess scenario regarding individual modules (absolute values). Path description: see Table 7.

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The global warming potentials of the three categories "vessel", "process" and "energy" are displayed in Figure 23. Be aware that the presented values are shares only: the absolute global warming potentials vary between different supply paths. A lower share of vessel emissions indicates a lower energy efficiency. Energy emissions are linked to energy losses of modules (e.g., transmission losses) whereas process emissions are linked amongst others to the production emissions of a module (e.g., production of onshore storage). Details to the allocation methodology can be found in Chapter 3.2.9.

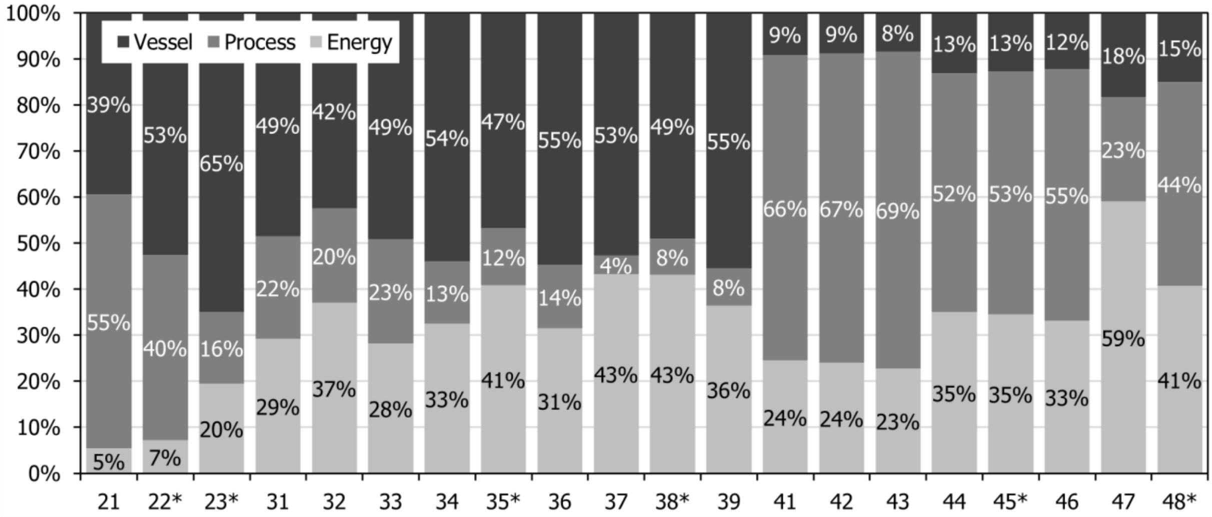

Figure 23: Hotspot analysis of global warming potential for the year 2020 in the best guess scenario regarding the allocated emissions (relative values). Path description: see Table 7.

Hotspot analysis of the costs

The dominating cost modules vary as displayed in Figure 25 (relative values) and Figure 26 (absolute values). Emission intensive modules tend to be cost intensive too. The dominating costs of the three categories "vessel", "process" and "energy" are displayed in Figure 24.

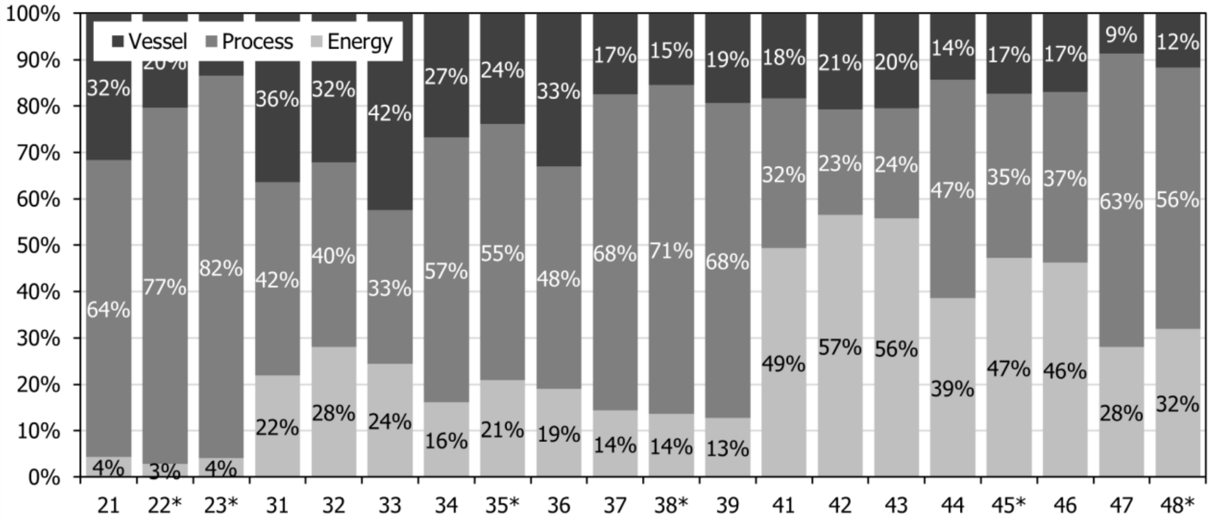

Figure 24: Hotspot analysis of costs for the year 2020 in the best guess scenario regarding the allocated costs (relative values). Path description: see Table 7.

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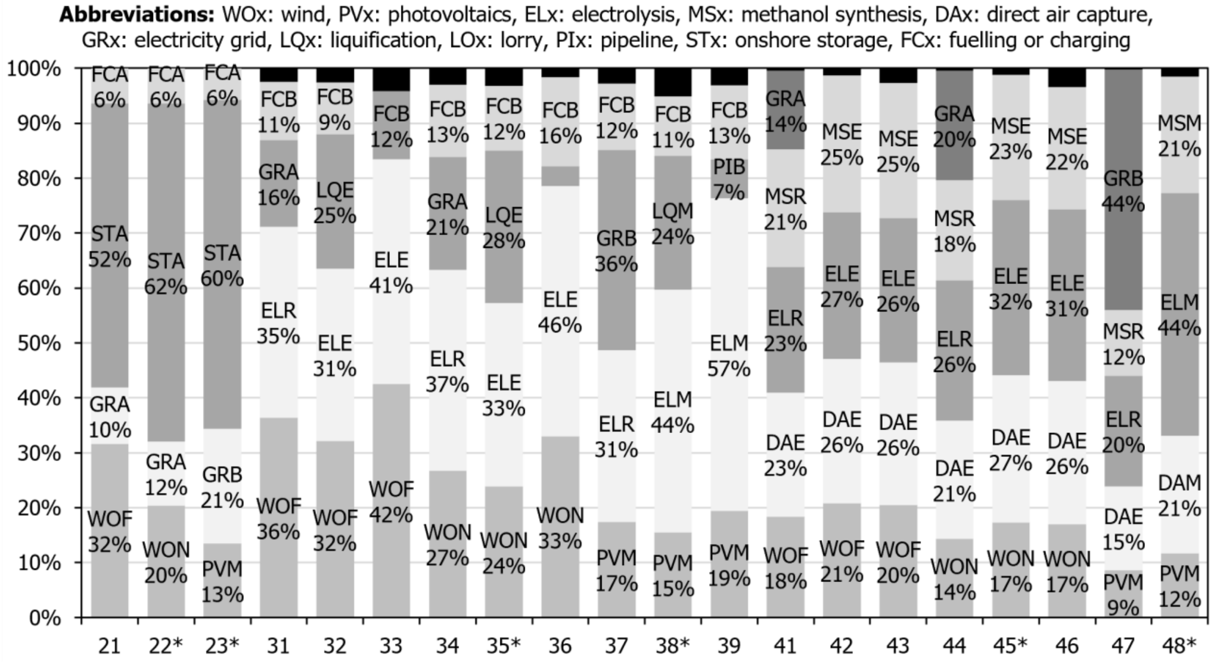

Figure 25: Hotspot analysis of costs for the year 2020 in the best guess scenario regarding individual modules (relative values). Path description: see Table 7.

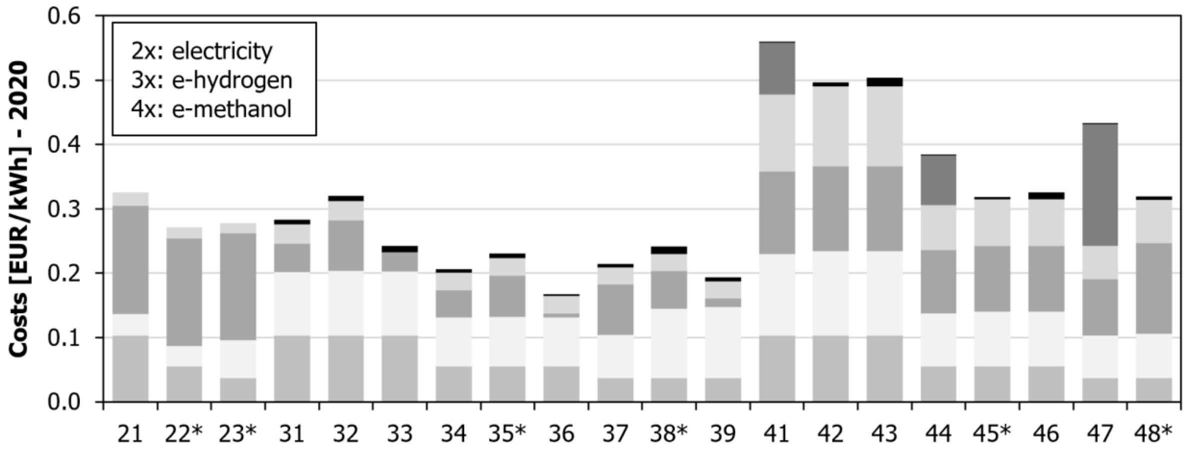

Figure 26: Hotspot analysis of costs for the year 2020 in the best guess scenario regarding individual modules (absolute values). Path description: see Table 7.

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3.4.2 Well-to-Wake: Results and Discussion

Emissions and costs for 2020 (status quo) and 2050 (long-term future perspective)

The global warming potentials from a Well-to-Wake perspective for the years 2020 and 2050 in the best guess scenario are depicted in Figure 27. The higher efficiency of the propulsion system in case of electricity is taken into account. Apart from one methanol path (path-ID: 48) all supply paths have significantly lower emissions than the reference diesel path (351 gCO2e(fossil)/kWh). Yet, none of the supply paths has net zero or close to net zero emissions. Indeed, the best-case emission level starts at 20 gCO2e(fossil)/kWh for the year 2020, respectively at 9 gCO2e(fossil)/kWh for the year 2050. The Well-to-Tank emissions strongly depend on the chosen supply paths (grey hatched). The battery-electric and hydrogen paths roughly have the same emissions whereas the emissions for the methanol paths are much higher. When comparing diesel (status quo) with alternative energy carriers there is a shift from Tank-to-Wake emissions (dark grey) to Well-to-Tank emissions (light grey). Indeed, Tank-to-Wake emissions account for over 75% in the diesel path whereas there are no Tank-to-Wake emissions in any of the alternative energy carriers. Thus, the choice of sustainable supply paths becomes very relevant in the future. Greenhouse gas emissions from the storage of energy carriers has a minor relevance for the hydrogen and methanol paths but it is particularly relevant for the direct use of electricity.

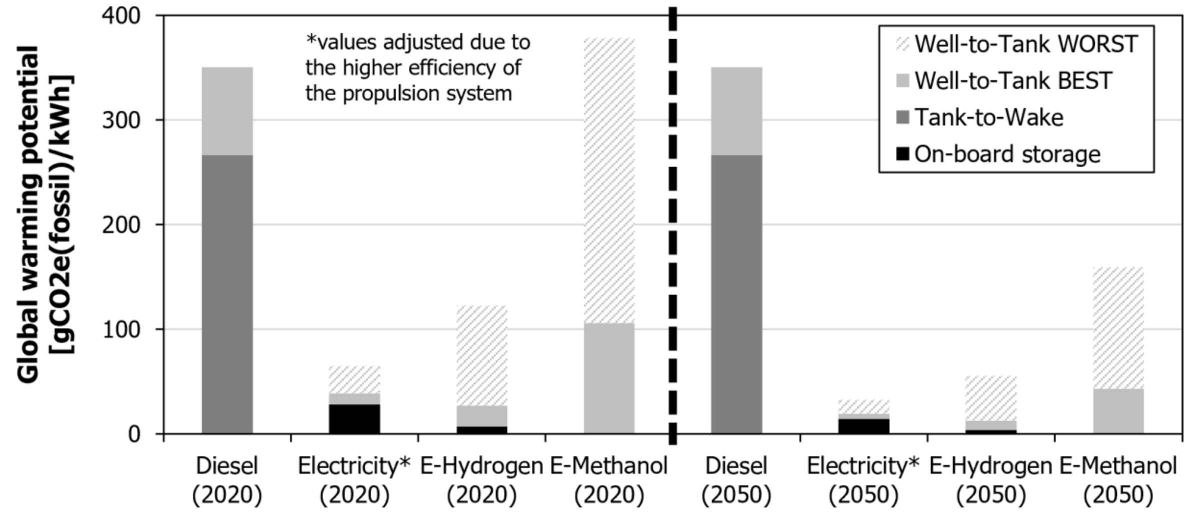

Figure 27: Global warming potential in [gCO2e(fossil)/kWh] for the years 2020 and 2050 in the best guess scenario from a Well-to-Wake perspective. Path-IDs: 11,22,35,45. Sources: see previous Chapters.

The nitrogen oxide emissions from a Well-to-Wake perspective for the years 2020 and 2050 in the best guess scenario are depicted in Figure 28. The higher efficiency of the propulsion system in case of electricity is taken into account. All supply paths have significantly lower emissions than the reference diesel path (4.0 gNOx/kWh). The battery-electric path has the lowest emissions with 0.05 gNOx/kWh for the year 2020, respectively with 0.03 gNOx/kWh for the year 2050. This path has much lower emissions than the hydrogen and methanol paths. The individual supply path within one energy carrier is not too relevant (grey hatched). In comparison to the global warming potential there is no shift from Tank-to-Wake emissions (dark grey) to Well-to-Tank emissions (light grey). Moreover, the Well-to-Tank part remains of subordinate relevance.

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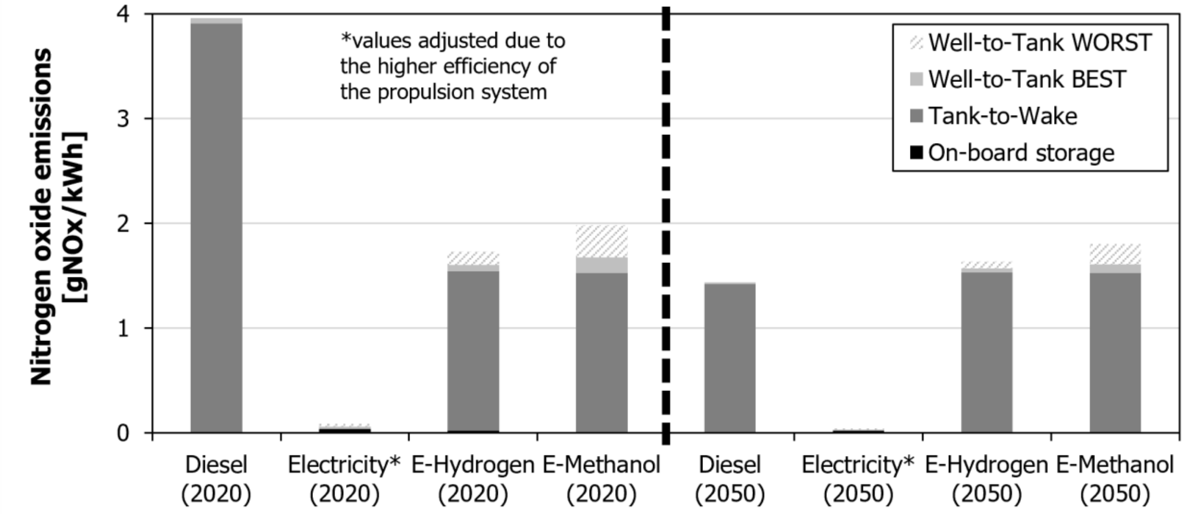

Figure 28: Nitrogen oxide emissions in [gNOx/kWh] for the years 2020 and 2050 in the best guess scenario from a Well-to-Wake perspective. Path-IDs: 11,22,35,45. Sources: see previous Chapters.

The particulate matter emissions from a Well-to-Wake perspective for the years 2020 and 2050 in the best guess scenario are depicted in Figure 29. The higher efficiency of the propulsion system in case of electricity is taken into account. The emissions are significantly higher than the reference diesel path (0.08 gPM10/kWh) for the hydrogen and methanol paths. However, the battery-electric path has slightly lower emissions (0.02 gPM10/kWh). The emission levels are expected to decrease until the year 2050. Yet, the hydrogen and methanol paths still have much higher emissions than the diesel and the battery-electric paths. The choice of individual supply paths within one energy carrier is relevant for both reference years (grey hatched). Well-to-Tank emissions (light grey) are more relevant than Tank-to-Wake emissions (dark grey) for all energy carriers.

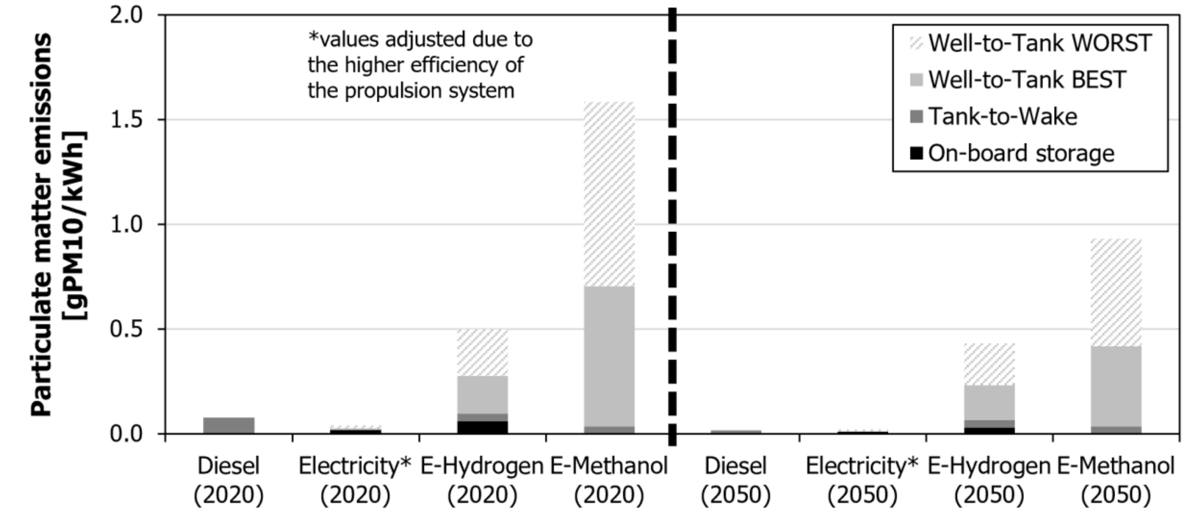

Figure 29: Particulate matter emissions in [gPM10/kWh] for the years 2020 and 2050 in the best guess scenario from a Well-to-Wake perspective. Path-IDs: 11,22,35,45. Sources: see previous Chapters.

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The costs from a Well-to-Wake perspective for the years 2020 and 2050 in the best guess scenario are depicted in Figure 30. The higher efficiency of the propulsion system in case of electricity is taken into account. Today, the Well-to-Tank costs for the alternative energy carriers are higher than those for the reference diesel path. Yet, they are expected to be lower than diesel for the year 2050.

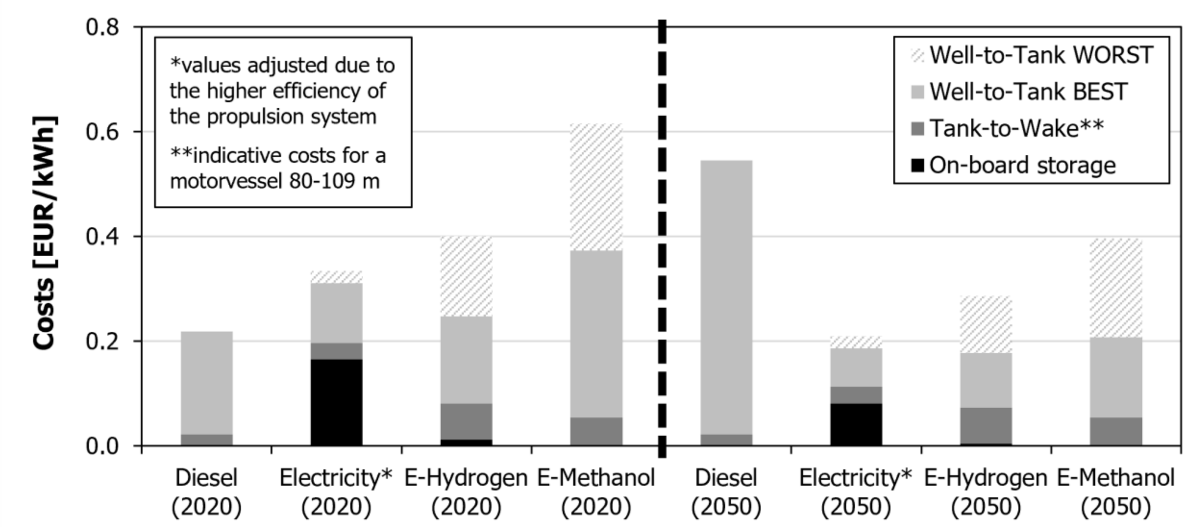

Figure 30: Costs in [EUR/kWh] for the years 2020 and 2050 in the best guess scenario from a Well-to-Wake perspective. Path-IDs: 11,22,35,45. Sources: see previous Chapters.

The energy efficiencies from a Well-to-Wake perspective for the years 2020 and 2050 in the best guess scenario are depicted in Figure 31. The battery-electric path has the highest Well-to-Wake energy efficiency (up to 79%), followed by the reference diesel path (38%), the hydrogen path (up to 24%) and the methanol path (up to 10%) for the year 2020. The energy efficiencies for the hydrogen path and the methanol path are expected to increase until the year 2050 (up to 29%, respectively up to 14%).

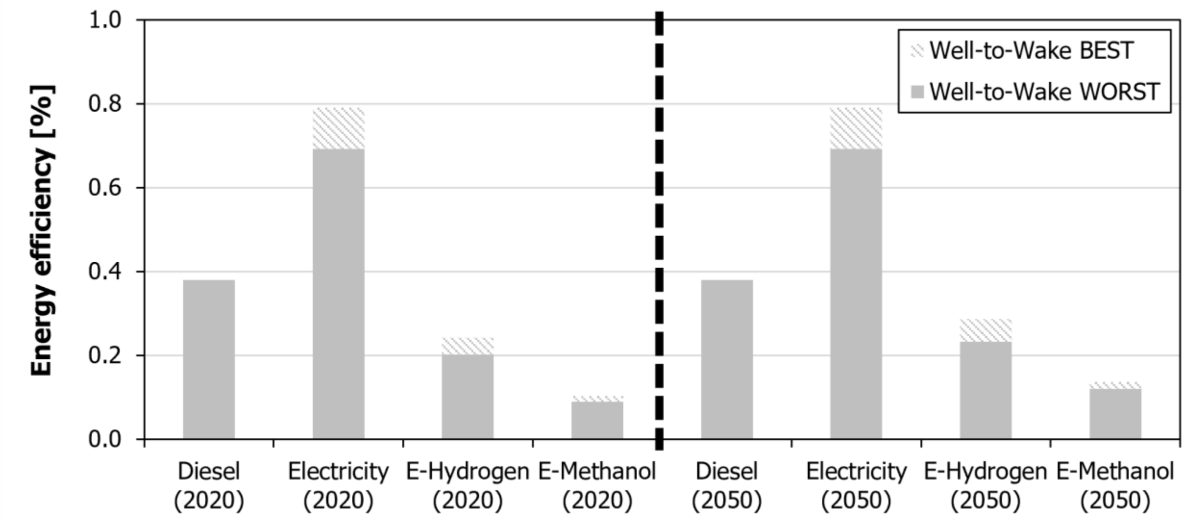

Figure 31: Energy efficiency in [%] for the years 2020 and 2050 in the best guess scenario from a Well-to-Wake perspective. Path-IDs: 11,22,35,45. Sources: see previous Chapters.

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Minimal share of European inland shipping fleet to be retrofitted in the future

If the energy demand of the European inland shipping is assumed to be constant in the future (6.2 TWh(diesel)/a), it can be calculated which share of the fleet must be retrofitted to meet a certain emissions reduction target. If no vessels would be retrofitted, the annual emissions would remain constant at 2.2 Mio. tCO2e(fossil)/a. At least 52% of all vessels must be retrofitted to meet a hypothetical emissions reduction target of 50% until the year 2050 (Figure 32). This "best-case scenario" can either be met with battery-electric vessels (dotted lines) or with e-hydrogen vessels (dashed lines, path with lowest emissions). If e-methanol vessels are used, this share increases to at least 62% (solid lines, path with lowest emissions). If the e-methanol path with the highest emissions would be chosen, the emissions reduction target could not be met at all. In order to consider the technological development, the specific emissions in Figure 32 refer to the year 2035: Some vessels will be retrofitted before 2035 (i.e., higher specific emissions) and some vessels will be retrofitted after 2035 (i.e., lower specific emissions).

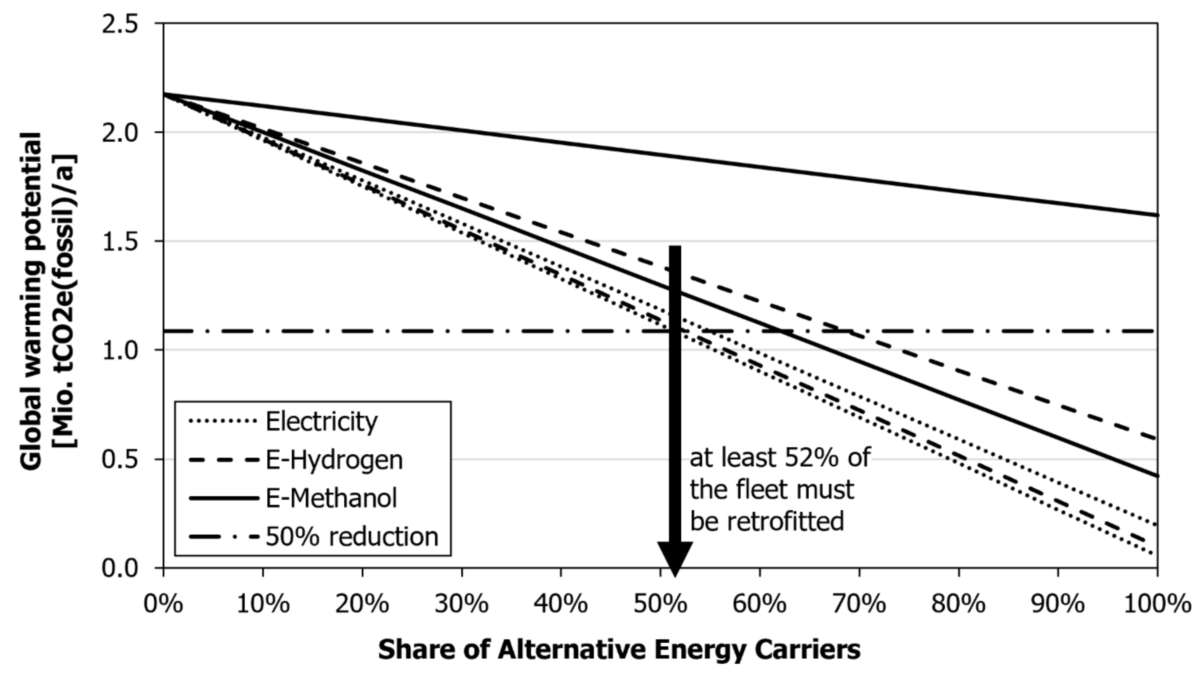

Figure 32: Minimal share of European inland shipping fleet which must be retrofitted to meet a (hypothetical) emissions reduction target of 50% until the year 2050. Details see main text body.

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3.5 Bio-Based Energy Carriers

3.5.1 Well-to-Tank: Results and Discussion

The global warming potentials for bio-based energy carriers are 13-34 gCO2e(fossil)/kWh for the year 2020, respectively 3-13 gCO2e(fossil)/kWh for the year 2050. The costs are 0.13-0.15 EUR/kWh for all supply paths in both reference years (see Figure 33). The biomass capacity is limited (see Chapter 2.3). Therefore, these supply paths are not likely to power the whole European inland and coastal shipping.

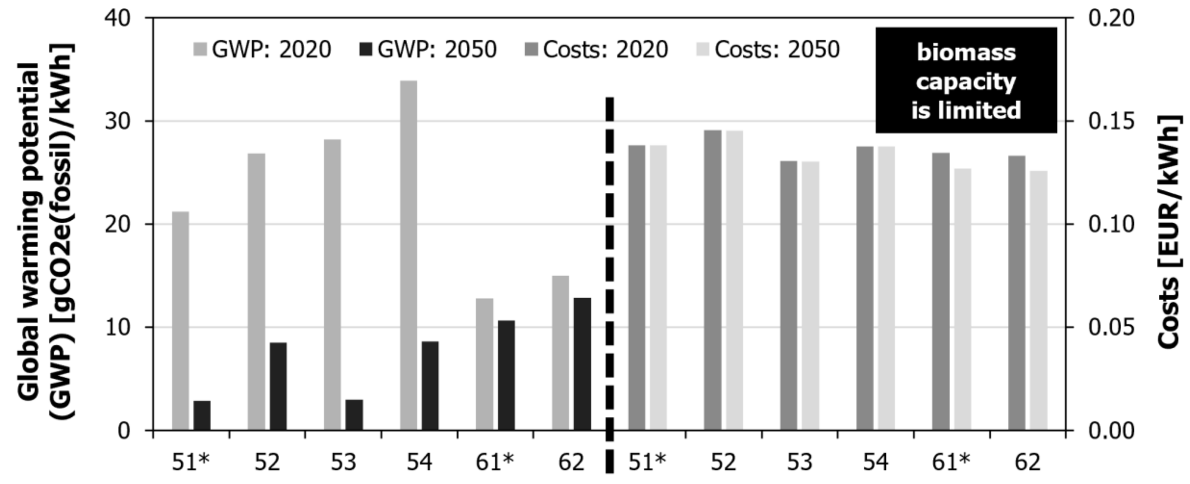

Figure 33: Global warming potential in [gCO2e(fossil)/kWh] and costs in [EUR/kWh] for the years 2020 and 2050 in the best guess scenario for the Well-to-Tank part. Best guess paths are marked with an asterisk. Path description: see Table 7. Bandwidths: not displayed.

The nitrogen oxide emissions are 0.02-0.04 gNOx/kWh for both reference years. The particulate matter emissions are 0.16-0.27 gPM10/kWh for the year 2020, respectively 0.07-0.27 gPM10/kWh for the year 2050 (see Figure 34). The biomass capacity is limited (see above).

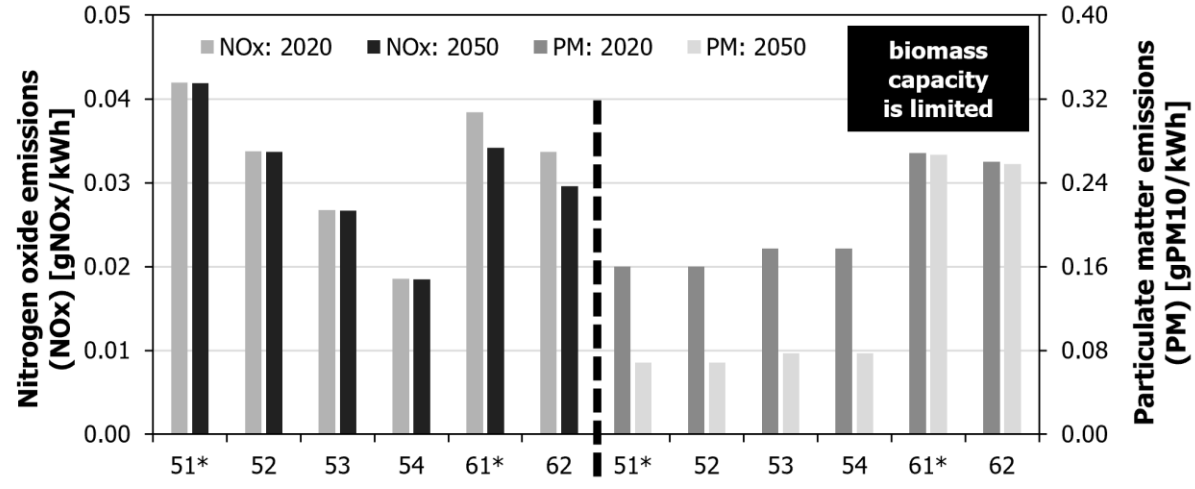

Figure 34: Nitrogen oxide emissions in [gNOx/kWh] and particulate matter emissions in [gPM10/kWh] for the years 2020 and 2050 in the best guess scenario for the Well-to-Tank part. Best guess paths are marked with an asterisk. Path description: see Table 7. Bandwidths: not displayed.

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The energy efficiencies are 34-81% for the year 2020, respectively 34-83% for the year 2050 (see Figure 35). The biomass capacity is limited (see above).

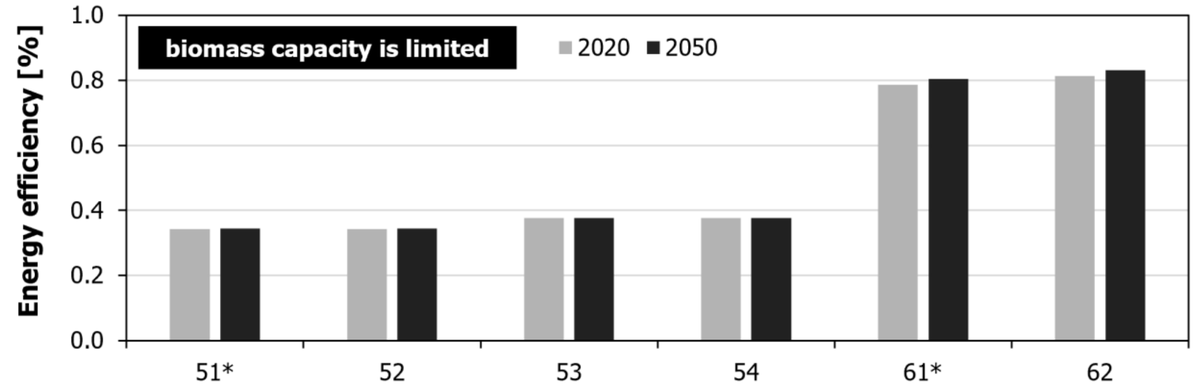

Figure 35: Energy efficiency in [%] for the years 2020 and 2050 in the best guess scenario for the Well-to-Tank part. Best guess paths are marked with an asterisk. Path description: see Table 7. Bandwidths: not displayed.

3.5.2 Well-to-Wake: Results and Discussion

As the biomass capacity is limited (see Chapter 2.3), the bio-based energy carriers are not likely to power the whole European inland and coastal shipping. Hence, no detailed comparison of bio-based supply paths is done from a Well-to-Wake perspective. When comparing the bio-based energy carriers to diesel the following differences are modelled for the year 2020 in the best guess scenario: ten to twenty-five times lower global warming potential, two to three times lower nitrogen oxide emissions, two to four times higher particulate matter emissions, roughly the same costs and a one to three times lower energy efficiency.

3.6 What-If-Scenario Analysis

3.6.1 Electricity from Non-Renewable Sources

If the electricity sources are not fully renewable the global warming potential of the supply paths increase more than tenfold as displayed in Figure 36. The greenhouse gas emission levels would become even worse than in the case of diesel. Thus, policy safeguards are needed to assure that the electricity sources really are renewable and additional.

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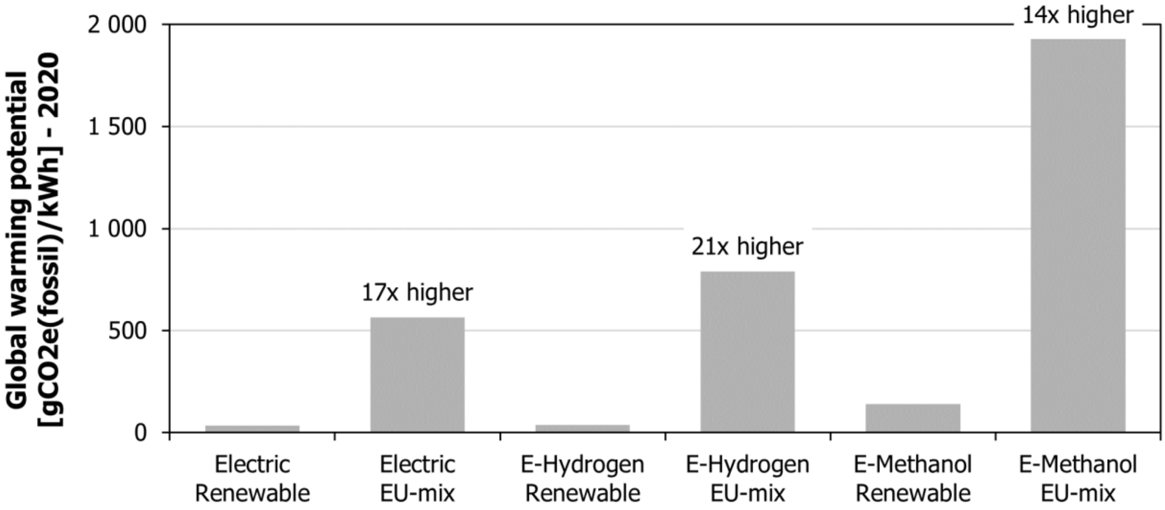

Figure 36: Global warming potential of different single paths using renewable electricity (wind onshore) or electricity from the grid (EU-mix) for the year 2020 in the best guess scenarios from a Well-to-Tank perspective. Path-IDs: 22,35,45.

3.6.2 Decentralised Usage of Energy Carriers

The geographical location of the harbour where the vessels are charged/fuelled does not have a significant impact on the global warming potential of the supply paths as displayed in Figure 37.

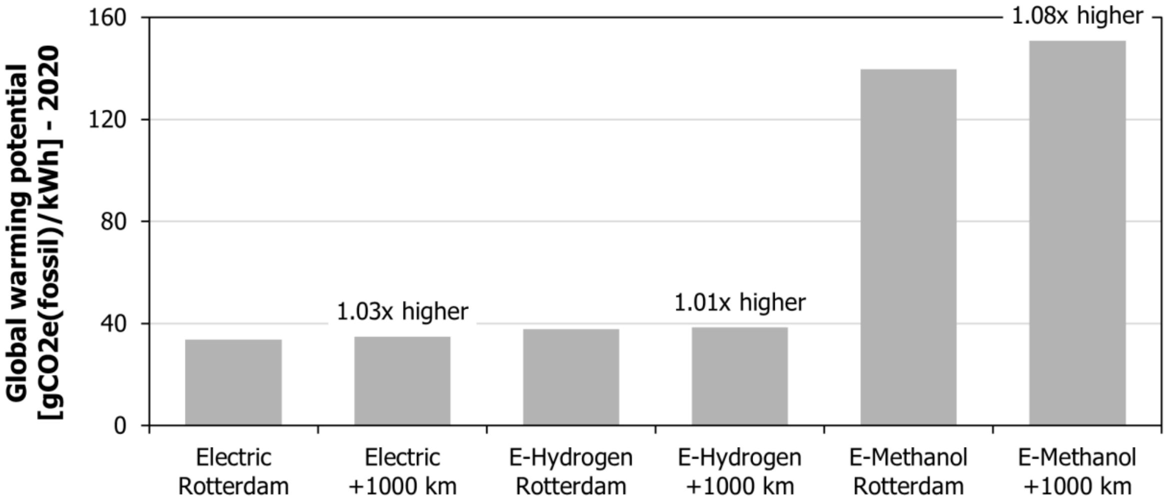

Figure 37: Global warming potential of different single paths (wind onshore) if energy carrier is used centralised (Rotterdam) or decentralised (+1000 km) for the year 2020 in the best guess scenarios from a Well-to-Tank perspective. Path-IDs: 22,35,45.

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3.7 Further Impacts of the Energy Carrier Paths

The production, distribution, and usage of (alternative) energy carriers cause greenhouse gas emissions, nitrogen oxide emissions, particulate matter emissions as well as costs. These four impact indicators are assessed in detail in this report. However, there are further environmental, social, political, financial, and technical impacts (see Table 11) that need to be taken into account when discussing individual paths. A detailed assessment of this "bigger picture" is outside the scope of this report. Nevertheless, the content of this Chapter can be used as a starting point for further projects.

The assessment of the further impacts is carried out intuitively with the expertise of the authors involved in this report. All impacts listed are interdependent and overlap with each other. The modelled paths use different energy carriers and consist of several individual modules (see Chapter 3.2.1). In addition, there are other aspects to consider, such as country-specific conditions or the need for materials, including water, which can be critical. The further impacts are rated on a three-point scale: "+" (good conditions and/or positive impact), "o" (neutral) and "-" (high risk and/or negative influence). The results are shown in Table 11.

(E) Environmental impacts include the pollution of air (other than greenhouse gases, nitrogen oxide, particulate matter), water and land. It also includes impacts on agriculture, land use, land use change and forestry (LULUCF). Water is required to produce e-hydrogen (electrolysis) or e-methanol. However, water is also a scarce resource that is vital for people and the environment and must therefore be protected. Biodiversity plays an equally crucial role in our lives. The selected modules may also be affected by climate change effects (in particular due to changing natural hazards) or may themselves have an influence on climate change. Paths with low negative environmental impacts effects are rated positively "+". Environmental impacts overlap with other impacts, particularly social and financial impacts.

(S) Social impacts include effects on human health (physical/psychological) and socio-political effects. The latter includes human rights (acceptance, availability, equal treatment, fairness, child labour, etc.), as well as security of supply, foreign dependencies, dangers from wars, terrorism and sabotage. Compliance with human rights and good conditions in terms of socio-politics effects are rated positively "+". Human health is rated neutral "o" (probably no negative influence) or negative "-" (harmful processes and/or substances). Social impacts overlap with other categories, particularly environmental and political impacts. The issues of conflict minerals and critical raw materials also play a role in the socio-political conditions.

(F) Financial impacts relate to opportunities and risks arising from changes in price levels, price fluctuations and thus from the general financial security/uncertainty of raw material procurement, plant investments and operations, as well as financial risks arising from climate protection and adaptation to climate change. These impacts overlap with political, technical, and environmental impact. In this Chapter, financial impacts are not evaluated in detail.

(P) Political impacts include effects and dependencies on political framework conditions, decision-making processes, communication and cooperation and interest groups, control mechanisms, transparency, susceptibility to fraud and corruption. Politics should set the framework conditions for the establishment of new technologies and ensure a stable environment for the economy. In a broader sense, this also includes the provision of subsidies. The more progressive the political framework conditions are for the implementation of the chosen paths, the more positive is the rating. Political impacts overlap with all other impacts.

(T) Technical impacts include the technical availability of raw materials and intermediates, the existence of mature production processes and the storage capability of energy sources. The higher the availability of raw materials, the degree of maturity of production processes and the better the energy sources produced can be stored, the more positive is the rating. Technical impacts overlap with other categories, particularly with financial and environmental impacts.

In general, a growing demand of renewable energy and energy storage systems for the coastal and inland shipping will lead to the situation that finite resources like land or materials become scarcer. Thus, a just transition towards a more sustainable future is needed (compare as well Chapter 2.4 about a systemic optimisation).

Direct and indirect effects of the individual modules are taken into account in the assessment. Thematically similar modules are assessed relative to each other. Example of S1 ("human rights") regarding the acceptance: Wind offshore is less controversial than wind onshore.

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Table 11: Further impacts of the energy carrier paths. The assessment is carried out intuitively with the expertise of the authors involved as a detailed assessment of this "bigger picture" is outside the scope of this report. For additional remarks see main text body.

+: Good conditions and/or positive influence
o: Neutral
-: High risk and/or negative influence
nc: Not considered
na: Not applicable

E: Environmental impacts
S: Social impacts
P: Political impacts
F: Financial impacts
T: Technical impacts

		Europe	MENA* (*example of Morocco)	Electricity, wind onshore Europe	Electricity, wind offshore Europe	Electricity, photovoltaics MENA*	Biomass without UCO Europe	Biomass UCO Europe	Water (for processes) MENA*	Water (for processes) Europe	Process: Water treatment	Process: Direct air capture	Process: Electrolysis (hydrogen)	Process: Methanol synthesis	Process: Biomass processing	Process: Hydrotreatment (UCO)	Transportation: Electricity grid	Transportation: Pipeline	Transportation: Vessel	Transportation: Lorry	Storage: Electricity	Storage: Hydrogen	Storage: Methanol
E1:	Imissions, emissions	na	na	o	o	-	na	na	na	na	o	o	o	o	o	o	o	o	-	-	-	o	o
E2:	Agriculture, LULUCF	na	na	o	o	-	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
E3:	Water resources	na	na	na	na	na	na	na	-	o	na	na	na	na	na	na	na	na	na	na	na	na	na
E4:	Biodiversity loss	na	na	o	o	o	-	o	o	o	nc	nc	nc	nc	nc	nc	o	o	-	-	nc	nc	nc
E5:	Climate change effects	na	na	o	o	o	o	o	-	-	o	o	o	o	o	o	o	o	o	o	o	o	o
S1:	Human rights	+	-	o	+	-	+	+	-	+	+	+	+	+	+	+	o	o	o	o	-	o	+
S2:	Health	na	na	o	o	o	o	o	-	o	o	o	o	-	o	o	-	o	-	-	-	o	o
S3:	Security of supply	na	na	o	o	+	o	o	-	o	o	o	o	o	o	o	o	o	o	o	o	o	o
S4:	Foreign dependence	na	na	-	-	-	+	+	-	+	-	-	-	-	+	+	-	-	o	o	-	o	o
S5:	Terrorism, sabotage	nc	nc	+	+	o	+	+	-	+	+	+	+	+	+	+	-	-	o	o	o	o	o
S6:	Proliferation	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
P1:	Political framework, subsidies	+	o	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
P2:	Decision making processes	o	o	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
P3:	Communication, cooperation	o	o	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
P4:	Controlling, corruption	o	-	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na
F1:	Price level	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
F2:	Price stability, fluctuations	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
F3:	Costs of climate change	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc	nc
T1:	Reliability, accidents	na	na	+	+	+	na	na	na	na	+	-	o	+	o	+	+	+	+	+	o	o	+
T2:	Availability of raw materials	na	na	o	o	+	o	-	-	o	+	o	o	+	+	+	o	+	+	+	-	o	+
T3:	Seasonal storage capability	na	na	-	-	-	+	+	+	+	na	na	na	na	na	na	na	na	na	na	na	na	na

E1: air pollutants (without CO2e, NOx, PM10), soil and water pollutants | **E2:** LULUCF: land use, land use change and forestry | **E3:** (no remarks) | **E4:** (no remarks) | **E5:** natural disasters (floods, storms, droughts, etc.) | **S1:** social acceptance, accessibility (fairness), child labour, etc. | **S2:** accidents, diseases, prevention, etc. | **S3:** conflict minerals, water scarcity, etc. | **S4:** global supply chains, including conflict minerals and critical raw materials | **S5:** (no remarks) | **S6:** (no remarks) | **P1:** strategies, laws, regulations, directives | **P2:** lack of long-term decisions | **P3:** stakeholder involvement | **P4:** including transparency, fraud risks | **F1:** (no remarks) | **F2:** (no remarks) | **F3:** including costs for climate change adaptation | **T1:** malfunctions, failures | **T2:** resource scarcity | **T3:** related to energy carriers

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Since the two modules "Water (for processes) MENA" and "Storage: electricity" have the most negative ratings they are discussed in more detail. In addition, the question of whether the energy carrier paths are (primarily) based in Europe or in MENA/Morocco is discussed as well in more detail.

Water supply: Large quantities of water are required for the production of e-hydrogen and for the production of e-methanol. The need for cooling water for the production facilities must also be taken into account. It is therefore important to have sufficient access to water as close as possible to the production site. However, the water required to produce renewable energy sources competes with the water requirements of humans and nature (essential food) as well as other uses in agriculture and industry. This can lead to conflicts, particularly in areas with scarce water resources. These conflicts can be exacerbated by climate change (irregular rainfall, longer dry periods). When selecting production technologies, the future water demand and water consumption for both production and cooling systems is a decisive criterion and should be kept as low as possible:

- Use of seawater instead of freshwater/groundwater (both in MENA and Europe)
- Use of closed circuits for system cooling or use of air-cooling systems

The water requirement depends on many factors (type and mode of operation of the electrolyser, type of cooling, composition of water used, climatic and hydrological conditions) and cannot be determined in general terms (Saravia et al. 2024). Security of water supply and the reduction of potential conflicts must be taken into account when selecting technology and locations. In this report, only desalinated seawater is used for the modelling (see Chapter 3.2.3).

Electricity storage: Today, the production of electricity storage systems requires materials such as lithium, which fall into the category of critical raw materials. These are raw materials that are important for the EU economy, as they are essential for the expansion of the renewable energy sector, digital industry, space and defence and health. At the same time, however, there is a high supply risk due to growth in demand and the difficulty of increasing their production. In addition to lithium, strategically important critical raw materials also include copper, gallium and aluminium (for example European Union 11/04/2024). These materials are also needed to produce wind turbines and photovoltaic plants. The availability of critical raw materials influences the supply and price of storage technologies and must be taken into account when planning production facilities. In addition, sources of raw materials for minerals and metals are often located in regions where they cause conflicts of use with indigenous populations and agriculture. Furthermore, severe negative environmental impacts were reported in several mining activities (Owen et al. 2023).

Political and social framework in MENA/Morocco and Europe: The feasibility of projects and the reliable operation of plants depend on the political prerequisites and social conditions at the chosen location. Two regions are favoured in this report: Europe and MENA/Morocco. It should be noted that the expansion of renewable energies is generally desired and promoted in both regions. Morocco has drawn up a national energy strategy and is targeting a 52% share of renewable energy in the electricity mix by 2030 (IEA 2024b). In 2022, however, about 80% of electricity production was still based on fossil fuels, the vast majority of which was coal. 4% of the electricity demand was covered by imports (IEA 2024c).

The overall electricity production in Morocco has risen by over 200% in the past 20 years. At the same time, its per capita consumption with 975 kWh/capita/year (2022) is six times lower than that in the European Union (own analysis based on statistical data from the European Union and Morocco). This is due to Morocco's lower level of industrialisation compared to the EU. Yet, it can be assumed that the growth trend in per capita electricity demand, which doubled between 2020 and 2022, will continue. This means that Morocco, with its ambitious climate target of net zero greenhouse gas emissions in 2050, faces the challenge of replacing the large proportion of fossil fuels still used today with renewable

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energy sources on the one hand and increasing electricity production overall in order to meet its own future demand on the other hand. In 2022, almost 600 GWh of electricity were produced by photovoltaics in Morocco (IEA 2024c). Yet, the annual energy demand of the European inland shipping (excluding coastal shipping) is about 2'600 GWh/a, i.e., more than four times higher! Foreign projects for the production of electricity and other energy sources in Morocco should not lead to Morocco's domestic goals regarding the transition to a renewable energy system being hindered.

A general assessment of the risk for investments in Morocco for investments in renewable energies was carried out in 2022 by the Wuppertal Institute as part of the MENA fuels project (Terrapon-Pfaff et al. 2022): In general, political stability and the economy are considered to be more stable than in neighbouring countries. Investment conditions and authorisation procedures have improved. In general, there is a high level of acceptance among the population for renewable energy projects. The quality of governance (corruption, lack of transparency) and bureaucratic hurdles can be challenging. The future effects of climate change on the country should not be neglected, as they are categorised as devastating (water shortages, droughts, sandstorms) and can also temporarily impair the performance of solar power plants and damage infrastructure.

To summarise the comparison of MENA/Morocco and Europe: MENA/Morocco is highly suitable for photovoltaics due to its favourable geographical location, i.e., the photovoltaic yield is much higher compared to Europe. In principle, some MENA countries like Morocco are suitable for the production of renewable energy carriers from an economical, a political and a social point of view. Yet, there are higher risks in comparison to Europe. Moreover, the negative impacts of climate change may be more challenging in MENA/Morocco than in Europe. Last but not least, it is absolutely crucial that the production of renewable energy carriers does not lead to an environmental burden shifting.

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4 Business Models

4.1 Introduction to Business Models

From a business/economy perspective, Inland Waterway Transportation (IWT) plays an important part within the transportation of goods within Europe. Currently, 6% of goods, particularly in the segments steel, agriculture, food and chemicals are transported by IWT within the EU. From an environmental point of view, IWT offers the possibility for increasing the model share of transportation of goods through energy-efficient vessels. According to the EU, the movement of goods by IWT amounts to approximately 17% of energy consumed of road transportation per ton kilometre. Within the framework of the European Green Deal and the Sustainable and Smart Mobility Strategy (NAIADES III), the goal has been set to achieve the transition to zero-emission barges by 2050. At the same time, the goal is to achieve an increase in modal share of 25% for IWT and short sea shipping by 2030, respectively 50% by 2050 (European Commission 2024a).

The research question to be answered in this section is "Could new business models and / or financing models in the IWT sector lead to profitable retrofitting of existing vessels with power systems using renewable energy?" The hypothesis to be considered are as follows:

- IWT vessels in the Rhine and Danube region are often owned by small family businesses[1], operating in the day-to-day spot market, without neither certainty on long-term income nor large financial resources for major investments such as retrofitting, leading to the continuation of status-quo.
- Alternative ways of financing and the knowledge on where to find funding for renewable energy alternatives has the potential to accelerate the rate of retrofitting in a significant way.

Important to note is that the sector of coastal shipping (e.g. short-sea-shipping) is not widely discussed in a separate way in the following Chapter. Further research, predominately in Work Package WP4, will look at adding those missing information on this important aspect.

4.1.1 Overview Sustainable Business Models

Quite extensive research is available when it comes to Sustainable Business Models (SBM) and possible definitions (Springer 2018b; García-Muiña et al. 2020); yet according to comprehensive overviews, the definitions remain fuzzy and manifold: SBM can be classified according to social aspects (e.g. social profits), value constellations, value propositions or economic aspects. Other categorisations look at technological, organisational, or social innovations for SBM to create (social) profit. Yet other studies focus on the partnerships (e.g. collaborations or private-public partnerships). One central aspect of SBM is the creation of value in "doing business". A traditional, but still quite common definition of sustainability in business is the triple bottom-line, where the dimensions people, planet and profit are looked at as key factors for sustainable business models. A practical, widely used practical approach is the Business Model Canvas (Osterwalder 2010), where business activities are bundled into nine building blocks: key partners, key activities, key resources, value proposition, customer relationships, customer segments, channels, cost structure and revenue streams. The idea of this model is to show how value is created for the customer while providing gains for the company. The method has been adapted over

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[1] This is particularly true for the Rhine region. While many shipping companies on the Danube are family-owned businesses stretching over generations, some larger shipping companies such as TTS (SY-partner), First-DDSG Logistics Holding GmH, Danube Shipping Wurm & Noé, SPaP or Rhenus Logistics operate on the Danube.

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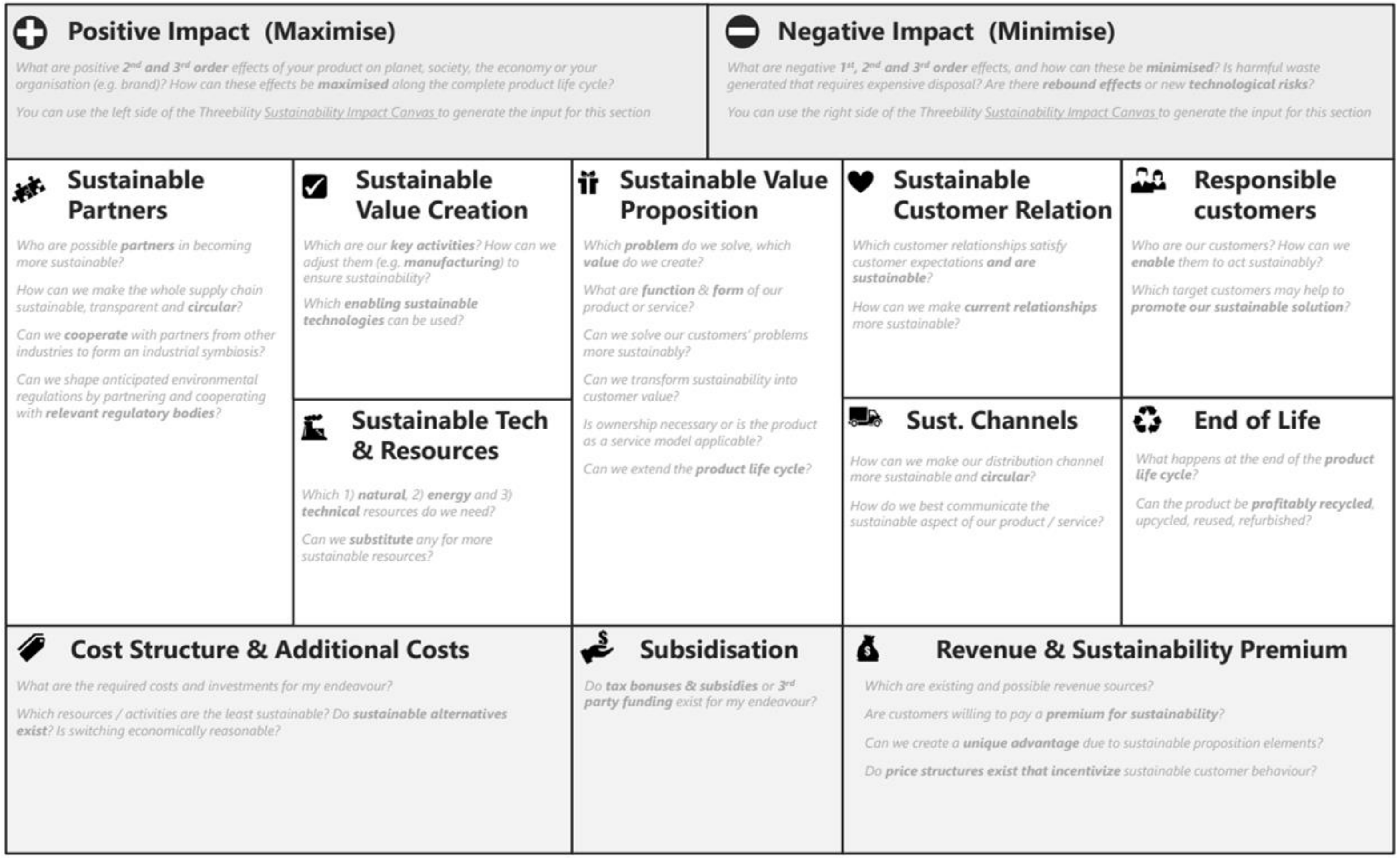
the years, nowadays with many different models available, incorporating sustainable elements of value creation as shown in Figure 38.



Positive Impact (Maximise)

What are positive 2nd and 3rd order effects of your product on planet, society, the economy or your organisation (e.g. brand)? How can these effects be maximised along the complete product life cycle?

You can use the left side of the Threebility Sustainability Impact Canvas to generate the input for this section

Negative Impact (Minimise)

What are negative 1st, 2nd and 3rd order effects, and how can these be minimised? Is harmful waste generated that requires expensive disposal? Are there rebound effects or new technological risks?

You can use the right side of the Threebility Sustainability Impact Canvas to generate the input for this section

Sustainable Partners

Who are possible partners in becoming more sustainable?

How can we make the whole supply chain sustainable, transparent and circular?

Can we cooperate with partners from other industries to form an industrial symbiosis?

Can we shape anticipated environmental regulations by partnering and cooperating with relevant regulatory bodies?

Sustainable Value Creation

Which are our key activities? How can we adjust them (e.g. manufacturing) to ensure sustainability?

Which enabling sustainable technologies can be used?

Sustainable Tech & Resources

Which 1) natural, 2) energy and 3) technical resources do we need?

Can we substitute any for more sustainable resources?

Sustainable Value Proposition

Which problem do we solve, which value do we create?

What are function & form of our product or service?

Can we solve our customers' problems more sustainably?

Can we transform sustainability into customer value?

Is ownership necessary or is the product as a service model applicable?

Can we extend the product life cycle?

Sustainable Customer Relation

Which customer relationships satisfy customer expectations and are sustainable?

How can we make current relationships more sustainable?

Sust. Channels

How can we make our distribution channel more sustainable and circular?

How do we best communicate the sustainable aspect of our product / service?

Responsible customers

Who are our customers? How can we enable them to act sustainably?

Which target customers may help to promote our sustainable solution?

End of Life

What happens at the end of the product life cycle?

Can the product be profitably recycled, upcycled, reused, refurbished?

Cost Structure & Additional Costs

What are the required costs and investments for my endeavour?

Which resources / activities are the least sustainable? Do sustainable alternatives exist? Is switching economically reasonable?

Subsidisation

Do tax bonuses & subsidies or 3rd party funding exist for my endeavour?

Revenue & Sustainability Premium

Which are existing and possible revenue sources?

Are customers willing to pay a premium for sustainability?

Can we create a unique advantage due to sustainable proposition elements?

Do price structures exist that incentivize sustainable customer behaviour?

Figure 38: Sustainable Business Model Canvas (Threebility 2023).

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Yet another approach on a different, more aggregated level is provided by Springer (2018b), defining sustainable business models as a synergy between sustainability, business models and system transformation as shown in Figure 39. Thereby, entrepreneurial sustainability, (e.g. in the form of managing for the triple bottom line) interacts with business change (adjustments, incremental/radial innovations) and system transition (parameters by a current regime and/or via pressure from niche level). The authors underline the importance of looking at both, the business model view as well as the transformational view. According to their research, models focusing on business models often assume that market forces provide sufficient incentives to create sustainable business, which is not always the case. On contrary, methodical approaches to economic system changes tend to focus strongly on governmental support and funding (Springer 2018b).

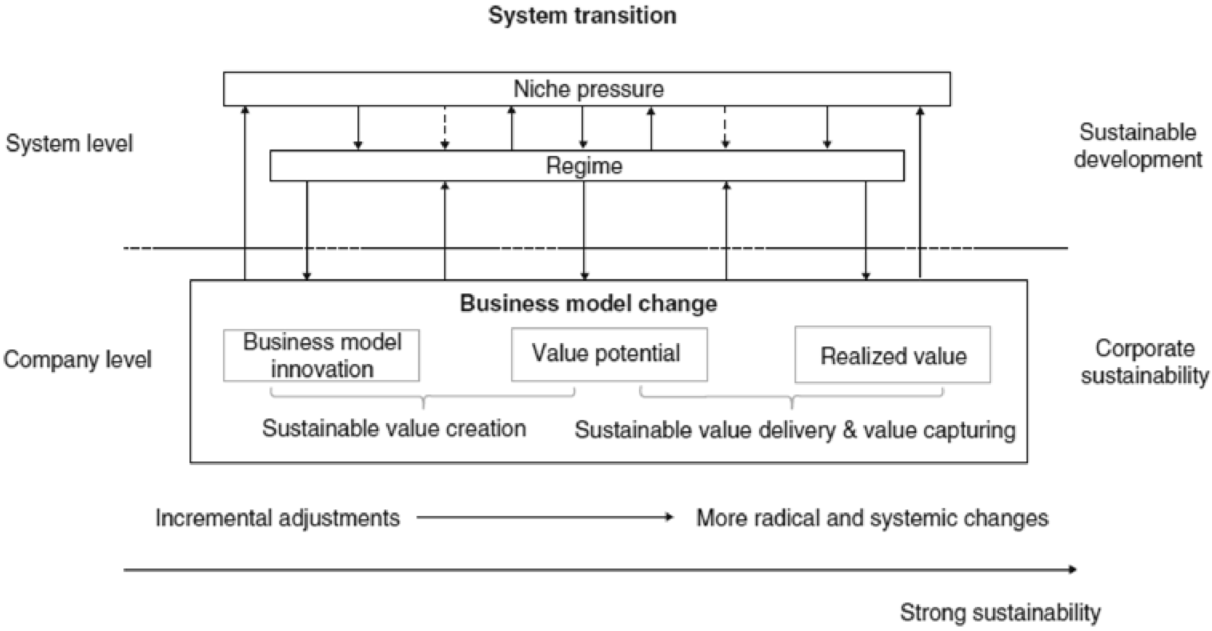

Figure 39: Integration of Business Model change and system change (Springer 2018b, p. 121).

Additionally, in the given context of IWT, the look at SBM itself is interesting as research has found, "that disruptive circumstances through external stakeholder pressures often lead to the creation of radical sustainable innovations, while sustaining circumstances where, for example, customers are willing to accept minor product adjustment typically lead to incremental sustainable innovations" (Aagaard 2019, p. 5).

The questions the IWT-sector can ask itself are in this context are as shown in Figure 40:

- Value proposition: what value is provided and to whom?
- Value creation & delivery: How is value provided?
- Value capture: How does the company make money and capture other forms of value?

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Figure 40: Business Models value creation framework (Aagaard 2019, p. 71).

Linking the two theoretical approaches (compare Figure 38 and 39), the additional question may be asked on what kind of disruptive measure will be necessary to attain a change in the current business set-up and which stakeholder(s) could drives such change. If alternatives can be found to the current model of paying for the transportation service (often in t/km), including the use of alternative, more sustainable power systems (e.g. via energy carrier), sustainable innovations may be explored. Possibilities may include horizontal or vertical extension of business models (e.g. collaborations, integration of supply chains) and/or inclusion of energy supply (infrastructure) along the value chain. Within the waterway transportation other factors such as time-charter models, long term arrangements vs short term spot market assignments play a role as well.

Common principles for sustainable business models include according to (Springer 2018a, p. 45).

- maximisation material productivity and energy efficiency
- creation of value from waste
- substitution with renewable and natural process
- delivery of functionality and ownership
- adopting a stewardship role
- encouraging sufficiency
- re-purposing the business for society/environment
- developing scale-up solutions

The authors refer to Pais and Provasi (2021; Springer 2018a) who identified relevant collaborative business models including:

- rental schemes
- peer-to-peer economy (e.g. AirBnB) with goods offered directly to
- on-demand economy (e.g. Uber)
- social lending and crowdfunding including loans via platforms

From those two theoretical approaches, the substitution with renewable energy, the delivery of functionality rather than ownership as well as rental schemes could provide insights for the business case of retrofitting existing IWT vessels.

4.2 Business Factors – Retrofitting

Within freight transportation, the cost for the delivery of goods is considered to be one of the most crucial factors for successful business operations besides frequency and reliability (Lu and Yan 2015; Hoyer 30/11/2017; PLATINA3 2023). A study in the framework of Novimar (Hoyer 30/11/2017)[2] strengthens these findings through interviewing the port of Duisburg, that business in the inland waterway transportation is mainly driven by the cost factor (price-performance ratio) for all kind of goods. Other factors with different importance for different transported goods relate to frequency, transport volume, flexibility, or transport time. Part of the decisive factors include personal preferences/habits, safety/damage susceptibility or legal matters. The interviewed experts did not allocate any weight to environmental sustainability and other factors such as information level/knowledge reg. the mode of transport, regularity (schedules) or capital lookup costs.

The IWT sector in Europe has seen a surplus in shipping capacity leading to challenging market conditions for ship owners, particularly on major waterways (Al Enezy et al. 2017). The question on how to achieve sustainable profitability has been researched but is challenged by the diversity and fragmentation of the industry with a wide range of vessel sizes, a broad range of small companies (with small market power), various operational aspects or transported goods (e.g. tank barge market vs. dry cargo sector). Customers on the other hand have a higher degree of market influence, often representing huge cargo flows or hiring multiple vessels (Al Enezy et al. 2017).

While IWT is already considered a clean an efficient and environmentally friendly means for the transportation of goods within Europe, an important financial aspect is the greening of the IWT and thereby the internalisation of external costs. So far, the internalisation has been driven mainly by the polluter-pays- principle within the EU (Al Enezy et al. 2017). According to the "Sustainable & Smart Mobility Strategy" of the EU (European Commission 2021), waterborne transport faces decarbonisation challenges given the net-zero goals for 2050 as currently no zero-emissions technologies are available[3]. Additionally, life cycles of vessels are long and investments are refuelling equipment and infrastructure are large (European Commission 2021).

Comparing externalities[4] of IWT transportation with rail and road, a 2019 study found that overall transportation modes environmental costs make up 44% percentage of externalities with large differences between the transport modes (European Commission et al. 2019). An average IWT vessel is listed with 1.9 Eurocent/tkm compared to 4.2 Eurocent/tkm for heavy goods vehicle, 1.1. for electric freight trains and 1.8 for diesel freight train. Looking at the current level of taxation for the different road modes, IWT vessels are taxed with 0.3 Eurocent/tkm (port dues) while heavy goods vehicles are taxed with 1.5, electric freight trains with 0.5 and diesel freight train with 1.3, respectively. IWT has a comparable low-cost coverage ratio for external costs of only 6%, compared to 15-25% for most vehicle categories. The study suggests environmentally differentiated port charges or fairway dues to internalise externalities in the maritime sector.

Costs for shipping are divided into two main categories: time (fixed costs) and distance costs[5] (Al Enezy et al. 2017). Several researchers and studies have developed and refined business model calculations with different stakeholders in mind (Budde Christensen et al. 2012)and even compared different means

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[2] The project was running between 2017 – 2021 and focused on the use of vessel trains.

[3] On small-scale but notable exception may be battery electric sailing vessels, which are available in specific places (e.g. ferries, short distance container transport)

[4] Including accidents, air pollution, climate change, noise, congestion, well-to-tank emissions, habitat damage

[5] Other studies use operational hours as variable costs

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of transportations with their relevant break-even points. Studies including interviews with ship owners show that the use of average cost values (benchmarks) may not be sufficiently accurate due to the heterogeneity of the IWT market. Cost models as decision making tools for ship owners should – according to Al Enezy et al. (2017)– allow for values based on user inputs (company specific values) The cost model can be used for calculations on certain trips (industry benchmark), changes in sub-markets (e.g. from coal to container), changes in contracts. Most relevantly for this study, investment decisions for installing new engines or retrofitting investments can be analysed. One important and constantly changing variable is the interest rate of financing costs, particularly important within this industry as capital costs can make up to almost half of the CAPEX for retrofitting vessels, labour costs being the second most important cost aspect (Rijkswaterstaat (cited in Al Enezy et al. (2017)).

Revenue for IWT companies is generated by contract work for clients; the revenue depends on the transport services performed (Karaarslan and Quispel 14/06/2021). Prices can be agreed per ton or as lumpsum payments for specific single shipments. Other options are time charter (days of vessel use) or long-term contracts. Another aspect of income is created through demurrage[6], particularly in the liquid freight shipping. Stakeholder interviews indicate no higher freight prices but potentially longer contract periods for "greener" vessels (Karaarslan and Quispel 14/06/2021). Interestingly and according to the same study, governmental contracts have so far not shown a significant preference for more sustainable vessels but are mostly based on best-prices[7]. The CCNR study authors speculate that IWT may already be seen as "greener" options for governments compared to other means of transportation.

Interviews amongst the market player show, that the use of efficient engines (stage V instead of CCR-2 - CCR-0) may lead to fuel reductions; however, stage V engines require the addition of urea, leading to no financial advantages concerning the OPEX. Diesel-electric or hybrid diesel engines can lead to savings or vice-versa, heavily depending on the sailing profiles. Ship-owners with experience of LNG-use indicate that lower OPEX[8] for LNG has not been sufficient to cover the higher CAPEX (Karaarslan and Quispel 14/06/2021).

The financing of powertrain replacement is normally done through bank mortgages[9]. This financing instruments constitutes 70-80% of all financing measures. Ships older than 50 years can normally loan sums up to 40% of the market value of the vessel, while vessels of 15 years and younger can get funding of up to 70% of the vessels value. Other ways of financing (e.g. crowdfunding or subsidies) are rare. Figure 41 shows, that vessel owners – independent of size – depend on third-party financing for investments in low-emission technologies (in Figure 41, the example of electrifying the drivetrain is chosen; only shipside, incurring further costs through the leasing/buying of the power source itself). According to expert interviews, those figures from 2020 have increased significantly – potential up to 30% - leading up to 2024, partially due to higher interest rates as well as low water periods (decreasing the availability of own capital of shipowners). Further Work Packages (particularly WP4) within this project may provide primary data to update and extend on the available data.

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[6] Delay in loading or unloading of vessels at ports

[7] A follow-up among the project group experts indicates, that this information may not be true for all aspects, as public procurement is seen as important aspects e.g. for vessels used for construction and dredging works.

[8] OPEX differences between LNG and diesel have been fluctuating; low oil prices have recently decreased possible gains for LNG OPEX.

[9] according to stakeholder interviews across Europe (Karaarslan and Quispel 2021.

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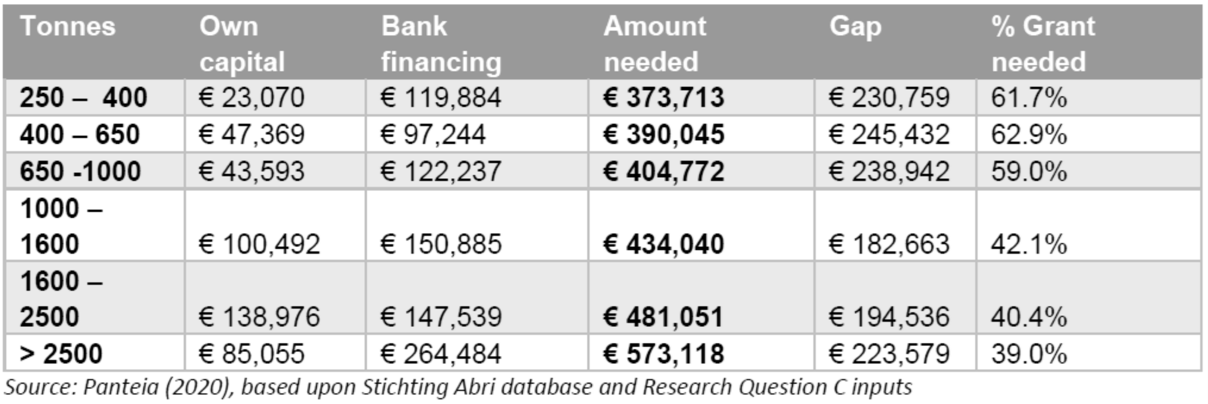

Tonnes	Own capital	Bank financing	Amount needed	Gap	% Grant needed
250 – 400	€ 23,070	€ 119,884	**€ 373,713**	€ 230,759	61.7%
400 – 650	€ 47,369	€ 97,244	**€ 390,045**	€ 245,432	62.9%
650 -1000	€ 43,593	€ 122,237	**€ 404,772**	€ 238,942	59.0%
1000 – 1600	€ 100,492	€ 150,885	**€ 434,040**	€ 182,663	42.1%
1600 – 2500	€ 138,976	€ 147,539	**€ 481,051**	€ 194,536	40.4%
> 2500	€ 85,055	€ 264,484	**€ 573,118**	€ 223,579	39.0%

Source: Panteia (2020), based upon Stichting Abri database and Research Question C inputs

Figure 41: Financial gaps for retrofitting (electric drivetrain) (Karaarslan and Quispel 14/06/2021, p. 23).

Looking at the market from a top-down view, the financing gaps (business as usual compared to various scenarios) ranges between 2.5-10 billion[10] euro in the timeframe up to 2050. According to this study within PLATINA3 (Roux 30/06/2022), most costs incur as CAPEX, while OPEX in various scenarios lead to reductions in financing of alternative power trains.

The market overview within the framework of the CCNR studies (Dahlke-Wallat et al. 2021) indicates, that two different target audiences need to be accounted for:

- Small, often family-owned businesses.
- Shipping companies (often in niche markets like tanker, container or pusher shipping)

In family-owned businesses factors such as the age of the owner and succession plans within the family play an important role in decision-making processes. Furthermore, a general challenge is the increasing lack of qualified personnel and the general decrease in the number of employees (Jacobs 2022).

A study within the prominent Work Package WP6.3 (Ecorys 30/04/2018) looked at the financial impact of greening the IWT for Europe, mainly with the aim of reducing the air pollutant emissions. Calculating the return on investments for cleaner fuel (Stage V diesel), the study found that with a total investment of EUR 1.06 billion, every invested Euro generates 6.6 Euros in return on investments for external costs leading to an overall societal benefit. The study suggested (as does the more recent CCNR-study), to create a Greening Fund on European level, with a dedicated, earmarked levy added to the fuel price, to guarantee a level playing field. On the technical side, barriers for technological innovations need to be considered. They include the following aspects: technical (compare D1.1 within the Synergetics for an assessment of various technologies), legal, financial, knowledge, market as well as culture. Those aspects can be divided in ship-related technical measures, infrastructure and ship-operational measures (Ecorys 30/04/2018). According to this study, the most significant barriers are to be found in the market for the exchange of diesel engines as well as the right sizing; in the financial area for auxiliary systems and in the technical area for shop-operational measures (sailing behaviour).

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[10] Experts within Synergetics estimate, that this cost assumptions should be increased by at least 50%, looking at todays market situation.

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In a study by the EICB some key research questions were identified through extensive stakeholder interviews and data collection as shown in the overview of the study results on the following pages (Dahlke-Wallat et al. 2021; Kriedel et al. 2022a; Kriedel et al. 2022b; Pringuey 2021).

Interviews within the Synergetics project team indicate, that similar results can be expected for the Danube region. However, one more challenging factor for the Danube region are shipping companies outside the EU, not adhere to the same regulatory framework as companies from within the EU.

Table 12: Summary of results of CCNR Study (Dahlke-Wallat et al. 2021).

Nr	Research question	Short summary of research results	Exploration of new developments / changes since CCNR-results
a	What are the possible triggers and financial drivers to enable a positive investment decision by shipowners to invest in technologies contributing to zero-emission performance?	The current means of financing are mortgages through financial banks and temporary grant schemes at European, national and regional level. The lack of financial capacity and incentives (→ no business case in the traditional model) hamper further developments as the return on investment is not given for shipowners/operators. Customers are not ready to pay additionally for sustainability services	The amended CSRD of the European Union may provide incentives for businesses to greening der supply chain and in adhering to the EU taxonomy. If prices for sustainably driven vessels can reflect this additional business values for customer, new technologies may become viable over time. Furthermore, new players in the market (with new fleets, not so much retrofit) may change the landscape of the IWT sector with new services and payment models (e.g. ZES)
b	What can we learn from other transport modes?	The importance of public participation in financing the energy transition of the various modes of transport is considerable. Air and rail transport receive strong economic support. At present, only road transport appears to be financing its own energy transition, while shipping is collectively trying to develop a financing system (in the form of a fund), which has taken several years to materialise due to difficult negotiations between countries.	The challenge in such comparisons is manyfold. The lifespan of vessel is very long. investments in infrastructure are costly the structural setup within the industry with many small, family-owned vessel owners is not comparable to any other transportation mode (rail: often with state involvement, lorries and airplanes with ownership of large multinational companies) biofuels used in other modes of transportation may be insufficient in quantity in the IWT
c	Which greening techniques fit into zero-emission development of IWT and what are the impacts?	Cost figures and development predictions for various energy carriers and energy conversion technologies have been assessed within 3 scenarios and described, looking 30 years into the future building from the PROMINENT research. 12 ship types have been looked at. New ships as well as retrofit solutions were considered in the calculations. It was found that retrofitting solutions often require major and costly conversions while sometimes still being the best choice given the longevity of vessel uses. CO2 emissions were the once found to be hardest to minimise. When options (other than drop-in fuels) are considered, cost factors like bunking (energy storage) and cost aspects come into the equation.	New technologies gain higher level of TRL, leading to a higher security regarding costs, quantity and scalability. Technology leaps within IWT are not expected due to the small size of the industry: it could be interesting looking at other industries to find new sustainable approaches.

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Nr	Research question	Short summary of research results	Exploration of new developments / changes since CCNR-results
		According to this study, the focus for sustainable investments should be on newbuilt ships; drop-in fuels could be a "in-between" solution for existing vessels.	
d	What is the potential of pay-per-use and leasing schemes for the IWT market?	The study found that the potential seems to be rather limited for pay-per-use or leasing schemes I the short- to mid-term. One salutation that may work (with first industry-examples) are containerised energy systems (e.g. battery containers); however, the potential is assessed to be a few hundred vessels only to begin with.	Through new payment models, new companies and players may enter the market, leading to further (and faster) developments in the future. Those new parties may have easier access to funds and financing. New payment models may be furthered by developments around automation and standardisation. Leasing schemes reduce the risk of substantial up-front payments, reducing the business risk for vessel owners (investment barrier). A barrier is the low level of standardisation within the IWT sector. Pay per use seems the more likely model than leasing, e.g. ZES with containerised battery solutions for dry cargo vessels carrying containers (with a limited market share)
e	What is the potential for joint procurement in the European IWT sector?	Join-procurement could lead to cost reductions (economy of scales), new market development an innovation. Another potential benefit is a higher level of standardisation.	Due to the current industry structure, joint procurement could only be applied to a limited number of vessels and may therefore not have a big impact (assumption: 1-5% reduction of investment costs)
f	What can be expected from national and European programs and products providing funding and financing?	Financial support on the EU level is often provided for pilot projects and/or demonstrators. What is missing is the funding of large-scale upscaling (including roll-out) initiatives for green technologies. In the Netherlands, funding options are available (EUR 92m until 2030) but mostly bound to nitrogen emission problems. Financial hedging of alternative fuels has been looked at in this part of the study as well to increase financial stability. However, it was found, that hedging is no common practice within IWT. Funding options are well known within the industry due to the available EIBIP funding database (outdated); according to an industry enquiry, funding levels of 50% are deemed to be necessary for successfully applying any funding scheme.	The CSRD may be a driver for the customers of IWT and for the (bigger) IWT-companies themselves, to speed along the introduction of polluter pays schemes. The study authors state, that any pay-per-use or energy-as-a-service solution should include CAPEX an OPEX as eligible elements of a funding scheme. The Innovation Fund – European Commission is available for the IWT sector under the registration for Use of renewable energy outside Annex I An overview of all national funding schemes is available in the final report to research question F As an update on the number for NL: an additional EUR 240m will be added due to ETS2; dedicated to the zero-emission transition of inland vessels.
g	What is the potential for polluter pays schemes in IWT?	Challenges in the IWT sector related to the high fragmentation of supply chains and complex structures; a responsibility in the	Options such as contributions based on number of vessels, load capacity/length,

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Nr	Research question	Short summary of research results	Exploration of new developments / changes since CCNR-results
h	What are requirements and boundaries considering level playing field and modal share?	sense of "polluter pays scheme" would therefore have to involve many different stakeholders. A scheme with the potential for a successful introduction has been identified as "earmarked contributions" from the sector that are in turn used to make the fleet more sustainable. The study defines a range of 4-8% per litre of fuel as feasible for the IWT sector without leading to market disruptions. Total contributions would thereby range between EUR 52 – 106m within the timeframe of 2025 – 2050. To gain acceptance within the sector, it is proposed, that this measure should be accompanied by an equal amount of public funding and be granted for all connected waterways within Europe	per tkm/pkm, km travelled, new engines, have been discharged due to low effectivity and/or unfairness. Positively considered were: flat rate for bunkered amount of fuel/energy, real-time measurement of emissions on board of vessels, calculated emissions, label[11] / energy index (for vessels) in combination with bunkered amount of fuel/energy per vessel. RED-III and ETS2 opt-in for inland navigation (e.g. planned in the Netherlands) are targeting the internalisation of external costs / polluter pay schemes.
i	What is the added value of a new European funding and financing scheme for IWT and how could this work?	The overall conclusion is that the IWT sector by itself cannot finance or fund the necessary changes required to reach the emission targets. An adapted legal framework seems to be the prerequisite to achieve emission-goals due to lacking business cases and/or the lack of own resources and (financial) incentives. It is suggested that the financing gap should be closed via non-refundable grants. Added value can – according to this study – be found in pay-per-use or leasing schemes, joint procurement, or fuel hedging activities. However, the study concludes that such measure will have a small overall impact. Public grants should be used to compensate vessel owners for higher TCO and be made available as "one-stop-shops" to facilitate the access to those funds. A funding scheme could e.g. take the form of a public-private partnership at European level (→ international convention)	In order for the Mannheim Declaration to be implemented, steps need to be taken to facilitate the greening of the IWT sector. PLATINA3 has been introduced as follow up to the CCNR studies to shape an action plan for the necessary development of funding and financing instruments. The results of the studies are as well used as part of the CCNR roadmap. A coordinated introduction y member states of ETS-2 and REDIII cold make a difference in financing and funding.

In summary, the studies concluded that possible transition pathways need to be identified promptly and that there is no "one size fits all" solution. The reports state that economic, technical, and regulatory aspects are all means playing important roles in achieving the transition to zero CO2-emissions by 2050. Regarding the funding, a funding gap for investments of an estimated EUR 10 billion[12] needs to be covered for the energy transition. According to this previous research, the transition cannot be financed by the industry itself. Furthermore, the current framework conditions do not incentivise the current

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[11] The EU Parliament, in its resolution P9_TA(2012)0367 calls on the EU Commission to devise a EU emissions labelling system for IWT providing information about the energy performance of ships, thereby promoting energy efficiency and creating stable framework conditions with the goal of establishing viable business cases for shippers.

[12] Current estimates with data from 2024 indicate at least EUR 15 billion.

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vessel owners to move towards "greener" fuel options for their vessels. The reports suggest European funding and financing mechanisms. Identified options include grands and financing instruments by the EU as well as market-based schemes potentially with labelling system (Dahlke-Wallat et al. 2021a). Additional information on coastal shipping is needed for a complete picture (compare Chapter 4.5).

CCNR Roadmap

The CCNR Roadmap builds on the finding of the CCNR studies and aims to significantly reduce GHG emissions within the inland navigation sector in accordance with the Mannheim Declaration[13]. The roadmap aspires to initiate activities going beyond pilot projects, thereby overcoming obstacles to the introduction of new technologies (CCNR 2022). The roadmap mentions "enabling measures" such as regulatory aspects, financing of the energy transition in general or emission-monitoring as well as "technology transition pathways. Importantly, the Roadmap focuses on "Tank-to-Wake" (TTW) approach and makes assumption about the upstream fuel chain. The Roadmap aims to provide a common vision within the IWT sector in Europe.

The Roadmap emphasises the importance of a technology neutral approach. The suggested pathways should ideally be based on no-regret investments and should include regulatory, logistical and infrastructural as well as incentivisation measures. The roadmap considers technologies from technology readiness level (TRL) 5 onwards.

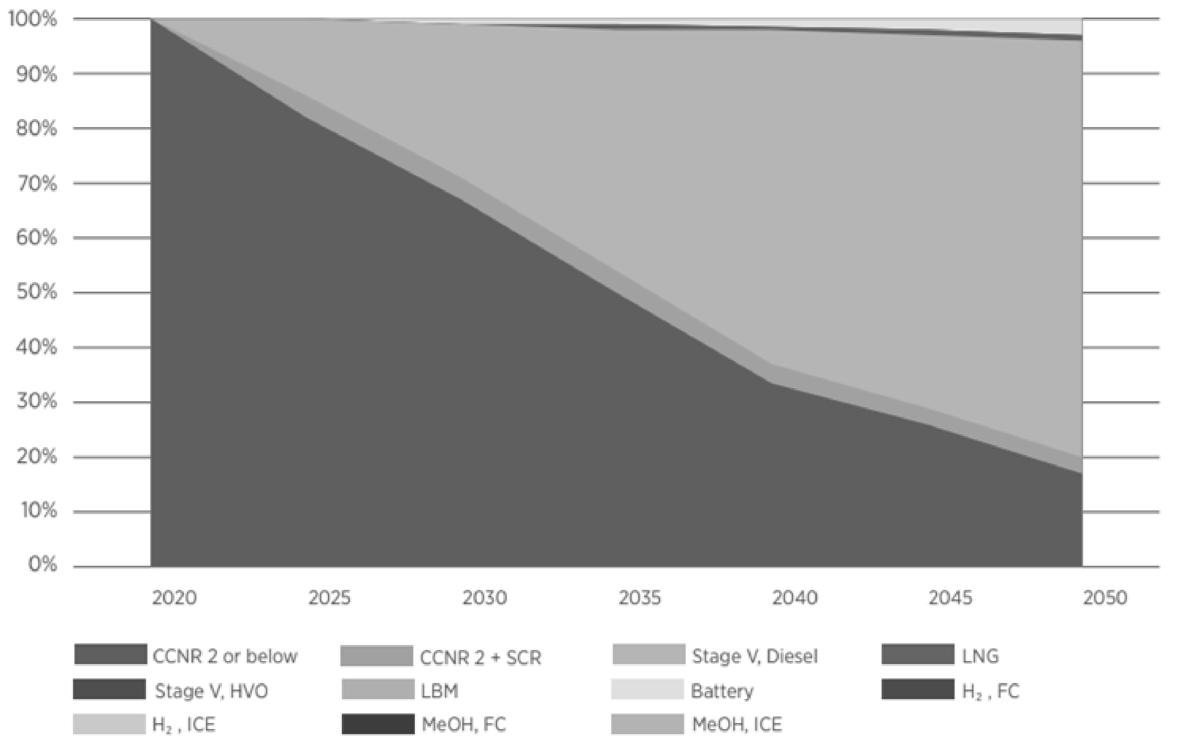

Figure 42: IWT-development of fuel usage - Business as usual (CCNR 2022, p. 41).

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[13] GHG emission reduction by 35% by 2035 compared to 2015, a pollutant emission reduction in the same time frame by 35% and a largely emission free (min 90%) inland waterway navigation by 2050.

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The Roadmap provides a scenario "business as usual" (BAU), indicating that under today's policy framework and pricing levels, change is assumed to happen very slowly (compare Figure 42). With fuels moving from today's emission limits (CCNR 2 or CCNR2 + Selective Catalytic Reduction Systems) towards Stage V, diesel with a very low share of battery electric powertrains and LNG. Batteries are predicted to being used primarily for ferries and daytrip and small cabin vessels, whereas LNG is assumed to be primarily used (10%) by motor tankers > 110m.

The conservative alternative pathways assume that a transition towards fuel substitutes is easiest, in case where they can be used in existing engines. Hence, Stage V HVO is assumed to gain a market share of approximately 50% by 2050, accompanied by Stage V diesel (10%) and batteries (15%). Another pathway focusing more on innovation shows a large variation of alternative fuels with the percentage of diesel fuel (Stage V) reduced to approximately 10% by 2050, while batteries are envisioned to gain a market share of approximately 35% besides the use of H2 (internal combustion engines as well as fuel-cells) with 25% and methanol with 20% (both in internal combustion engines as well as fuel cells). Particularly challenging seems to be the powertrain replacement of large push boats (>2 000 kW). Highest uncertainties in terms of technology readiness, availability and financial viability are attributed to biofuels. Compared to the conservative scenario, the innovative scenario is expected to have significantly higher costs (factor 1.6-2.9).

The Roadmap concludes, that investments for green technologies should be financially supported for both, newly built vessels as well as for retrofitted vessels. The cost gap identified amounts to EUR 2.65 billion I the average "conservative" scenario and to EUR 7.8 billion in the average "innovative" scenario according to the modelling. The Roadmap suggests a mix of European financial support dedicated to IWT in combination with private and public investments including contributions from the IWT sector. Currently, no viable business case has been identified by Dahlke-Wallat et al. (2021) using zero-emission technologies. The specific recommended actions are provided in Appendix 7.2. Further information on the roadmap can be found in Deliverable D1.3 of this project.

4.2.1 Policy Developments within the EU

The EU has been following the goal of internalising external costs within the sector of transportation (goods and people) through the "user pays" and "polluter pays" principle. Its primary choice on reaching fair and transparent conditions for the transportation sector are (EUI et al. 2019):

- market-based instruments (e.g. taxes, charges, tradeable permits)
- regulatory measures (e.g. land use planning, regulations, fees, restrictions)
- and voluntary instruments

While the Eurovignette Directive has been an important step within the EU for road transportation, no similar measures have been established yet in the maritime sector. However, current legislation includes e.g. an IMO sulphur cap or the NOx Tier III standard for new ships on Nitrogen Emission Control Areas (NECAs). Other measures implemented include SEMP, CII, EEOI and EEDI[14]. The use of more fuel-efficient vessels is viewed as a priority; particularly the availability of favourable conditions for battery-electric vessels. Ports are viewed as particularly important infrastructure within the shipping industry regarding the availability of charging structure or regulatory possibilities such as environmentally differentiated port charges of fairway dues (European Commission et al. 2019). The EU supports efficient

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[14] No further references are included in this report; information can be found on the IMO webpage

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waterborne transportation through the FuelEU Maritime Initiative to enhance production and scale-up production of maritime fuels. The European Commission considers (European Commission 2021):

- to establish a Renewable and Low-Carbon Fuels Value Chain Alliance including stakeholders from industry, public authorities and civil society
- to complement actions under the European Clean Hydrogen Alliance
- building on the success of the European Battery Alliance

The following paragraphs provide additional information regarding recent developments. A broader and more in-depth look at policies (e.g. RED3, FuelEU, ETS) and scenarios is taken in Deliverable D1.3.

Corporate Sustainability Reporting Directive (CSRD)

From 2024 onwards, the EU legislation requires a broad set of companies to report on their Corporate Social Responsibilities (CSR). The directive is based on The European Green Deal, which - in short - is a commitment by the European Parliament to sustainably decouple economic growth from resource use and climate neutrality by 2050. The reporting of economic activities is thereby seen as a prerequisite to environmentally sound business activities, relating to the Action Plan Financing Sustainable Growth of the European Commission (European Parliament and Council 14/12/2022). With the amendment of the directive of 26 December 2022, a broader number of companies[15] are required to disclose ESG risk dimensions as part of the Supervisory Review and Evaluation Process (SREP). The European Commission highlighted in further Guidelines (supplement on reporting climate-related information) the benefits of such reporting by increasing awareness and understanding for climate-related risks and opportunities. The beneficiaries of better sustainability reporting are seen to be investors as well as actors within the civil society (e.g. NGOs and social partners) and in a broader view all individual citizens. The directive 2013/34/EU has been amended (by Directive 2022/2464) to focus further on data harmonisation and comparability using disaggregated data. The directive aims to avoid diverging rules on national level and to avoid an information gap between disclosure needs (e.g. from investors) in comparison to information provided by the companies themselves. While the CSRD sets the EU's legal framework for mandatory sustainability reporting, the European Sustainability Reporting Standards (ESRS) acts as its operational tool to outline the specific reporting requirements. The reporting covers a wide range of sustainability topics in the areas of environmental, social and governance (ESG) and is based on the so-called double materiality, focusing on the inside-out perspective on how a company is affecting its environment as well as the outside-in perspective considering how the environment affects the business. In the overarching and governance standards reporting is required for the area of business models, policies, outcome of policies, risks and risk management as well as key performance indicators relevant to the business. The environmental standards cover climate change, environmental pollution, water and marine resources, biodiversity and ecosystems, and resource consumption and circular economy. In the area of climate change, companies must present their impacts and strategies. This also applies to greenhouse gas emissions (Scope 1-3), which must be recorded in accordance with the Greenhouse Gas (GHG) Protocol. In IWT this includes upstream- and downstream transport.

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[15] Under the original directive: (parent) companies with an average number of > 500 employees; under the new amended directive: including small and medium-sized undertakings with securities admitted to trading on regulated markets in the EU; additionally, even undertakings not trading securities on regulated markets need to disclose information given their importance particularly looking at value chains. Additionally, from 30 June 2024, even companies from third-countries need to disclose information in case their securities are traded within the EU (for companies with a turnover of more than EUR 150m or branches of companies with a turnover of more than EUR 40m).

EU Taxonomy

The EU Taxonomy is an EU-wide taxonomy system for sustainable activities. It is part of the EU's sustainable finance framework, was developed as part of the action plan on financing sustainable growth and is a tool for market transparency. Its purpose is to direct investments to areas most needed according to the European Green Deal objectives, and thus help them to scale up. The EU Taxonomy serves as a tool aiding investors in recognising environmentally sustainable economic activities. Businesses subject to the Corporate Sustainability Reporting Directive (CSRD) must include information in their annual reports regarding the extent to which their activities align with the EU Taxonomy (Taxonomy-eligibility) and adhere to the criteria specified in the Taxonomy delegated acts (Taxonomy-alignment). The taxonomy regulation entered into force in 2020.

There are 4 overarching conditions that must be met by an economic activity to qualify as environmentally sustainable (*Taxonomy-aligned*):

- "Making a substantial contribution to at least one environmental objective,
- doing no significant harm to any of the other five environmental objectives,
- complying with minimum safeguards (ensure alignment with the OECD Guidelines for Multinational Enterprises); and
- complying with the technical screening criteria."

The environmental objectives are: (i) climate change mitigation; (ii) climate change adaptation; (iii) the sustainable use and protection of water and marine resources; (iv) the transition to a circular economy; (v) pollution prevention and control; (vi) the protection and restoration of biodiversity and ecosystems. Besides making a direct contribution to one of the six environmental objectives by their own performance, economic activities can also "directly enable" other activities to increase their environmental performance (so called "enabling" activities).

Delegated Acts: There are two legally binding acts, that elaborate on the detailed provisions in the Taxonomy Regulation. The *Climate Delegated Act* defines the technical screening criteria for economic activities. Currently, the Climate Delegated Act encompasses economic activities within sectors accounting for nearly 64% of direct greenhouse gas (GHG) emissions in Europe (in sectors such as forestry, manufacturing, energy, transport, …). Contents are shown in the EU Taxonomy Compass (visual representation of the contents of the EU Taxonomy and Taxonomy Delegated Acts). The *Disclosure Delegated Act* specifies "the content, methodology and presentation of information to be disclosed by non-financial and financial companies subject to the NFRD/CSRD" (Corporate Sustainable Reporting Directive). A third delegated act, *Environmental Delegated Act*, is still under development.

The steps for companies to assess their alignment with the EU Taxonomy are as follows:

- Identify the activities that are covered by the EU Taxonomy (*Taxonomy-eligible activities*), for a quick visualisation the EU Taxonomy Compass can be used
- Assess whether the activities meet the technical screening criteria (*Taxonomy-aligned activities*)
- Check compliance of the activities with minimum safeguards
- Apply the relevant reporting rules (a specified in the Disclosure Delegated Act)

Regarding shipping, in the EU Taxonomy are currently following activities listed (shown in the EU Taxonomy Compass) (only contributing to climate adaptation):

- Inland freight water transport (contributing to climate mitigation and climate adaptation)
- Inland passenger water transport (contributing to climate mitigation and climate adaptation)
- Retrofitting of inland water passenger and freight transport (contributing to climate mitigation and climate adaptation)

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- Retrofitting of sea and coastal freight and passenger water transport (contributing to climate mitigation and climate adaptation)
- Sea and coastal freight water transport, vessels for port operations and auxiliary activities (contributing to climate mitigation and climate adaptation)
- Sea and coastal passenger water transport (contributing to climate mitigation and climate adaptation)

The EU Taxonomy is thereby an important tool for those companies that are a) subject to the Corporate Sustainability Reporting Directive (CSRD) and must fulfil sustainability disclosure requirements, b) seeking competitive advantage by enhancing access to financial markets and gaining reputational benefits or c) seeking guidance to improve sustainability performance and climate resilience.

There are currently no direct funding/financing activities within the IWT sector in direct relations to the adherence of the EU taxonomy. Companies adhering to the EU Taxonomy have the (future) benefit, that investors will more likely invest in Taxonomy-aligned activities. Additionally, adherence to the taxonomy will be a prerequisite to make use of EIB loans (green loan facilities).

Renewable Energy Directive RED III

In 2023 the existing directive EU/2018/2001 has been revised to reflect the urgency of the energy transition with the EU. Countries have had an 18-months transition period to implement the revisions in their national laws. Within the new directive, the overall target for renewable energy has been increased from 32% to a binding target of 42.5% (voluntary: 45%). Importantly for the transition of the IWT sector, a strong focus in given towards the electrification in various sectors.

For the transport sector, as one of the sectors with sizable challenges for the transition towards renewable energy, the following targets have been set:

- 14.5% reduction in greenhouse gas intensity by 2030 using renewables OR
- A share of at least 29% of renewables for the final consumption of energy in the transport sector by 2030

Additionally, a minimum share of 1% for renewable fuels of non-biological origin has been set as well as a target of 5.5% of advanced biofuels (non-food-based-feedstocks).

RED II revision (RED III): RED III and the subsequent supply of renewable energy helps to stay within the emission cap set in ETS 2: Since energy suppliers are required to achieve a certain amount of CO2 reduction per energy quantity through standardising the maximum number of grams of CO2eq per MJ supplied on average. The latest expectation is that 14.5% CO2eq reduction will be realised because of RED III in 2030.

RED III, Taxonomy and ETS 2 are interlinked and complementary, creating mutual synergies. Everything that is already renewable falls outside ETS 2 and there no emission rights have to be paid over by energy suppliers. Also, RED III partially contributes to meeting the requirements to meet Taxonomy criteria.

FuelEU Maritime

The regulation 2023/1805 has entered into force in Autumn 2023 and will become applicable by 1.1.2025. It is directly enforced by the EU. The regulation establishes maximum limits for the annual average greenhouse gas emissions of the energy consumed by ships and applies for all vessels within the EU with a gross tonnage of above 5 000. For voyages between two EU-ports, 100% of energy use is applied, for voyages with starting- or ending point outside of the EU, a 50% share is calculated.

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Calculations are based on a Well-to-Wake approach and include CO2, CH4 and N2O but all electricity is set at zero-emission (incl. electricity from the EU grid).

With this requirement in place, greenhouse gas intensity of on-board energy will taper off between 2025 (2%) – 2050 (80%). Ships not compliant with the reduction targets will incur penalties.

EU Emission Trading System

The maritime sector has become part of the EU ETS since January 2024. Included are vessels above 5000 gross tonnage entering EU ports, regardless of the flag of origin. Emissions occurring within the EU (between two EU ports) are fully covered, emissions from voyages with starting or ending point outside of the EU are covered by 50% of the emissions. Shipping companies under this new rule have to purchase and use EU ETS emission allowances for each tonne CO2 (equivalent). The EU member states are responsible for the compliance. For shipping companies, the ETS covers a phasing-in between 2025 and 2027[16], with the system fully in place by 2027.

ETS revision (ETS 2): ETS 2 acts on fossil energy and is thereby particularly relevant for energy suppliers. All renewable energy already supplied from the RED III obligation will replace fossil diesel. This renewable volume is out of scope of ETS 2 (Tachi and Quispel 2023):

- ETS revision (ETS 2) and ETD revision mainly affect the price of fossil fuel, as it becomes higher.
- ETS 2 stipulates that allowances must be bought on the volume of fossil fuel emissions. The effect is estimated at 15 cents per litre of fossil diesel in the short term, since there are mechanisms in place to keep the CO2 price at 45 euros per ton of CO2 (more emission rights will be added, to reduce prices above 45 euros).
- In addition, ETS 2 also ultimately has an indirect normative effect. The emissions cap will continue to fall each year towards 2044 as the issuance of emission rights is phased out. Indeed, if not decided otherwise, no new allowances will be issued from 2044 onwards. Supplying and using fossil fuels will still be technically possible after 2044, but probably in very limited volumes and at very high costs. It is therefore to be expected that inland navigation will use virtually no fossil fuel after 2044 and will therefore rely almost entirely on the use of renewable fuel.

However, it is important to note, that those aspects will only apply to member states deciding to opt-in. Inland navigation is not included by default. Currently, only the Dutch government has approved this opt-in.

Multimodal Trans-European Transport Network (TEN-T)

The revised directive (European Commission and Directorate-General for mobility and transport 2023) acknowledges challenges in setting-up a coherent transportation network within the EU, particularly in regard to permission granting procedures, cross-border procedures and investments. It aims to further the completion of the TEN-T in a timely and synchronised manner. Under the revision, Sustainable Urban Mobility Plans (SUMPs) must be adopted by the designated urban nodes along the TEN-T network. This SUMPs aim to facilitate the integration of diverse transportation modes and further a shift towards sustainable mobility. Within the area of European Maritime Space, a higher integration with other transportation modes is envisioned. The transport links with countries bordering the EU are to be strengthened (Ukraine, Moldova, the six Western Balkan partners).

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[16] 2025: 40% of their 2024 emissions have to be reported; 2026: 70% of the emissions of 2025 have to be reported

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Energy Taxation Directive Revision

The ETD (Energy Taxation Directive) revision proposes the introduction of a minimum excise tax on fuel and energy. The minimum is 3.2 cents per litre of fossil diesel. Member states may introduce higher excise tax rates. In addition, according to Article 15.1 of the proposal, there is a possibility to apply a zero rate for several types of fuels within a transition period of 10 years. Popular renewable fuels for inland navigation such as HVO and FAME can, depending on the feedstock, meet this 10-year transition period. And for renewable fuels, a significantly lower minimum excise tax is proposed from 2033 compared to fossil fuels.

4.2.2 Financing and Funding Options

Non-repayable grants are a key factor in establishing a business rationale for implementing innovative green technologies and achieving the break-even threshold within IWT (Dahlke-Wallat et al. 2021). This is essential given the substantial financial gap and elevated project risks, allowing ship owners to secure funding through various financial instruments and products, including those supported by the EU. In the EU, there are major funding programs that support investments into energy transition actions towards a zero-emission European IWT sector, which are all part of the InvestEU programme (see more detailed description below):

- Horizon Europe (for research and innovation actions)
- LIFE program (for activities such as testing, demonstrating, and piloting the efficacy of novel technologies, approaches, or policies as means for policy implementation)
- Connecting Europe Facility (CEF, for large-scale roll-out and deployment actions)
- Innovation Fund (for actions backing the commercialisation and widespread adoption of advanced and sufficiently developed low-carbon technologies and processes)

The InvestEU programme is a single fund since the new Multiannual Financial Framework (MFF) in 2021 was introduced. The purpose is to overcome the problem and complexity of the current multitude of financial instruments. Most importantly, financial support is provided through the TEN-T-infrastructure project "Connecting Europe Facility 2021 – 2027"[17] providing grants to projects through calls for proposals. Research projects are funded via the Horizon Europe program. Funding for small businesses, common in the IWT sector, is available through the "Invest EU" programme. The European Investment Bank can support IWT projects through loans and investments in "infrastructure, fleet acquisition, retrofitting, innovation, research and development" (Jacobs 2022). The taxonomy sets screening criteria to guide market participants when taking investment decisions. Furthermore, the Corporate Sustainability Reporting Directive may become a major driver in the EU for sustainable IWT.

The level of financial support allocated for the shift towards zero-emission IWT varies significantly across countries and regions. Nations such as the Netherlands, Belgium, Luxembourg, France, Germany, and Switzerland, and Austria offer diverse and appealing financing options for the IWT sector. In contrast, countries like Hungary, Romania, Slovakia, Croatia, and Bulgaria, or the Czech Republic do not present any financial incentives related to IWT.

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[17] European Climate, Infrastructure and Environment Executive Agency (CINEA)

PLATINA3 (Deliverable 2.5) provides a comprehensive overview of funding and financing aspects for the energy transition within the European IWT-fleet (Roux 30/06/2022). Main finding includes:

- economic, financial, technical and regulatory objectives need to be taken into consideration.
- many funding and financing options are available, however not all deemed to be adequate to support the energy transition within IWT.
- the existing financing and funding options could be better used
- a European financial instrument could support the energy transition
- a layout of all stakeholders an their intentions is recommended
- a combined instrument with funds from EU, national and regional money is deemed to be non-feasible; recommended is a decentralised set-up with national contact points and co-fundings

As a summary, the authors of PLATINA3, D2.5 state: The current framework does not enable to trigger the energy transition at the level of the individual vessel owner and the vessel owners do not have the financial capacity to finance the transition by their own means. In addition, no mechanism currently exists to ensure that those who invest today in expensive emission reduction technologies and take a financial burden and risk in doing so are not put at competitive disadvantage compared to those who decide to invest at a later stage (and still use relatively low-cost fossil gasoil and continue to use old diesel engines) […]. A clear European strategy between the EU, national governments and IWT sector representatives regarding the funding and financing of the energy transition towards 2050 is therefore required, as well as a clear action plan to overcome the financial the related financial challenge (Roux 30/06/2022, p. 9).

The study estimates that a funding gab of 2-5 – 10 billion euro[18] (depending on transition pathways) needs to be bridged by stakeholders other than the vessel owners. The study recommends focussing on the improved use of existing instruments in the current phase of MMF 2021 - 2027 (Multiannual Financial Framework), improving the grounds for the introduction of a European wide instrument between 2028 – 2035.

A comprehensive overview is provided in PLATINA4Action (Deliverable 5.1) on funding instruments (not publicly available yet). The report includes follow-up works for the time frame 2028 – 2035 and available instruments such as Innovation Fund and CEF-AFIF.

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[18] As noted in previous Chapters, this number may be significantly greater in today's market.

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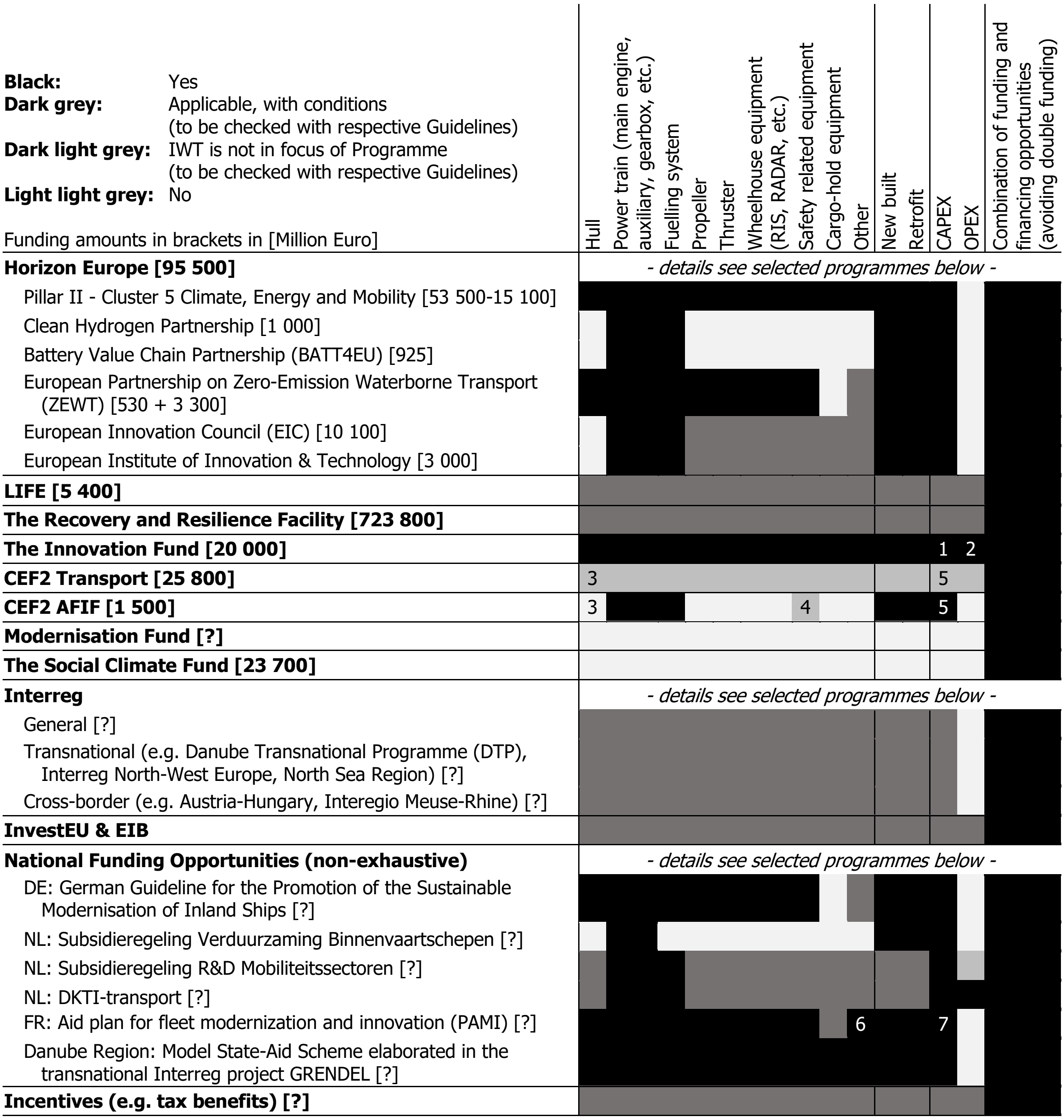
Table 13: Funding and financing instruments for inland vessels 2021-2027 (Karaarslan 2022). For additional remarks see main text body. Source: own adaptation of table provided in Roux (30/06/2022, p. 28).



Black: ■ Yes
Dark grey: ▓ Applicable, with conditions (to be checked with respective Guidelines)
Dark light grey: ▒ IWT is not in focus of Programme (to be checked with respective Guidelines)
Light light grey: ░ No

Funding amounts in brackets in [Million Euro]

	Hull	Power train (main engine, auxiliary, gearbox, etc.)	Fuelling system	Propeller	Thruster	Wheelhouse equipment (RIS, RADAR, etc.)	Safety related equipment	Cargo-hold equipment	Other	New built	Retrofit	CAPEX	OPEX	Combination of funding and financing opportunities (avoiding double funding)
Horizon Europe [95 500]	*- details see selected programmes below -*													
Pillar II - Cluster 5 Climate, Energy and Mobility [53 500-15 100]	■	■	■	■	■	■	■	■	■	■	■	■	░	■
Clean Hydrogen Partnership [1 000]	░	■	■	░	░	░	░	░	░	■	■	■	░	■
Battery Value Chain Partnership (BATT4EU) [925]	░	■	■	░	░	░	░	░	░	■	■	■	░	■
European Partnership on Zero-Emission Waterborne Transport (ZEWT) [530 + 3 300]	■	■	■	■	■	■	■	░	▓	■	■	■	░	■
European Innovation Council (EIC) [10 100]	░	■	■	▓	▓	▓	▓	▓	▓	■	■	■	░	■
European Institute of Innovation & Technology [3 000]	░	■	■	▓	▓	▓	▓	▓	▓	■	■	■	░	■
LIFE [5 400]	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	■
The Recovery and Resilience Facility [723 800]	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	■
The Innovation Fund [20 000]	■	■	■	■	■	■	■	■	■	■	■	■ 1	■ 2	■
CEF2 Transport [25 800]	▒ 3	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒ 5	▒	■
CEF2 AFIF [1 500]	░ 3	■	■	░	░	░	▒ 4	░	░	■	■	■ 5	░	■
Modernisation Fund [?]	░	░	░	░	░	░	░	░	░	░	░	░	░	■
The Social Climate Fund [23 700]	░	░	░	░	░	░	░	░	░	░	░	░	░	■
Interreg	*- details see selected programmes below -*													
General [?]	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	░	■
Transnational (e.g. Danube Transnational Programme (DTP), Interreg North-West Europe, North Sea Region) [?]	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	░	■
Cross-border (e.g. Austria-Hungary, Interegio Meuse-Rhine) [?]	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	░	■
InvestEU & EIB	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	■
National Funding Opportunities (non-exhaustive)	*- details see selected programmes below -*													
DE: German Guideline for the Promotion of the Sustainable Modernisation of Inland Ships [?]	■	■	■	■	■	■	■	░	▓	■	■	■	░	■
NL: Subsidieregeling Verduurzaming Binnenvaartschepen [?]	░	■	░	░	░	░	░	░	░	■	■	■	░	■
NL: Subsidieregeling R&D Mobiliteitssectoren [?]	▓	■	■	▓	▓	▓	▓	▓	▓	▓	▓	■	▒	■
NL: DKTI-transport [?]	▓	■	■	▓	▓	▓	▓	▓	▓	▓	▓	■	■	■
FR: Aid plan for fleet modernization and innovation (PAMI) [?]	■	■	■	■	■	■	■	▓	■ 6	■	■	■ 7	░	■
Danube Region: Model State-Aid Scheme elaborated in the transnational Interreg project GRENDEL [?]	■	■	■	■	■	■	■	■	■	■	■	■	░	■
Incentives (e.g. tax benefits) [?]	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	■

*Remarks: **1:** for small scale projects: max. 60%, for large scale projects: max. 60% | **2:** for small scale projects: 0%, for large cale projects: max. 60% | **3:** exception: bunker vessels | **4:** in relation to the fuelling system | **5:** eligible costs: difference compared to conventional systems | **6:** integration of IWT in the logistics chains waste management/treatment*

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HORIZON Europe

Horizon Europe (2021-2027) represents a €100 billion research and innovation framework program. The overarching aim of the program is to generate scientific, technological, economic, and societal impact through the European Union's investments in research and innovation. The programme seeks to fortify the scientific and technological foundations of the Union, promoting competitiveness across all Member States. This is done through a three-pillar structure known from the previous Programme (Pillar 1 "The Excellence Science", Pillar 2 "Clusters – Global Challenges & European Industrial Competitiveness", Pillar 3 "Innovative Europe").

Eligible actions are only those that implement the objectives of the Programme, and there are clear guidelines which research activities are not supported (human closing, modification of genetic heritage of human beings, …). Eligible actions are mainly research and/or innovation actions.

Any legal entities are eligible and shall be part of a consortium where three independent legal entities from different Member States are included. Third countries with IWT such as Switzerland, Serbia, Ukraine, Republic of Moldova, and potentially Bosnia and Herzegovina are also eligible.

Fundings are provided as set in the Financial Regulation, mainly grants, prices and procurements, and potentially financial instruments within blending operations.

Programme for the Environment and Climate Action (LIFE)

Initiated in 1992, the LIFE Programme stands out as the sole EU fund exclusively committed to environmental and climate objectives. The Programme is positioned between EU programmes supporting research and innovation and EU programmes financing large-scale deployment of measures. Objectives are:

- support the transition to a sustainable, circular, energy-efficient, and climate-neutral economy reliant on renewable energy,
- safeguard, restore, and enhance environmental quality, encompassing air, water, and soil,
- address and reverse the decline in biodiversity and combat ecosystem degradation, including the facilitation and management of the Natura 2000 network, thereby promoting sustainable development.

Eligible actions are only those that implement the general and specific objectives of the LIFE Programme. Experience from 2014-2020 shows that the LIFE Programme does not finance research activities or large infrastructure (EUR >500 000).

Eligible entities are all legal entities established in a Member State or linked overseas countries, and any legal entity created under Union law or any international organisation. Third countries with IWT such as Switzerland, Serbia, Ukraine, Republic of Moldova, and potentially Bosnia and Herzegovina are also eligible.

Fundings are provided in any form, mainly grants, prices and procurement, as well as financial support through the utilisation of financial instruments within blending operations.

LIFE Projects directed to IWT:

- LIFE CLINSH: improve air quality near ports (finished already)

Connecting Europe Facility (CEF)

CEF is a key EU funding instrument that supports the development of high-performing, sustainable, and efficiently interconnected trans-European networks in the fields of transport, energy, and digital services. Inland waterways are among the transport modes eligible for CEF funding. The focus is on decarbonisation and making transport connected, sustainable, inclusive, safe and secure.

Eligible actions (studies, works, other accompanying measures) are those that contribute to the aim of the CEF and take into account long-term decarbonisation commitments.

Eligibility criteria meet entities established in Member States, legal entities formed under the Union law, and international organisations as specified in the work programs, as well as entities established in a third country associated with the Programme (Switzerland, Serbia, Ukraine, Republic of Moldova, and potentially Bosnia and Herzegovina).

Fundings are provided in forms of grant and procurement, and potentially blending operations (in the transport sector for actions towards smart, interoperable, sustainable, inclusive, accessible, safe and secure mobility).

CEF Funding directed to IWT:

- Flagship project Seine-Escaut (part of the TEN-T), aimed to enhance inland waterway connection between France and Belgium
- Many other projects on the Trans-European Transport Network
    - Improving navigation on the Danube
    - Enhancement of cross-border navigation with the River Information Services (RIS)
    - Sustainable and smart mobility infrastructure: upgrade of maritime ports to reduce GHG emissions from moored vessel through on-shore power supply
    - Enhancing inland waterway transport infrastructure: modernising infrastructure, and inland ports
- Every year CEF Transport grant calls are opened for projects that contribute to a good trans-European transport network, see https://www.inlandwaterwaytransport.eu/cef-funding/

Innovation Fund

The Innovation Fund is a financial instrument that aligns with the European Commission's strategic vision for achieving a climate-neutral Europe by 2050. It is financed from the revenues of the EU ETS (EU Emissions Trading System, the world's largest carbon pricing system) and is a follow up of the NER300 programme.

The objective of Innovation Fund is to (a) support projects demonstrating highly innovative technologies, processes, or products that are adequately advanced and hold significant potential for reducing greenhouse gas emissions on the one hand, and (b) provide financial assistance customised to the market needs and risk profiles of eligible projects, while attracting additional public and private resources.

Eligible actions are those fulfilling the objective. The focus of the Innovation Fund is especially on innovative low-carbon technologies in energy intensive industries, carbon capture (and utilisation/ storage) innovative renewable energy generation and energy storage.

The Innovation Fund is open for projects from the waterborne transport sector, and all legal entities established in the Member States are eligible. Assistance is extended through grants and contributions for blending operations within the framework of the Union's investment support instrument.

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From within Synergetics, signals are mixed on the accessibility of funds: some partners report this scheme as very intensive to apply and with a low chance of funding; other voices are more optimistic (compare PLATINA4Action Stage Event, 6th November 2024). The proposal of the Innovation Fund is structured in several award criteria. The scoring of these criteria is difficult to estimate as the call text of the proposal can be interpreted in different ways and is strongly dependent on the assessment of the evaluators. The application process is very resource intensive. This is difficult to manage, especially if the chances of success are difficult to assess.

European Investment Bank EIB

The EIB supports sustainable transportation activities under the European Green Deal and in its plan "Cohesion Orientation 2021 – 2027". While the EIB financing focus has been mostly on railway projects and urban mobility, financing of retrofitting within the IWT-sector and coastal shipping is within its area of responsibility. Besides the traditional lending of money, EIB can support the transition with advisory services and technical assistance for smaller transport companies. EIB applies the EU Taxonomy as technical screening criteria.

In its policy document "Transport Lending policy" (European Investment Bank 2022), the connectivity of different transport modes (within the TEN-T) with IWT and short sea shipping routes explicitly mentioned. Within the document, priorities for waterborne transportation include zero-emission ports as well as the transition to new and retrofitted zero and low-emission vessels (with the link to the Smart and Sustainable Mobility Strategy). Investment priorities are given amongst other areas to infrastructure upgrade, digitalisation and fleet renewal.

Within its traditional lending-business, viable business projects can be funded with up to 50% of the total amount and a minimum of 25 million Euro. Lower amounts can be funded via intermediary lending agreements with commercial banks. Within the waterborne sector, other services of the EIB such as mapping of grant programs for eligibility could be interesting. Requirements for such advisory services are sufficient large projects, which could e.g. be achieved by clustering ship companies with similar funding requirements and needs.

Others

Other financing instruments include TEN-T, ESIF, and Private Investment and Public-Private Partnerships

TENT-T: EU's trans-European transport network policy. The TEN-T policy is currently revised to make it greener in line with the "European Green Deal" and the "Sustainable and Smart Mobility Strategy". The objective is to complete the TEN-T core network by 2030. CEF gives fundings for projects on the Trans-European Transport Network, thus the TEN-T regulation is directly linked to the CEF as the TEN-T defines projects that are eligible under CEF.

ESIF (European Structural and Investment Fund)

JTF (Just Transition Fund): https://www.egen.green/grants/just-transition-fund/

ERDF (European Regional Development Fund): https://www.egen.green/grants/erdf/

IPCEI (Important Projects of Common European Interest): https://www.egen.green/grants/ipcei/

RFF (Recovery and Resilience Facility)

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4.2.3 Accessibility of Funding

In the CCNR study (CCNR 2022), the level of visibility and accessibility of the IWT sector for funding initiatives and financial products that support the shift towards an environmentally friendly and efficient fleet was analysed. Regarding visibility, the satisfaction was high since several projects and initiatives were evaluated for their positive impact in furnishing essential information to interested stakeholders. Accessibility on the other side can be improved.

In the European IWT sector funding and financing programs and products are generally well-known and primarily recognised through various tools like the EIBIP funding database. Overall, feedback from the sector regarding awareness, satisfaction with the current information level, and its targeted dissemination is positive. To further enhance awareness and visibility in the sector, success stories should be leveraged as tools to share knowledge and lessons learned.

Many vessel owners/ operators struggle to allocate in-house resources for project applications within existing support schemes. Some choose to collaborate with consultants, while others seek advice from regional entities or industry associations. The demands of project management and reporting also require substantial resources. Therefore, there is a pressing need for harmonisation and simplification of administrative processes to reduce time requirements. From a project engineering perspective, it is advisable for multiple applicants to join forces when engaging consultants or other service providers.

Furthermore, the sector emphasises a preference for a minimum 50% funding rate for investments in green technology. Having an initial financial contribution from the program or supportive financial institutions would also be a significant advantage for the sector.

National and Regional Funding

There are substantial differences in the level of financial support for transitioning to zero-emission IWT across different countries and regions. The Netherlands, Belgium, Luxembourg, France, Germany, Switzerland, and Austria offer numerous appealing financing opportunities for the sector. In contrast, countries such as Hungary, Romania, Slovakia, Croatia, Bulgaria, or the Czech Republic lack any financing incentives related to IWT. An overview of financial support schemes focused on greening inland waterway transport is given in Appendix 7.3.

4.3 Clean Energy Infrastructure Development

With the transition to a green inland waterway transport system, alternative energy carriers will be needed. These alternative/ clean energy carriers (e.g., H2, electricity, methanol), do not count as drop in fuels (e.g., biodiesel) and are thus not compatible with existing infrastructure and engine systems. They will need new infrastructure along waterways (waterways, locks, berths and ports).

Economic barriers and the current low demand for clean energy from vessel owners are the reason for a hindered clean energy infrastructure development. With the help of policies and incentives/ fundings the demand for clean energy can grow, giving energy suppliers the opportunity and means to invest in the required clean energy infrastructure. For this to happen, following conditions have to be met to support the transition (as part of PLATINA3 report; Deliverable 4.2) (Karaarslan 2022):

- For economies of scale, synergies with other transport modes and sectors should be built.
- Clean energy has to be competitive compared to currently used fossil fuels (in terms of prices, availability, service, flexibility). This can be facilitated by laws and regulations.
- Cumbersome regulations and permits increase the cost of clean energy even more. From previous projects lessons should be learned to be able to ease and align relevant rules and procedures.

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- Map the details and possibilities on how existing bunker infrastructure can be utilised.
- Demand for clean energy must increase significantly.

Besides the clearly needed new infrastructure for clean energies, current IWT infrastructure faces several difficulties, which will also need to be addressed (Seitz and Oganesian 2023):

- Blockages caused by insufficient water depths during low water periods and blockages due to ice are significant challenges for IWT. These issues lead to substantial economic losses and negatively impact the reliability and predictability of transportation along this waterway.
- Another critical obstacle to consider in port infrastructure is the availability of road and rail connections. In the context of IWT, the "last mile" often needs to be covered by road, rail, or a combination of both. The effectiveness of IWT can be significantly hampered by inadequate connections between ports and the broader transport network. Therefore, to promote a modal shift towards greater use of IWT, it is essential to integrate road and rail infrastructure development with port development plans and IWT infrastructure strategies, addressing the missing links in the network.
- Since in Europe IWT crosses several national borders, often regulatory and legal barriers hinder projects to be developed or slow them down. This is seen with projects like that FAST Danube project or the Seine-Scheldt link (France-Belgium).

These difficulties lead to capacity constraints and must be addressed to use the full potential of IWT.

Status quo and developments in clean energy infrastructure

There are several policies that are relevant for the development of alternative clean energy infrastructure (Karaarslan 2022):

- EU Green Deal and Sustainable and Smart Mobility Strategy (SSMS):
- The EU Green Deal sets the aim of a 90% GHG emissions reduction and a zero-pollution ambition from transport by 2050. To achieve this, the SSMS lays out the importance of a broad uptake of lower and zero-emission vessels and the development of the necessary alternative energy infrastructure (this is defined as the first flagship/action area of the strategy). The first flagship references therefore to following more binding directions of infrastructure development: Alternative Fuel Infrastructure Regulation (AFIR), TEN-T regulation and the Renewable Energy Directive (RED)
- Fit For 55:
- The Fit For 55 package was presented in 2021. It contains proposals on how the EU's climate and energy goals until 2030 and 2050 can be reached in various sectors, including IWT. Proposals that are specifically relevant for IWT are: AFIR, RED and ETD (Energy Taxation Directive Revision).
- Alternative Fuel Infrastructure Regulation (AFIR): The Alternative Fuels Infrastructure Directive (AFID) has recently been revised and remodelled to a regulation (AFIR). The AFIR advocates for national policy frameworks to include comprehensive strategies aimed at advancing clean energy (with focus on electricity and hydrogen) in sectors challenging to decarbonise, like inland waterway transport (IWT). Specifically, Member States are encouraged to devise explicit plans for decarbonising IWT within the TEN-T network, fostering collaboration with other relevant Member States. Together, AFIR and TEN-T should provide the necessary infrastructure to create a covering network for bunkering and using renewable energy (shore power, bunkering points, etc.) with interoperability.

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- Trans-European Transport Network (TEN-T) policy revision: The TEN-T regulation is an EU legal framework designed to construct an effective, EU-wide and multimodal transportation network, including inland waterways and ports. Its aim is to develop a dependable and interconnected TEN-T network that provides sustainable connectivity throughout the EU. The TEN-T should be completed by 2050 with intermediate deadlines in 2030 and 2040. Requirements for IWT are specified in Article 21. Member States must guarantee that inland ports within the comprehensive network are equipped with facilities to enhance the environmental performance of vessels by 2050. These facilities include reception and degassing facilities, noise reduction measures, as well as initiatives to mitigate air and water pollution. Additionally, Member States are mandated to deploy alternative fuels infrastructure in inland ports in accordance with AFIR regulations. Core ports must meet the same requirements by 2040.
- CCNR roadmap
- The CCNR developed a roadmap aiming at "largely" eliminating GHG emissions and air pollutions from IWT by 2050. Intermediate goals are reducing GHG emissions and air pollutants by 35% by 2035 compared to 2015 levels.

The existing energy infrastructure utilised by IWT primarily relies on bunkering facilities for fossil diesel/gasoil. The Netherlands, particularly the Rotterdam region, serves as the principal bunkering hub for IWT in Europe. Bunkering volumes in other European regions are considerably smaller, with fossil diesel being the predominant fuel. In the Netherlands, approximately 65% of fuel is delivered via bunkering boats (ship-to-ship), while the remaining 35% is supplied at bunkering stations (station-to-ship). About 100 bunker boats and 25 pontoon-based bunker stations with shops are operational, while diesel deliveries by lorry (lorry-to-ship) are negligible. In Belgium and Germany, bunkering boats account for most fuel deliveries. The bunkering infrastructure and its technical requirements to operate it in a conventional way is very fragmented across Europe. Individual components of the station are normally standardised to international standards, requirements at a national level are harmonised at a European level. However, for building the bunkering infrastructure, local organisations (landowners, permit applications) play a relevant role, and national environmental laws may be different in each country. Thus, regulations and processes related to bunkering infrastructure can vary greatly between countries.

The current bunkering infrastructure market is a relatively mature market. There is a geographical wide coverage, and normally there are large hubs with large supply volumes. Economically, the bunkering market is defined by small profit margins, requiring substantial sales volumes to make a viable business proposition. To minimise costs, bunkering of diesel is done by minimal time loss (minimal administrative costs, waiting and bunkering time). In the EU-funded CEF project LNG Breakthrough, the cost advantage of LNG over diesel was even eliminated in one of the pilot demonstrations due to the additional time required for LNG bunkering. Bunkering of LNG can be seen as an example for clean energy infrastructure for IWT. LNG is not provided by traditional bunkering infrastructure that is used for e.g., (bio)diesel, but by lorry-to-ship operations or at various locations by station-to-ship. The construction of this bunkering station in Cologne showed that clean energy infrastructure can be very complex (legal and technical challenges), time-consuming and costly. In 2022 the first permit has been given to the Dutch port of IJmuiden for bunkering hydrogen.

The current bunker infrastructure appears inadequate for delivering environmentally friendly energy sources like hydrogen and electricity, necessitating the development of new infrastructure. The existing technical specifications, permits, and procedures for constructing bunkering infrastructure, as well as the guidelines and regulations for bunkering operations, are highly fragmented. This complexity should be considered when planning the future clean energy infrastructure for inland waterway transport (IWT). Valuable insights can be gleaned from the establishment of the (limited) LNG bunkering infrastructure and the recent approval for bunkering hydrogen in the Netherlands.

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There are already quite a few projects and initiatives related to the development of clean energy infrastructure for IWT. Some are:

- H2 meets H2O
- Rhine Hydrogen Integration Network of Excellence (RH2INE)
- The MAGPIE project
- PIONEERS project
- NEEDS project
- GRIP project

Future Clean Energy Infrastructure: Outlook

TEN-T-corridors and European Member States

In PLATINA3 the four TEN-T corridors (Rhine-Alpine (RALP), North Sea-Baltic (NSB), North Sea-Mediterranean (NSM) and Rhine-Danube (RD)) were interviewed on how they see their role in clean energy infrastructure development for IWT. They see themselves as coordinators and accelerators for the energy transition and the adoption of clean energy in IWT. However, their effectiveness relies on collaboration with other stakeholders such as River Commissions and Member States. Particularly, Member States play a crucial role as they are responsible for devising their own national plans for clean energy deployment. It is essential for these plans to align across corridors, thus the corridors do play an important role. Most corridors are already actively involved in implementing clean energy infrastructure by fostering collaboration among stakeholders and coordinating efforts. Numerous relevant projects are currently underway or anticipated to start before 2030, with the corridors expected to continue their facilitating and coordinating functions (Karaarslan 2022).

To identify the position of European IWT countries towards clean energy infrastructure, they were questioned based on the CCNR energy roadmap. Outcomes were, that the more innovative energy transition pathway should be pursued, even though the conservative pathway seems more realistic. As technological solutions, batteries, H2 and HVO are the most promising to reach the climate and energy goals of 2030. Regarding clean infrastructure it is relevant to understand the development of the energy demand, and here lies also the uncertainty: most countries do not know how the energy demand will develop in their country, how fast the energy mix will change to become more sustainable, or if there is enough clean energy for IWT. Overall, the countries objectives and plans on clean IWT and infrastructure varies. Some have clear goals with funding schemes, others do not. The AFIR is supposed to change that, since it states that countries must create plans to promote alternative fuels in transportation and build the necessary infrastructure (Karaarslan 2022).

Ports and energy suppliers

Ports can be seen as logistic hubs, centres of production, utilisation and transportation of clean energy. For a clean energy infrastructure, port development is therefore crucial. In Europe, there is a total of 226 ports on inland waterways, most of them serving as an interface between different transport modes and as a regional business platform for trade and industry. In several policy instruments (SSMS, NAIADES III, Green Deal for Europe), ports play a significant role in the transition towards a clean energy infrastructure. Ports help to support achieving the zero-emission goal, green energy can be produced there, and thus serving as a clean energy promotor for vessels. In Europe there are only few alternative energy bunkering infrastructure today (LNG bunkering station in Cologne and Ruse (Bulgaria), methanol bunkering in Gothenburg). However, there are some projects aiming at an increased uptake of clean energy technology/ infrastructure (e.g., PIONEERS, MAGPIE, AFIF). But especially in the Danube region ports have an untapped potential to serve as centres for producing and distributing clean energy. Projects such PIONEERS (port of Antwerp-Bruges) or MAGPIE (port of Rotterdam) should function as a

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forerunner. Difficulties between ports are however their differences. They have different organisational, financial and governance conditions so the pathways to reach the climate goals are different and must be adapted to port traffic, hinterland conditions, industrial and energy sectors in the port area, etc. Thus, a cooperation between stakeholders is crucial. At the moment, lack of demand for clean energy is one of the main reasons why ports do not invest in clean energy infrastructure (Karaarslan 2022).

Several ports in Europe have their own strategy to become more sustainable and provide clean energy infrastructure. Port of Rotterdam will serve as the main demonstrator port in the MAGPIE project, where different projects will be tested (e.g., Ammonia bunkering, E-barges, shore power peak shaving, …). The port of Hamburg is part of the initiative "Sustainable Energy Hub Hamburg" where renewable energy companies should increasingly contribute to the handling, production, distribution and use of sustainable fuels and energy sources. Port of Gothenburg rebuilds a completely new quay to ease the transition to renewable fuels. In Switzerland the H2-Hub Switzerland was created in 2024 to establish the Basel region as Switzerland's hydrogen hub.

In all ports the focus is on providing onshore power supply (OPS) for vessels to reduce GHG emissions in ports. For that, high-voltage power transmission infrastructure and voltage transformers are necessary and must be built if not already existing. Hydrogen and ammonia both need specialised handling and storage infrastructure (e.g., reinforced storage tanks, cryogenic tanks if necessary). For safety reasons comprehensive ventilation, hazard containment, leakage detection, fire prevention and work safety systems are of crucial importance. Vessels run on battery electric propulsion need specific infrastructure elements like battery containers, high power charging stations, container lifting and handling gear, and battery management systems. For safety reasons fire prevention, training of battery movement and charging is necessary. Challenges for deployment of alternative fuels are high capital costs, fuel and bunkering uncertainty, coordination complexities and lack of space in congested ports. Special attention needs to be paid at spatial safety when building new bunkering infrastructure for alternative fuels (ESPO and EFIP 2022).

Today's energy suppliers supply mainly fossil fuels to vessel owners/operators, their infrastructure is designed almost solely for fossil fuels and alternative fuels, that can use the existing infrastructure (i.e., biodiesel). Clean energy cannot be stored or bunkered using the same infrastructure, due to technical and legal/safety reasons. Major adjustments would be necessary to adapt today's infrastructure to new, clean energies, as was also seen by the start of LNG bunkering. For both battery electric propulsion and hydrogen there are two developments that aim at easing the take up of these energies at ports. The ZES company (NL) offers a pay-per-use model of modular battery container solutions to overcome the high CAPEX and OPEX for vessel owners for battery-electric propulsion. At the moment, the slow bureaucratic procedures in establishing publicly available charging infrastructure seem to be a significant hindrance. Another threat that should be considered is congestion on the electricity grid. For hydrogen, the R2HINE initiative (GER) conducted a study that showed swappable tube-containers with pressurised hydrogen exchanged at container terminals is a good option to move forward in relation to energy infrastructure for IWT (Karaarslan 2022).

Vessel owners and operators

Diesel fuel is the most used fuel still and is of high demand. The way of bunkering is very efficient, there's high availability on short notice, high service, flexibility, and low prices. With that, route planning is not very strict, and bunkering is only planned roughly.

In general, fluid fuels are preferred from vessel operators, so handling is similar to the one of diesel. Difficult is, that it is not known yet, which alternative fuel will make the IWT market. Thus, several fuels need to be available at the beginning, however bunkering infrastructure is not made for that. Additionally, alternative fuels have a lower volumetric and gravimetric energy densities than fossil diesel, thus

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more frequent bunkering (and more infrastructure) is needed, which contradicts the current way. It is not certain, that terminal owners are willing to invest in more infrastructure to keep up the normal handling capacity of the terminal (Karaarslan 2022).

Role of Energy Suppliers

Energy suppliers can play a significant role in greening the inland waterway transports in Europe. Their roles include inter alia:

- Investing in renewable energy sources
- Offering green energy options: providing renewable energy contracts or green tariffs to incentivise operators to switch to cleaner energy sources
- Developing infrastructure for electric vessels (installing charging stations or battery-swapping stations)
- Promoting energy efficiency technologies (hybrid propulsion systems, energy management systems, lightweight materials) or offer incentives or subsidies for operator to retrofit their vessels with these technologies
- Supporting research and development
- Collaborating with government and industry partners
- Providing education and outreach

There are several projects in Europe that are linked to greening the shipping sector and that involve energy suppliers:

- H2Ports initiatives in Spain (port of Valencia): aims to implement hydrogen-powered vessels and infrastructure in ports (hydrogen mobile supply station), involve partnerships between energy companies, port authorities, and research institutions.
- Rhine-Main-Danube LNG Masterplan: ended in 2015, and involved energy companies collaborating with transport operators to promote the use of bio-LNG (liquefied natural gas) as a low-carbon fuel for inland navigation.
- Zero-Emission Services (ZES) in the Netherlands: aims to deploy battery-electric vessels for freight transport, supported by renewable energy sources and charging infrastructure provided by energy companies.
- RH2IWER: focusing on hydrogen roll-out in inland navigation (with FC system)
- FASTWATER: demonstrating pathways for methanol take-up

European Clean Hydrogen Alliance

Established in July 2020, the European Clean Hydrogen Alliance aims to support the widespread implementation of clean hydrogen technologies by 2030. It brings together renewable and low-carbon hydrogen production, industry demand, mobility, and various other sectors, along with hydrogen transmission and distribution. The goal is to promote investments and to boost clean hydrogen production and use. In order to promote investments in clean hydrogen, the European Clean Hydrogen Alliance has compiled a pipeline of feasible investment projects. Most projects cover hydrogen production and its application across various industries, the other projects focus on the energy sector, transmission and distribution and buildings and mobility. Projects in the energy sector focus on renewable hydrogen and storage, they include hydrogen production, storage and usage to balance the electricity grids.

For the purpose of the operational work, six thematic roundtables (RT) were created that reflect the activities of the entire hydrogen value chain: RT1-Renewable and low carbon Production, RT2-Transmission and Distribution, RT3-Industrial Applications, RT4-Mobility Applications, RT5-Energy Sector and RT6-Buildings. In RT1-Renewable and low carbon production, the focus is, among others, on electrolysis

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using renewable electricity (wind) and grid connected sourcing of electricity. In this roundtable several energy suppliers are members, the facilitating organisation is SolarPower Europe.

Each roundtable identified barriers and mitigation measures. For RT1-Renewable and low carbon production barriers and mitigation measures are: lack of demand (bottleneck for scaling up cost competitive hydrogen production), regulatory framework needs to be clarified (RED II, TEN-E), and administrative barriers alleviated. There is also a financial gap, for that effective support schemes have to be created (European Clean Hydrogen Alliance 2021).

European Battery Alliance (EBA250)

The European Battery Alliance was launched in 2017 to ensure safer traffic, cleaner vehicles and more sustainable technological solutions, by creating a battery cell manufacturing value chain in Europe. The annual market value is estimated at EUR 250 billion from 2025 onwards.

The industrial development program is driven by EIT InnoEnergy. Today more than 800 stakeholders are active, representing the entire battery value chain. EBA250 is a project-driven community, key objectives were defined and actions prioritised to reach the goals of EBA250:

- "Secure access to sustainably produced battery raw materials at reasonable cost.
- Make Europe the global leader in sustainable battery technology.
- Support European battery manufacturing in order not to miss the expected massive growth in market demand.
- Create and support new markets for batteries, e.g., through the "Clean Energy" & the "Mobility" packages.
- Grow Europe's R&I capacity. Develop and strengthen skilled workforces in all parts of the value chain and make Europe attractive for world-class experts.
- Involve the EU citizens in the journey: inform, educate & motivate
- Ensure maximum safety for European citizens and create a competitive advantage through standardisation"

4.4 Compilation of Market Information and Business Models

To analyse the competitive situation of businesses, SWOT analysis is a classical tool, often used in corporate planning and/or marketing contexts. This analysis focuses on internal aspects of organisations (strengths and weaknesses) as well as external factors (threats and opportunities):

Strengths:	aspects providing an advantage over others
Weaknesses:	disadvantages in relation to other businesses
Opportunities:	external aspects leading to an advantageous business environment
Threats:	external aspects potentially leading to disadvantages

Those four factors can then be combined towards developing four strategies:

- Strengths combined with opportunities
- Strengths combined with threats
- Weaknesses combined with opportunities
- Weaknesses combined with threats

This model is used to assess the current market situation within the IWT sector and to propose possible ways forward. Based on the information compiled and analysed in the previous Chapters the strengths, weaknesses, opportunities and threats as shown in Table 14 can be identified (top-down view, for the whole sector). Strengths and weaknesses refer to the businesses themselves, whereas opportunities and threat refer to the market conditions and other external factors such as policy interventions.

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Table 14: SWOT-analysis for viable business cases within the IWT-sector (Rhine and Danube region); concentrating on "greening" aspects.

	EXTERNAL: Opportunities	**EXTERNAL: Threats**
	Sector is a key means of transportation for a future-proof, sustainable (freight) mobility within Europe (cross-border) EU policy interventions in favour of IWT (e.g. CSRD, EU subsidies, energy labelling of vessels, EU taxonomy, ETS-2, RED-III) Third-party interest in financing/greening the IWT-Sector (e.g. through CSRD) Potential use of other developments: digitalisation, automation, standardisation Potential of combining energy carriers such as batteries, H2; HVO and integration of related technologies (e.g. creation of energy hubs) Cost reductions due to (expected) economies of scale Digitalisation and automation as opportunities for electric drivetrains: availability of shared data	Very strong focus on transport performance-cost ratio Changing policy conditions (EU-level, national level), leading to high risk-levels for potential investors; unclear future carbon taxation regime Fast "greening" developments within other means of transportation (rail, road) Complexity of other challenges to deal with: digitalisation, automation, climate change Parallel investments in infrastructure required
INTERNAL: Strengths Available large potential for retrofitting of existing vessels (>90% market share) due to long life-span High stability of sector and personal commitment of vessel owners Available knowledge base within industry	**Maximise opportunities** Collaboration with third parties à e.g. long-term contracts for green shipments to fulfil CSRD requirements Business models like pay-per-use bypassing high infrastructure costs Potential for monetisation of additional services; e.g. energy hubs Leverage EU competitiveness /welfare focus to promote shipbuilding activities within EU	**Leverage strength** Development of long-term financing instruments available for small businesses Strengthen regulatory policy framework to provide stability and security
INTERNAL: Weaknesses Currently no financial first-mover advantages within the market for green technologies Changing legal framework without clear long-term outlook Considerable backlog in financial investments Lack of available funding/financial incentives within the sector (small, family-owned businesses), high CAPEX Structural challenges due to lack of qualified personnel and succession processes Small financial wiggle-room for vessel-owners (scaling-up often not possible): downward competition spiral Low level of standardisation (particularly vessels) Low acceptance among the work-force for new technologies High infrastructure costs Cultural change of market needed for higher market penetration High complexity of logistics and coordination with alternative fuels Complex legal procedures for the introduction of new technologies (e.g. lengthy approval processes for hydrogen as fuel)	**Building strengths** Make best use of (available) EU funding instruments Lobbying for further instruments and financing support, focusing on stable conditions Educating the workforce on the advantages and "future-proof" concepts to create acceptance for new technologies (and according investments) Integration of carbon insetting, CO2-pricing in business models Provision of additional services within the Sector (e.g. CSRD requirements)	**Avoid and counter threats** Make best use of intermodal transportation, e.g. prepare for higher standardisation Work towards a high level of policy stability and reliability from the sector organisations

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4.4.1 Values for Developing a Viable Business Case

In the framework of Synergetics, only retrofitting solutions are considered. Defining possible starting points regarding sustainable business innovations and models can be as follows:

- Technological innovation: switch from fossil fuel towards sustainable alternatives through retrofitting of current vessels; potentially in combination with other IWT-innovations in the area of automation
- Currently incremental innovations with price aspects and insecurities in the policy area hampering the development of alternative solutions.
- Organisational innovation: given the focus on retrofitting of existing vessels, the innovation potential is limited; a radical innovation could happen through the involvement of third parties in case new, sustainably fuelled vessels are introduced as competitors into the existing market.
- Social innovation: Depending on the policy development, the remuneration models for IWT companies may see a shift towards being paid for "sustainable transportation" and not only for the transportation service itself (→ requirement for companies to lower emissions in supply chain)

Lending from the framework for business model creation (see Figure 40) and the three dimensions for sustainable business models, the following topics can be identified:

Table 15: Business Innovations and Value Chain

Business Model	**Value Proposition**	**Value Creation and Delivery**	**Value Capture**
Technological innovation	The value of sustainable transportation may in the future raise, given the policy interventions within the EU, thereby supporting the introduction of technological innovations not currently viable today	Innovations in regard to automation/digitalisation may foster the introduction of sustainable fuel alternatives (potentially more applicable to new vessels)	The pricing of external costs for emissions may lead to a level playing field of various fuels, fostering the value capture of technological innovation
Organisational Innovation	New customer segments may become part of the market, given the changing policy environment towards sustainable transportation	New collaboration with partners (third parties) may lead to new business opportunities, particularly leading to financing-models for upfront investments within the IWT sector	Business models "pay-"per-use" or "energy-as-a-service" may become more viable given new policy environments and/or new technological innovations
Social Innovation	The availability of sustainable transportation by ship may be valued as a base-level service by society and thereby be remunerated differently	The IWT-sector may provide additional value to partners along the supply-chain of goods, leading to a new revenue stream not solely focused on the transportation of good but on the reduction of emissions	

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4.4.2 Case in Points: Applied Sustainable Business Models

Product Service Systems (PPS) – Pay-per-Use

Product Service Systems are defined as integrated offers consisting of products and services. This combination can lead to innovative new and sustainable business models, improving the value proposition for customers. In the case of pay per use business models, users pay for the actual use of a service without having to buy a product or service itself thereby changing the value proposition (compare Figure 40): The customer only pays if the service is used, allowing for a higher flexibility and an increased awareness of the services needed ("use pattern) while at the same time strengthening the sharing economy. Research indicates, that the link between sustainability and pay-per-use is not always conclusive and needs to be actively developed as part of the business proposition (Bocken et al. 2018). Importantly, changing an existing business model towards a sustainable PPS often goes together with adapted use pattern focusing on sufficiency requiring a behavioural change from customers.

In the case of IWT, a pay-per use (financing) model lowers has the potential to lower CAPEX requirements for retrofitting for ship owners, allowing the faster introduction of green technologies in the sector while at the same time allowing for risk minimisation in regards of new(er) renewable technologies. The sustainability aspects are thereby mostly achieved through the changing of power train, not so much in trying to optimise/minimise tkm. Business risks associated with pay-per-use systems include higher wear and tear of products, higher maintenance costs and rapid depreciation due to intensive usage. For the business model to be successful, accurate measurement and monitoring of products and services throughout the whole life cycle used is required, e.g. through data analytics or tracking systems.

Case in Point: Zero Emission Services ZES

Synergetics partner ZES, together with its financial partner ING, developed pay per use financing services allowing ship owners to reduce CAPEX: Ship owners switching to ZES battery packs pay for the cost of the energy consumed (variable costs) as well as a rental fee for the battery container (fixed costs). The adaptation from a conventional fossil fuel power train as required by the NRMM standard for re-motorisation (to at least stage V), to a electric power train is financed by a third party financial institute.

The ZES charging stations allow for a quick exchange of battery packs within a 15 minutes timeframe, limiting the disruption time. ZES designs its charging station with open access, making it available for electric lorries and Energy Hubs (storage) for energy suppliers. The ambition of ZES is to provide power for 400 vessels by 2050 through the provision of 650 battery packs and 20 docking stations throughout 40 so called "zero emission corridors" along the inland waterway transportation in Europe.

Further information regarding the specific costs and rates are included in Work Package WP2.

Insetting

Insetting describes the practice to generate GHG emission reductions within a company's own supply chain. Insetting compares to the more commonly used "offsetting" of GHG emissions, where companies compensate their CO2 emissions unrelated to their own value chain through the use of carbon credits (often verified by third parties). Insetting has been applied as a concept since 2009 mainly in an agricultural context e.g. through agroforestry or reforestation with focus on local communities and the improvement of livelihoods (International Platform for Insetting March 2022). Insetting has been driven by the Science Based Targets Initiative including requirements for companies to reduce emissions along their value chains (Scope 3). Nowadays, Value Chain Interventions (Scope 3) in the voluntary marked are guided by principles set by companies such as "Gold Standard". According to the Insetting Platform,

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insetting typically consists of 4 phases: Scoping study, Feasibility study, Project initiation and implementation as well as operation, monitoring and certification (2021).

Within the Scope 3 Standard the quantification of Interventions, leading to emission reductions for goods and services is standardised (Gold Standard May 2021):The scope 3 standard defines emissions associated with purchased goods as follows: Emissions in a given year (E(y)) = Volume of Goods or Services Purchased x Emission Factors (EF). The concept of "Supply Shed" where sourcing comes from a group of suppliers within a geographic area to overcome the challenge of traceability of small suppliers may be applied (in case direct traceability is not applicable). For the calculations, average date, supplier specific data or a combination of both may be applied, most often, a combination of both (e.g. general assumptions, country/region specific average data combined with supplier-specific data) are used. ISO 14040 (LCA), 14044 (Environmental Management) and 14064 (GHG-accounting) provide definitions and requirements. The establishment of a baseline prior to the intervention with enough granularity is key to verify the reduction of emissions. The equation thereby reads: EF(by) = EAP(by)/P(by) where "by" stands for baseline year, EAP for the total net emissions associated with the intervention in the baseline year and P(by) for the production of the goods (or services) associated with the intervention (supplier or Supply Shed) in the baseline year. The quantification of the emissions defines as follows: EF(yn) = EAP(yn)/P(yn) where yn is any given year.

When using insetting in a business case, the carbon price is used to monetise the value of a supply chain intervention. While often more costly than offsetting activities, advantages include a risk minimisation for sustainability requirements as well as positive marketing potentials for the companies involved. Initiatives such as SBTi reject offsetting but encourage insetting activities. As insetting is a long-term activity, a strong focus on governance is required which may be achieved through insetting funds or internal carbon pricing within the companies using the concept.

Future Proof Shipping

Future Proof Shipping (FPS) as partner of the Synergetics group is a case in point for the insetting business model. FPS currently (2024) retrofits inland container vessels to be fuelled with green hydrogen. These vessels are (or will) be available for charter in their sustainable everyday business concept. To further leverage those green transportation services, FPS, together with Zero Emission Services (ZES) and 123Carbon is developing an insetting platform for the inland waterway transportation initiated by the RH2INE initiative. The goal of the insetting project is to empower cargo owners to fund carbon reduction projects within their supply chain while at the same time decoupling the emission-reductions form the physical transportation process (existing logistics operations). Within this project, the Smart Freight Centre's provides the framework separating the emission reductions from the transportation of goods. Form a technological point of view, blockchain technologies enable the traceability and accountability of the transactions.

For the development of the insetting platform, ISO guidelines and the GLEC framework are used as baselines for emissions. Emission reductions from FPS-vessels are then benchmarked against those values and reductions transferred into tokens (1 token = 1t CO2). In the future the goal is to create the pricing of those tokens retroactively, depending on actual costs (fuel, number of trips, etc.).

A key challenge for the insetting platform within the IWT sector is the implementation of policy revisions, particularly ETS and RED III. Currently, insetting is part of the voluntary emissions market – a fact that may change through the expansion of the policy framework within the EU. Given the policy changes under way, topics such as avoidance of double-counting and a clear separation between voluntary and compulsory activities need to be taken into consideration.

Further information regarding the specific costs and rates are included in Work Package WP2.

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4.5 Concluding Points on Business Models

Available and developing sustainable technologies and energy carriers make it possible to reach ambitious emission and net-zero goals stipulated by the EU "Fit-for-55" and various national policies within IWT and coastal shipping. A major challenge for the implementation within the sector is the economic viability of those technologies. Calculations from studies such as CCNR, Prominent or NEEDS reveal that it will be no easy feat to overcome current financial disadvantages in Total Cost of Ownership (TCO) for sustainable fuels. Substantial financing gaps are particularly apparent in CAPEX for the replacement of power trains on existing vessels. While funding and financing schemes are available on EU as well as on national level, lending schemes and funds typically cover no more than 40-60% of overall funds needed. Additionally, while overview platforms for available financing and funding for the sector are already in place, it seems to be challenging for small companies and individual vessel owners to have access to information providing enough details and guidelines to be of real use. Traditional lending via banks thereby still constitutes the main source of funding. Easier accessibility to information and alternative funding and financing for green technology could provide a promising path to further investments into alternative power-trains and fuels.

Besides high CAPEX, challenges include the limited availability of investors, unfavourable demographics within the industry, low levels of standardisation leading to limited upscaling potential and unclear future policy developments with potentially significant differences in national implementations. The near future will show if current policy developments, particularly CSRD / ESRS will provide enough of a trigger within the sector for ship owner and companies to retrofit existing diesel engines.

Pay-per-use or leasing schemes have the potential to overcome (some) hurdles to finance retrofit investments. Studies as well as best practice examples indicate that pay-per-use business models as for example Zero Emission Shipping (ZES) are currently more advantageous for businesses than other options such as leasing. Yet, both business models face limitations in large-scale adaptations within the industry. Joint-procurement, as further option to facilitate financing, has been deemed to be challenging to be implemented within the Rhine and Danube region by a recent CCNR-study due to (amongst several reasons) the high fragmentation of the market.

Based on those findings and learnings, one major focus of the business model's exploration within this project has been on the potential of new value propositions and the question of how a business organisation can monetise emission-reductions in this very price-sensitive market. One interesting approach is the concept of insetting, meaning that CO2-emission avoidance is calculated and sold to interested stakeholder along the supply chain. Future Proof Shipping is currently building such an insetting platform and network, sharing some interesting insights within the framework of the project. Available research indicates that behavioural aspects, culture change and knowledge-transfer may play a crucial role if such new approaches succeed in the market. A future focus should therefore be provided on such non-technological aspects.

On the side of infrastructure, current bunkering infrastructure is not suitable for supplying clean energy (except HVO) for the sector. The biggest challenge is of economic nature and is related to a lack of demand from vessel operators for clean energy. Policies and incentives, such as grants, could encourage collaborative projects to create an initial surge in demand for clean energy, especially by adopting a corridor approach. This approach will guarantee an initial uptake of clean energy large enough to attract investment from clean energy suppliers to develop the necessary infrastructure. When favourable conditions are in place, clean energy suppliers can transition more smoothly compared to individual vessel owners and invest in infrastructure once there is a prospect of a market. Several initiatives in this direction are already in place, and are supported by European policies (SSMS, EU Green Deal, TEN-T, CEF-AFIF, etc.). Another economic challenge is the current way of bunkering, which is characterised by

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high flexibility, high availability and low prices. For alternative fuels this necessary set-up of new infrastructure will be a challenge to compete with, especially in the beginning, given the importance of pricing, availability and flexibility of vessels.

The business environment within IWT and coastal shipping is highly challenging, with many uncertainties regarding the development of fuel costs, technology-paths and the policy development with its effects. Variables such as loss of cargo space, payload, availability of the necessary infrastructure or ease of refuelling/recharging will become more important to look at going forward. Discussions with industry representatives indicate that there is currently no perceived (financial) first-mover-business advantage for companies seeking to transition to sustainable fuels other than green "marketing" claims.

Other options combining business level and policy framework conditions such as "polluter pays schemes" leading to earmarked contributions for fleet-renewal and retrofitting may be interesting contributions to a faster greening of the industry. Policy developments such as ETS-2 opt-in are available to nations within the current legal framework and have the potential to accelerate the sector’s development towards zero-emission performance. Such options have been evaluated in depth in recent studies but have not been the focus of this research.

Another limitation of this research is the role of coastal shipping that has only been marginally included in this Chapter. This is due to lacking secondary data. The collection of primary data on this topic is planned for Work Package WP4 within the Synergetics project and will be of high relevance.

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5 Conclusion and Outlook

From a systemic perspective, the environmental performance of coastal and inland shipping can be improved by three options (descending priorities): avoid (reduce overall amount of shipping), shift (road to shipping/rail and shipping to rail) and improve (particularly by retrofitting of existing vessels).

All energy sources must be fully renewable. For example, if electricity from the EU-grid is used, the greenhouse gas emissions increase more than tenfold. Similarly, all energy sources must be additional to minimise the risk of burden-shifting. For example, if PV electricity from Morocco is not additional, the resulting domestic energy deficit is likely to be compensated by coal (today's main energy source).

Bio-based energy carriers (biofuels) are likely only to play a minor role in the greening efforts of the European coastal and inland shipping since the biomass capacities are (strongly) limited by nature itself. Indeed, the biomass potential for producing sustainable biofuels does not even cover today's demand. Biofuels might however be applied for specific regions where infrastructure for e-fuels is difficult to implement. They might as well be used as an add-on for e-fuels to reduce the effect of production fluctuations and/or the necessity of larger interim storage capacities. They can also be relevant for the early years of the transition phase from fossil to renewable energy carriers. However, lock-in effects must be avoided, e.g. relying on HVO slows down targeted measures to develop scalable alternatives.

The current electricity production capacities are not sufficient to power the European coastal and inland shipping. Hence, decisive action is needed to expand the current capacities as using electricity from the EU-grid is not an option (see above). In contrast to biofuels, an expansion of these capacities is not limited by nature. It might however be limited by influences such as political coherence on national and trans-national level or behavioural influences (e.g. by the not-in-my-backyard attitude).

There will not be zero emissions for any of the energy carriers neither in the near-term future nor in the long-term future as there will always remain upstream emissions (e.g. from the production of wind turbines and photovoltaic panels). This emphasises the relevance of avoiding the use of energy where possible.

For the renewable electricity used, the reduction of emissions from the electricity production has the highest influence on the overall results. In direct comparison, using large amounts of PV electricity from MENA significantly increases the emissions compared to wind electricity in all paths investigated. Further hotspots along the supply chain are electrolysers for the e-hydrogen paths, direct air capture and methanol synthesis plants for e-methanol paths as well as energy storages for battery-electric paths. This is partly an issue of the transport mode (large batteries are needed for reasonable sailing ranges) and partly an issue of the overall energy system (interim storage will be needed for any kind of renewable electricity usage).

The transportation of renewable energy carriers has little impact on the global warming potential of the corresponding overall supply chain. Hence, there is not a significant increase in the total emissions level if vessels are charged/fuelled decentralised.

Regarding the global warming potential, there will be a shift from Tank-to-Wake emissions (today) to Well-to-Tank emissions (future) as more and more renewable energy carriers are used. Meaning, well-chosen supply paths ("today's decisions") become even more important in the future.

From a Well-to-Wake perspective and excluding operational boundaries (e.g., time loss), battery-electric paths and e-hydrogen paths show the lowest global warming potentials as well as the lowest costs. Regarding the nitrogen oxide emissions and the particulate matter emissions, the battery-electric paths outperform the e-hydrogen paths by a factor of more than ten. E-methanol paths perform worst on all indicators (even with the best path). Thus, extra care is needed if e-methanol paths are chosen.

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A major advantage of battery-electric and e-hydrogen paths is that no carbons need to be included in the value chain. However, some restrictions must be noted: Not all paths lead to these low levels of greenhouse gas emissions. Some paths can show as high emissions as the best e-methanol paths. In addition, drawbacks for on-board storages are higher than for e-methanol (required space, regulations, fuelling times, sailing range restrictions, etc.). Likewise, infrastructure development appears to be more challenging than for e-methanol and the competition with other sectors and utilisation requirements might be higher.

The efficiencies of the propulsion system have a large impact on the Well-to-Wake emissions as these losses lead to "further losses" along the whole upstream supply chain. In general, energy losses in later parts of the value chain have a greater impact than those before. Battery-electric system clearly outperform all other propulsion systems with an efficiency of 90% (compared to 38%).

The emissions and costs can be further reduced by a more sustainable "upstream" production. For example: Wind turbines and photovoltaic panels can be produced using renewable energy – either by using renewable energy in China (today's main production country) or by shifting the whole production to Europe (and then use renewable energy too).

Assuming a constant energy demand of the European inland shipping, at least 52% of all vessels must be retrofitted to meet a hypothetical greenhouse gas emissions reduction target of 50% until the year 2050 (path with lowest emissions). This number indicates the urgence of acting/retrofitting now. A similar minimum retrofit share can be assumed for the European coastal shipping.

From the business point of view, the landscape is currently shifting fast. Various new and adapted EU and national policies are implemented, furthering zero-emission projects or on a more aggregated level "green" transportation (compare as well D1.3 on recommendations for harmonisation between ETS-2 and RED-III). On the one hand, those development favour the emergence of new businesses, new business models and new main players such as energy service providers. On the other hand, the changing policy environment leads to insecurity for ship owners and (future) investors, potentially leading to a "wait and see" attitude without clearly visible financial first-mover advantages. Emerging business cases utilising both, the regulatory framework as well as new forms of conducting business show possible paths for viable business cases in the future. Case in points are ZES with a pay-per-use solution or Future Proof Shipping with the concept of insetting.

However, structural challenges within the sector and the lack of monetisation of carbon emission reductions hinder a faster advancement of low-emission technologies within the existing fleet of waterborne transportation. While current literature on inland shipping and particularly the Rhine is extensive, some critical gaps in available data were identified during this explorative part of the project: updated information on cost data seems to be crucial (e.g. accurate financing gap for retrofitting with alternative technologies, costs for setting-up new infrastructure); the role of non-EU countries and stakeholders for the Danube-region should be put under further consideration and the sector of coastal shipping requires more focus.

The insights of this report on the suitability of identified technical solutions shall provide valuable input for the tools which are developed in the SYNERGETICS project. Further research is needed for an in-depth assessment of storages (limited data available) as well as of Tank-to-Wake costs and of further impacts of the energy carrier paths (outside the scope of this report).

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6 Bibliography

Aagaard, Annabeth (2019): Sustainable Business Models. Cham: Springer International Publishing.

Al Enezy, Osama; van Hassel, Edwin; Sys, Christa; Vanelslander, Thierry (2017): Developing a cost calculation model for inland navigation. In *Research in Transportation Business & Management* 23 (23), pp. 64–74. DOI: 10.1016/j.rtbm.2017.02.006.

Al-Breiki, Mohammed; Bicer, Yusuf (2020): Technical assessment of liquefied natural gas, ammonia and methanol for overseas energy transport based on energy and exergy analyses. Edited by International Journal of Hydrogen Energy (45 (2020) 34927-34937, 60).

Allekotte, Michel; Althaus, Hans-Jörg; Bergk, Fabian; Biemann, Kirsten; Knörr, Wolfram; Sutter, Daniel (2021): Umweltfreundlich mobil! Ein ökologischer Verkehrsartenvergleich für den Personen- und Güterverkehr in Deutschland. Edited by Umweltbundesamt. Institut für Energie- und Umweltforschung (Ifeu); INFRAS; Öko-Institut e.V. Dessau-Rosslau.

Allekotte, Michel; Bergk, Fabian; Biemann, Kirsten; Deregowski, Carolin; Knörr, Wolfram; Althaus, Hans-Jörg et al. (2020): Ökologische Bewertung von Verkehrsarten. Edited by Umweltbundesamt. Institut für Energie- und Umweltforschung (Ifeu); INFRAS; Öko-Institut e.V. Dessau-Rosslau.

Allekotte, Michel; Biemann, Kirsten; Colson, Marie; Heidt, Christoph; Kräck, Jan; Knörr, Wolfram (2024): Aktualisierung TREMOD/TREMOD-MM und Ermittlung der Emissionsdaten des Verkehrs nach KSG im Jahr 2023. Edited by Umweltbundesamt. Institut für Energie- und Umweltforschung (Ifeu). Dessau-Rosslau.

Anthes, Ralph; Notter, Benedikt; Biemann, Kirsten; Dobers, Kerstin (2022): Environmental Methodology and Data: Update 2022. Edited by EcoTransIT World. Hannover.

Biemann, Kirsten; Helms, Hinrich; Münter, Daniel; Liebich, Axel; Pelzeter, Julia; Kämper, Claudia; Müller, Johannes (2024): Analyse der Umweltbilanz von Kraftfahrzeugen mit alternativen Antrieben oder Kraftstoffen auf dem Weg zu einem treibhausgasneutralen Verkehres Forschungsberichts. Edited by Umweltbundesamt. Dessau-Rosslau.

Bionaz, David; Marocco, Paolo; Ferrero, Domenico; Sundseth, Kyrre; Santarelli, Massimo (2022): Life cycle environmental analysis of a hydrogen-based energy storage system for remote applications. In *Energy Reports* 8, pp. 5080–5092. DOI: 10.1016/j.egyr.2022.03.181.

BL2F (2024): Black liquor to fuel. A new, clean fuel for aviation and shipping. Edited by BL2F. Available online at https://www.bl2f.eu/, checked on 08/10/2024.

Bocken, Nancy M.P.; Mugge, Ruth; Bom, Colin A.; Lemstra, Hidde-Jan (2018): Pay-per-use business models as a driver for sustainable consumption: Evidence from the case of HOMIE. In *Journal of Cleaner Production* 198, pp. 498–510. DOI: 10.1016/j.jclepro.2018.07.043.

Braun, Josua; Kern, Jürgen; Scholz, Yvonne; Hu, Wenxuan; Moser, Massimo; Schillings, Christoph et al. (2022): Technische und risikobewertete Kosten-Potenzial-Analyse der MENA-Region. MENA-Fuels: Teilbericht 10. Edited by Deutsches Zentrum für Luft- und Raumfahrt (DLR), Wuppertal Institut. Wuppertal, Stuttgart, Saarbrücken.

Brown, Adam; Waldheim, Lars; Landälv, Ingvar; Saddler, Jack; Ebadian, Mahmood; McMillan, James et al. (2020): Advanced Biofuels – Potential for Cost Reduction. Edited by IEA Bioenergy.

Budde Christensen, Thomas; Wells, Peter; Cipcigan, Liana (2012): Can innovative business models overcome resistance to electric vehicles? Better Place and battery electric cars in Denmark. In *Energy Policy* 48, pp. 498–505. DOI: 10.1016/j.enpol.2012.05.054.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

Bundesnetzagentur (2022): Genehmigung des Szenariorahmens 2023-2037/2045. Edited by Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen. Bonn.

Carvalho, Francielle; O'Malley, Jane; Osipova, Liudmila; Pavlenko, Nikita (2023): Key Issues in LCA Methodology for Marine Fuels. Edited by International Council on Clean Transportation (ICCT). Washington.

CCNR (2018): Mannheim Declaration "150 years of the Mannheim Act – the driving force behind dynamic Rhine and inland navigation". Edited by Central Commission for the Navigation of the Rhine (CCNR). Strasbourg.

CCNR (2022): CCNR Roadmap for reducing inland navigation emissions. Edited by Central Commission for the Navigation of the Rhine (CCNR). Strasbourg.

CCNR (2023a): Annual Report 2023. Inland Navigation in Europe: Market Observation. Edited by Central Commission for the Navigation of the Rhine (CCNR). Strasbourg.

CCNR (2023b): Mannheim Declaration: "150 years of the Mannheim Act – the driving force behind dynamic Rhine and inland navigation". Report on progress, 6 December 2023. Edited by Central Commission for the Navigation of the Rhine (CCNR). Strasbourg.

ChemAnalyst (Ed.) (2024): Europe Methanol Market Analysis. Available online at https://www.chemanalyst.com/industry-report/europe-methanol-market-215, checked on 02/12/2024.

Clean Hydrogen Joint Undertaking (2022): Strategic Research and Innovation Agenda 2021 - 2027. Annex to GB decision no. CleanHydrogen-GB-2022-02. Edited by Clean Hydrogen Joint Undertaking. Brussels.

Cole, Wesley; Karmakar, Akash (2023): Cost Projections for Utility-Scale Battery Storage: 2023 Update. Edited by National Renewable Energy Laboratory (NREL). Golden.

Crenna, Eleonora; Gauch, Marcel; Widmer, Rolf; Wäger, Patrick; Hischier, Roland (2021): Towards more flexibility and transparency in life cycle inventories for Lithium-ion batteries. In *Resources, Conservation and Recycling* 170, p. 105619. DOI: 10.1016/j.resconrec.2021.105619.

Dahlke-Wallat, Friederike; Friedhoff, Benjamin; Jasa, Justin; Grasman, Alex; Ramne, Bengt; Kreukniet, Niels; Kalisch, Thilo (2024): SYNERGETICS D1.1 - Relevant Identified Technical Solutions.

Dahlke-Wallat, Friederike; Friedhoff, Benjamin; Karaarslan, Salih; Martens, Sophie; Quispel, Martin (2021): Study on Financing the energy transition towards a zero-emission European IWT sector. "Assessment of technologies in view of zero-emission IWT" - Edition 2. Edited by Central Commission for the Navigation of the Rhine (CCNR). Strasbourg.

Dai, Qiang; Kelly, Jarod C.; Gaines, Linda; Wang, Michael (2019): Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications. In *Batteries* 5 (2), p. 48. DOI: 10.3390/batteries5020048.

DIN DIN EN 16603-11:2020-02, 2013: DIN EN 16603-11:2020-02 Raumfahrttechnik - Definition des Technologie-Reifegrades (TRL) und der Beurteilungskriterien (ISO 16290:2013, modifiziert); Deutsche Fassung EN 16603-11:2019.

Ecorys (2018): D6.3 Business economic and financing options for greening innovations in IWT D6.3 Business economic and financing options for greening innovations in IWT D6.5 Financial impact of Greening IWT for Europe. Edited by PROMINENT.

EMBER (2024): European Clean Power Pathways Explorer. Available online at https://ember-climate.org/data/data-tools/european-clean-power-pathways-explorer/, checked on 04/09/2024.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

ESPO; EFIP (2022): The new energy landscape. Impact on and implications for European ports. European Sea Ports Organisation (ESPO); European Federation of Inland Ports (EFIP).

EUI; Serafimova, T.; Finger, M. (2019): Internalising the external costs of transport: European University Institute (EUI).

European Clean Hydrogen Alliance (2021): The European Clean Hydrogen Alliance Reports of the Alliance Roundtables on Barriers and Mitigation Measures. Edited by European Clean Hydrogen Alliance.

European Commission (09/12/2020): COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Sustainable and Smart Mobility Strategy – putting European transport on track for the future.

European Commission (2021): Sustainable & Smart Mobility Strategy. Putting European transport on track for the future. Edited by European Commission. Available online at https://transport.ec.europa.eu/system/files/2021-04/2021-mobility-strategy-and-action-plan.pdf, checked on 09/09/2024.

European Commission (24/06/2021): COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. NAIADES III.

European Commission (2024a): Mobility and Transport. Inland Waterways. Edited by European Commission. Brussels. Available online at https://transport.ec.europa.eu/transport-modes/inland-waterways_en, checked on 02/12/2024.

European Commission (2024b): Monitoring, reporting and verification of EU ETS emissions. Edited by European Commission. Available online at https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/monitoring-reporting-and-verification-eu-ets-emissions_en, checked on 20/11/2024.

European Commission; Directorate-General for mobility and transport (2023): Impact assessment of Directive 2005/35/EC on ship-source pollution – Executive summary: Publications Office of the European Union.

European Commission; Directorate-General for mobility and transport; Wijngaarden, L.; Schroten, A.; Essen, H.; Sutter, D.; Andrew, E. (2019): Sustainable transport infrastructure charging and internalisation of transport externalities – Executive summary: Publications Office.

European Investment Bank (2022): Transport Lending Policy 2022: The Way Forward. Edited by European Investment Bank. Luxembourg.

European Parliament and Council (14/12/2022): DIRECTIVE (EU) 2022/2464. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022L2464, checked on 09/09/2024.

European Union (16/09/2016): REGULATION (EU) 2016/ 1628 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 14 September 2016 - on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/ 2012 and (EU) No 167/ 2013, and amending and repealing Directive 97/ 68/ EC.

European Union (21/12/2018): DIRECTIVE (EU) 2018/ 2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 11 December 2018 - on the promotion of the use of energy from renewable sources. RED II.

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Funded by the Swiss State Secretariat for Education, Research and Innovation

European Union (27/06/2022): Regulations (Non-legislative acts): COMMISSION IMPLEMENTING REGULATION (EU) 2022/996 of 14 June 2022 on rules to verify sustainability and greenhouse gas emissions saving criteria and low indirect land- use change-risk criteria.

European Union (01/10/2023): Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. RED III.

European Union (21/11/2023): Commission Delegated Regulation (EU) 2023/2485 of 27 June 2023 amending Delegated Regulation (EU) 2021/2139 establishing additional technical screening criteria for determining the conditions under which certain economic activities qualify as contributing substantially to climate change mitigation or climate change adaptation and for determining whether those activities cause no significant harm to any of the other environmental objectives.

European Union (11/04/2024): Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020Text with EEA relevance.

Fasihi, Mahdi; Efimova, Olga; Breyer, Christian (2019): Techno-economic assessment of CO2 direct air capture plants. Edited by Journal of Cleaner Production (224 (2019) 957-980).

FfE (2022): Wasserstofftransportoptionen. Edited by Forschungsstelle für Energiewirtschaft (FfE). Munich.

Food and Agriculture Organization of the United Nations (Ed.) (2024): FAOSTAT. Available online at https://www.fao.org/faostat/en/#data/BE, checked on 12/12/2024.

Fortune Business Insights (2024): Glycerin-Marktgröße, Anteil und Branchenanalyse, nach Qualität (USP-Qualität und technische Qualität), nach Anwendung (Körperpflege, Lebensmittel und Getränke, Pharmazeutika, Polyetherpolyole, chemische Zwischenprodukte, Tabak und andere) und regionale Prognose, 2024 – 2032. Edited by Fortune Business Insights. Available online at https://www.fortunebusinessinsights.com/de/glyzerinmarkt-102168, checked on 04/11/2024.

Fraile, Daniel; Vandenberghe, Alexander; Klonari, Vasiliki; Ramirez, Lizet; Pineda, Ivan; Tardieu, Pierre et al. (2021): Getting fit for 55 and set for 2050. Electrifying Europe with wind energy. Edited by European Technology and Innovation Platform on Wind Energy (ETIP Wind), WindEurope.

Frank, Edward D.; Elgowainy, Amgad; Reddi, Krishna; Bafana, Adarsh (2021): Life-cycle analysis of greenhouse gas emissions from hydrogen delivery: A cost-guided analysis. Edited by International Journal of Hydrogen Energy (46 (2021) 22670-22683).

García-Muiña, Fernando E.; Medina-Salgado, María Sonia; Ferrari, Anna Maria; Cucchi, Marco (2020): Sustainability Transition in Industry 4.0 and Smart Manufacturing with the Triple-Layered Business Model Canvas. In *Sustainability* 12 (6), p. 2364. DOI: 10.3390/su12062364.

Gielen, Dolf; Dolan, Greg; Kang, Seungwoo; Boshell, Francisco; Goeppert, Alain; Prakash, Surya G. et al. (2021): Innovation Outlook: Renewable Methanol. International Renewable Energy Agency (IRENA); Methanol Institute. Abu Dhabi.

Gold Standard (2021): Value Chain (Scope 3) Interventions - Greenhouse Gas Accounting & Reporting Guidance. Version 1.1. Value Change. Available online at https://goldstandard.cdn.prismic.io/goldstandard/value_change_scope3_guidance-v.1.1.pdf, checked on 02/10/2024.

Guerra, Carlos Fúnez; Reyes-Bozo, Lorenzo; Vyhmeister, Eduardo; Salazar, José Luis; Caparrós, María Jaén; Clemente-Jul, Carmen (2021): Sustainability of hydrogen refuelling stations for trains using electrolysers. In *International Journal of Hydrogen Energy* 46 (26), pp. 13748–13759. DOI: 10.1016/j.ijhydene.2020.10.044.

Hamelin, Lorie; Borzęcka, Magdalena; Kozak, Małgorzata; Pudełko, Rafał (2019): A spatial approach to bioeconomy_ Quantifying the residual biomass potential in the EU-27. In *Renewable and Sustainable Energy Reviews* 100.

Hank, Christoph; Sternberg, André; Köppel, Nikolas; Holst, Marius; Smolinka, Tom; Schaadt, Achim et al. (2020): Energy efficiency and economic assessment of imported energy carriers based on renewable electricity. 4, 2256. Edited by Sustainable Energy Fuels (5).

Harmsen, Jorrit; t' Hart, Pieter (2021): Green Maritime Methanol. Towards a zero emissions shipping industry. Edited by Green Maritime Methanol project. TKI Maritime and the Netherlands Ministry of Economic Affairs.

Hassan, I. A.; Ramadan, Haitham S.; Saleh, Mohamed A.; Hissel, Daniel (2021): Hydrogen storage technologies for stationary and mobile applications: Review, analysis and perspectives. In *Renewable and Sustainable Energy Reviews* 149, p. 111311. DOI: 10.1016/j.rser.2021.111311.

Hengstler, Jasmin; Russ, Manfred; Stoffregen, Alexander; Hendrich, Aline; Weidner, Simone; Held, Michael; Briem, Ann-Kathrin (2021): Aktualisierung und Bewertung der Ökobilanzen von Windenergie- und Photovoltaikanlagen unter Berücksichtigung aktueller Technologieentwicklungen. Edited by Umweltbundesamt. Dessau-Rosslau.

Hoyer, Katja (2017): Deliverable 2.1 - Detailed requirements. T2.1 - Determining detailed requirements for the baseline logistics model. Edited by Novimar.

Hren, Robert; Vujanović, Annamaria; van Fan, Yee; Klemeš, Jiří Jaromír; Krajnc, Damjan; Čuček, Lidija (2023): Hydrogen production, storage and transport for renewable energy and chemicals: An environmental footprint assessment. In *Renewable and Sustainable Energy Reviews* 173, p. 113113. DOI: 10.1016/j.rser.2022.113113.

Icha, Petra; Lauf, Thomas; Kuhs, Gunter (2023): Entwicklung der spezifischen Treibhausgas-Emissionen des deutschen Strommix in den Jahren 1990 - 2022. Edited by Umweltbundesamt. Dessau-Rosslau.

IEA (2024a): Electricity 2024 - Analysis and forecast to 2026. Edited by International Energy Agency (IEA).

IEA (2024b): Morocco Renewable Energy Target 2030. Edited by International Energy Agency (IEA). Available online at https://www.iea.org/policies/6557-morocco-renewable-energy-target-2030, checked on 20/11/2024.

IEA (2024c): Morocco: Electricity. Sources of electricity generation. Edited by International Energy Agency (IEA). Available online at https://www.iea.org/countries/morocco/electricity, checked on 20/11/2024.

IINAS (2023): GEMIS v5.1. Globales Emissions-Modell integrierter Systeme. Edited by International Institute for Sustainability Analysis and Strategy (IINAS). Darmstadt.

International Platform for Insetting (2022): A practical guide to insetting. 10 lessons learnt and 5 opportunities to scale from a decade of coporate insetting practice. Edited by Sandra Brandt, Tilmann Silber.

IRENA (2022): Green hydrogen for industry: A guide to policy making. Edited by International Renewable Energy Agency (IRENA). Abu Dhabi.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
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Funded by the Swiss State Secretariat for Education, Research and Innovation

IRENA (2024): Renewable Energy Statistics 2024. Edited by International Renewable Energy Agency (IRENA). Abu Dhabi.

Jacobs, Karin (2022): Inland waterway transport in the EU. Edited by European Parliamentary Reserarch Service.

Jöhrens, Julius; Allekotte, Michel; Heining, Florian; Helms, Hinrich; Räder, Dominik; Köllermeier, Nadine; Wassmuth, Volker (2022): Vergleichende Analyse der Potentiale von Antriebstechnologien für Lkw im Zeithorizont 2030. Teilbericht im Rahmen des Vorhabens „Elektrifizierungspotential des Güter- und Busverkehrs - My eRoads". Edited by P. Transport ConsultT.V. ifeu. Heidelberg, Karlsruhe.

Karaarslan, Salih (2022): D4.2 Report on findings, perspectives and recommendations on clean energy along waterways and ports. PLATINA3 IWT policy platform - infrastructure. With assistance of Niels Kreukniet, Virginia Oganesian, Dejan Trifunovic, Kai Kempmann, Michelangelo De Lisi, Ruxandra Matzalik Florescu et al. Edited by PLATINA3.

Karaarslan, Salih; Quispel, Martin (2021): Study on Financing the energy transition towards a zero-emission Eurpen IWT sector. Final overiew study report. Edited by CCNR. Rotterdam.

KBOB (2024): Liste der Ökobilanzdaten im Baubereich (2009/1:2022, Version 6). Edited by Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren (KBOB). Bern.

Khandelwal, Mehul; van Dril, Ton (2020): Decarbonisation options for the Dutch biofuels industry. PBL Netherlands Environmental Assessment Agency; TNO. The Hague.

Kistner, Lukas; Bensmann, Astrid; Hanke-Rauschenbach, Richard (2024): Potentials and limitations of battery-electric container ship propulsion systems. In *Energy Conversion and Management: X* 21, p. 100507. DOI: 10.1016/j.ecmx.2023.100507.

Klinger, Anna-Lena Klingler; Zimmermann, Felix; Dörr, Julian; Stöhr, Timo; Reichert, Andreas; Christian, Sven; Göhler, Georg (2024): Wasserstoffspeicher für dezentrale Energiesysteme. Edited by Fraunhofer IAO. Heilbronn.

Kortsari, Annie; Mitropoulos, Lambros; Heinemann, Trine; Mikkelsen, Henrik Hagbarth (2020): E-Ferry Project. D7.5 Final validation and evaluation report. Edited by ARO, CERTH, Marnav. Aeroskoebing.

Kramer, Ulrich; Bothe, David; Gatzen, Christoph; Reger, Maximiliane; Lothmann, Marion; Dünnebeil, Frank et al. (2021): Future Fuels: FVV Fuels Study IV. Transformation of Mobility to the GHG-neutral Post-fossil Age. Edited by FVV Forschungsvereinigung Verbrennungskraftmaschinen e.V. Frankfurt am Main.

Kreidelmeyer, Sven; Dambeck, Hans; Kirchner, Almut; Wünsch, Marco (2020): Kosten und Transformationspfade für strombasierte Energieträger. Edited by Prognos AG. Basel.

Kreidelmeyer, Sven; Trachsel, Tim; Mendelevitch, Roman; Wissner, Nora; Sutter, Jürgen; Friedrichsen, Nele; Bunnenberg, Lennart (2023): Systemischer Vergleich verschiedener Wasserstofftransportrouten. Edited by Prognos AG, Öko-Institut e.V., IREES GmbH. Basel, Berlin, Karlsruhe.

Kriedel, Norbert; Roux, Laure; Zarkou, Athanasia; Fahrner, Lucie; Meissner, Sarah (2022a): Market Insight Inland Navigation in Europe. Edited by Central Commission for the Navigation of the Rhine (CCNR). Strasbourg.

Kriedel, Norbert; Roux, Laure; Zarkou, Athanasia; Fahrner, Lucie; Meissner, Sarah; Pelagatti, Denise (2022b): Inland Navigation in Europe - Market Observation: Annual Report 2022. Edited by Central Commission for the Navigation of the Rhine (CCNR). Strasbourg.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

Kuzma, Samantha; Bierkens, Marc F.P.; Lakshman, Shivani; Luo, Tianyi; Saccoccia, Liz; Sutanudjaja, Edwin H.; van Beek, Rens (2023): Aqueduct 4.0: Updated decision-relevant global water risk indicators. Edited by World Resources Institute. Washington.

Lauf, Thomas; Memmler, Michael; Schneider, Sven (2023): Emissionsbilanz erneuerbarer Energieträger. Bestimmung der vermiedenen Emissionen im Jahr 2022. Edited by Umweltbundesamt. Dessau-Rosslau.

Laursen, R.; Barcarolo, D.; Patel, H.; Dowling, M.; Penfold, M.; Faber, J. et al. (2022): EMSA: Update on potential of biofuels for shipping, American Bureau of Shipping, CE Delft and Arcsilea 2022.

Lee, Hoesung; Romero, José (2023): Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by Intergovernmental Panel on Climate Change (IPCC). Geneva.

Liebich, Axel; Fröhlich, Thomas; Münter, Daniel; Fehrenbach, Horst; Giegrich, Jürgen; Susanne, Köppen et al. (2021): System comparison of storable energy carriers from renewable energies. Edited by German Environment Agency. Institut für Energie- und Umweltforschung (Ifeu); Deutsches Zentrum für Luft- und Raumfahrt (DLR); JOANNEUM RESEARCH Forschungsanstalt. Dessau-Rosslau.

Linde (2022): Tomorrow's fuel today. Linde H2 refueling technologies. Edited by Linde. Pullach.

Lu, Chunxia; Yan, Xiaowen (2015): The break-even distance of road and inland waterway freight transportation systems. In *Marit Econ Logist* 17 (2), pp. 246–263. DOI: 10.1057/mel.2014.14.

Mendelevitch, Roman; Heinemann, Christoph; Krieger, Susanne; Dünzen, Kaya; Göckeler, Katharina; Haller, Markus; Winger, Christian (2023): PTX Business Opportunity Analyser (BOA): Data Documentation. Edited by Öko-Institut e.V. Freiburg, Berlin.

Motola, V.; Hurtig, O.; Scarlat, N.; Buffi, M.; Georgakaki, A.; Letout, S.; Mountraki, A. (2023): Clean Energy Technology Observatory: Advanced biofuels in the European Union - 2023 Status Report on Technology Development, Trends, Value Chains and Markets. Luxembourg: Publications Office of the European Union.

Mucci, Simone; Mitsos, Alexander; Bongartz, Dominik (2023): Cost-optimal Power-to-Methanol: Flexible operation or intermediate storage? In *Journal of Energy Storage* 72, p. 108614. DOI: 10.1016/j.est.2023.108614.

NHOA Energy (2024): Environmental Product Declaration PowerIsland #3. Edited by NHOA Energy. Milano.

NREL (2024): Utility-Scale Battery Storage. Edited by National Renewable Energy Laboratory (NREL). Available online at https://atb.nrel.gov/electricity/2024/utility-scale_battery_storage, checked on 25/11/2024.

Ortiz Cebolla, R.; Dolci, F.; Weidner, E. (2022): Assessment of Hydrogen Delivery Options. Feasibility of Transport of Green Hydrogen within Europe. Edited by European Commission. Brussels.

Osterwalder, Alexander (2010): Business model generation: a handbook for visionaries, game changers, and challengers: John Wiley & Sons.

Owen, John R.; Kemp, Deanna; Lechner, Alex M.; Harris, Jill; Zhang, Ruilian; Lèbre, Éléonore (2023): Energy transition minerals and their intersection with land-connected peoples. In *Nat Sustain* 6 (2), pp. 203–211. DOI: 10.1038/s41893-022-00994-6.

Pais, Ivana; Provasi, Giancarlo (2021): Share vs Platform Economy. 217-226 Pages / Sociologica, Vol. 14 No. 3 (2020): Power and Control in Platform Monopoly Capitalism. DOI: 10.6092/issn.1971-8853/11540.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

PLATINA3 (2023): D.1.4 Report on economic barriers to modal shift: challenges & best practices, recommendations. With assistance of Janeta Toma. Horizon 2020 Programme of the EU.

Pringuey, Jean-Nicolas (2021): Etude sur le financement de la transition énergetique pour une navigation intérieure zéro émission. Question de recherche B - Quels sont les enseignements pouvant être tirés des autres modes de transport? Edited by Cerema. CCNR.

Radojčić, Dejan; Simić, Aleksandar; Momčilović, Nikola; Motok, Milorad; Friedhoff, Benjamin (2021): Design of Contemporary Inland Waterway Vessels. The Case of the Danube River. Cham: Springer International Publishing.

Ramasamy, Vignesh; Zuboy, Jarett; O'Shaughnessy, Eric; Feldman, David; Desai, Jal; Woodhouse, Michael et al. (2022): U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022. Edited by National Renewable Energy Laboratory (NREL). Golden.

Riemer, Matia; Wachsmuth, Jakob; Pfluger, Benjamin; Oberle, Stella (2022): Welche Treibhausgasemissionen verursacht die Wasserstoffproduktion? Edited by Umweltbundesamt. Dessau-Rosslau.

Rijksoverheid (2024): Aanpak stikstofuitstoot verminderen. Available online at https://www.rijksoverheid.nl/onderwerpen/aanpak-stikstof-natuur-water-en-klimaat/aanpak-stikstofuitstoot-verminderen, checked on 18/11/2024.

Röck, M.; Martin, R.; Hausberger, S. (2020): JEC Tank-To-Wheels report v5: Heavy duty vehicles. EUR 30271 EN. With assistance of P. Hanarp, C. Bersia, M. Colombano, H. Gräser, G. Gomes Marques, H. Mikaelsson et al. Edited by Publications Office of the European Union. Luxembourg.

Roux, Laure (2022): Funding and financing the energy transition of the European IWT fleet. D2.5. Edited by PLATINA3. CCNR.

Ruiz, Pablo; Sgobbi, Alessandra; Wouter, Nijs; Thiel, Christian; Dalla Longa, Francesco; Kober, Tom et al. (2015): The JRC-EU-TIMES model. Bioenergy potentials for EU and neighbouring countries. In *European Commission: JRC Science for Policy Report*. DOI: 10.2790/39014.

Ryste, Jon Anders (2019): Comparison of Alternative Marine Fuels. Edited by DNV. Høvik.

Saravia, Florencia; Gehrmann, Stefan; Schwarz, Stefanie; Koch, Marie-Ann (2024): Gesamtwasserbedarf für die Wasserelektrolyse. Wie groß ist der Wasserfußabdruck einschließlich der Kühlsysteme? In *Factsheet DVGW Deutscher Verein des Gas- und Wasserfaches e.V.*

Schick, Christoph; Brand, Heike; Münkel, Annika; Scheben, Heike; Wiesmeth, Michael; Blesl, Markus et al. (2018): Energiesystemanalyse Baden-Württemberg. Edited by Forschungsverbund STRise - Stuttgart Research Initiative on Integrated Systems Analysis for Energy. Stuttgart.

Schuller, Oliver; Kupferschmid, Stefan; Hengstler, Jasmin; Whitehouse, Simon (2021): Final Report 2nd Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel. Edited by Sphera. Chicago.

Seitz, Manfred; Oganesian, Virginia (2023): D4.4 Report on barriers towards implementation of waterway and port infrastructure investments and proposed solutions. PLATINA3 IWT policy platform - infrastructure. With assistance of Michelangelo De Lisi, Juha Schweighofer, Severin Fraundorfer, Nik Delmeire, Ruxandra Florescu, Salih Karaarslan. Edited by PLATINA3.

Shin, Hyun Kyu; Ha, Sung Kyu (2023): A Review on the Cost Analysis of Hydrogen Gas Storage Tanks for Fuel Cell Vehicles. In *Energies* 16 (13), p. 5233. DOI: 10.3390/en16135233.

Soler, Alba; Gordillo, Victor; Lilley, William; Schmidt, Patrick; Weindorf, Werner; Houghton, Tom; Dell'Orco Stefano (2022): E-Fuels: A techno-economic assessment of European domestic production and imports towards 2050. Edited by Concawe. Brussels.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
Funded by the Horizon Europe guarantee of the United Kingdom, under project No 10068310
Funded by the Swiss State Secretariat for Education, Research and Innovation

Springer (Ed.) (2018a): Sustainable Business Models: The Case of the Collaborative Economy. With assistance of Maria Aluchna, Boleslaw Rok (Sustainable Business Models, Principles, Promise, and Practice).

Springer (Ed.) (2018b): Sustainable System Value Creation: Development of Preliminary Frameworks for a Business Model Change Within a Systemic Transition Process. With assistance of Katariina Koistinen, Minttu Laukkanen, Marja Mikkilä, Janne Huiskonen, Lassi Linnanen (Sustainable Business Models, Principles, Promise, and Practice).

Statista (2024): Leading HVO biodiesel producers by operating capacity in Europe in 2020. Statista. Available online at https://www.statista.com/statistics/1297126/leading-hvo-biodiesel-producers-by-capacity-in-europe/, checked on 05/12/2024.

Stolten, Detlef; Emonts, Bernd (2016): Hydrogen Science and Engineering. Weinheim: Wiley-VCH.

Tachi, Khalid; Quispel, Martin (2023): Onderzoek normering emissies binnenvaart. Edited by Expertise en Innovatie Centrum Binnenvaart (EICB).

Terrapon-Pfaff, Julia; Prantner, Magdolna; Ersoy, Sibel (2022): Risikobewertung und Risikokostenanalyse der MENA-Region. Bericht im Rahmen des Forschungsvorhabens MENA-Fuels – Roadmaps zur Erzeugung nachhaltiger synthetischer Kraftstoffe im MENA-Raum. Edited by Wuppertal Institut.

The Methanol Institute (2024): E-Methanol and Biomethanol plants. Available online at https://www.methanol.org/renewable/, checked on 03/09/2024.

Threebility (2023): The Sustainable Business Model Canvas. Available online at https://www.threebility.com/sustainable-business-model-canvas, checked on 24/09/2024.

Transport & Environment (2023): How to guarantee green batteries in Europe. Making sure the EU's battery carbon footprint rules are fit for purpose. Edited by Transport & Environment. Brussels.

Usman, Muhammad R. (2022): Hydrogen storage methods: Review and current status. In *Renewable and Sustainable Energy Reviews* 167, p. 112743. DOI: 10.1016/j.rser.2022.112743.

van Essen, Huib; van Wijngaarden, Lisanne; Schroten, Arno; Sutter, Daniel; Bieler, Cuno; Maffii, Silvia et al. (2019): Handbook on the external costs of transport. Edited by CE Delft. Brussels.

van Grinsven, Anouk; van den Toorn, Emiel; van der Veen, Reinier; Kampman, Bettina (2020): Used Cooking Oil (UCO) as biofuel feedstock in the EU. In *CE Delft* December 2020.

van Leeuwen, Charlotte; Zauner, Andreas (2018): Innovative large-scale energy storage technologies and Power-to-Gas concepts after optimisation. D8.3: Report on the costs involved with PtG technologies and their potentials across the EU. Edited by University of Groningen. Groningen.

van Rossum, Rik; Jens, Jaro; La Guardia, Gemma; Wang, Anthony; Kühnen, Luis; Overgaag, Martijn (2022): European Hydrogen Backbone. Edited by Guidehouse. Utrecht.

WATTLAB (2024): WATTLAB. Get independent energy production on board with Solar Hatches. Available online at https://wattlab.nl/en, checked on 04/09/2024.

Weiszflog, Elsa; Abbas, Manan (2022): Life Cycle Assessment of Hydrogen Storage Systems for Trucks. Gothenburg.

Ye, Linghe; Lu, Lin (2023): Environmental and economic evaluation of the high-pressured and cryogenic vessels for hydrogen storage on the sedan. In *International Journal of Low-Carbon Technologies* 18, pp. 144–149. DOI: 10.1093/ijlct/ctac126.

ZES (2024): Zero Emission Services. Edited by Zero Emission Services (ZES). Available online at https://zeroemissionservices.nl/en, checked on 09/12/2024.

Zhang, Lei; Jia, Cunqi; Bai, Fuqiao; Wang, Wensen; An, Senyou; Zhao, Kaiyin et al. (2024): A comprehensive review of the promising clean energy carrier: Hydrogen production, transportation, storage, and utilization (HPTSU) technologies. In *Fuel* 355, p. 129455. DOI: 10.1016/j.fuel.2023.129455.

Funded by the Horizon Europe Programme of the European Union under grant agreement No 101096809
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7 Appendices

7.1 Overview of Supply Path

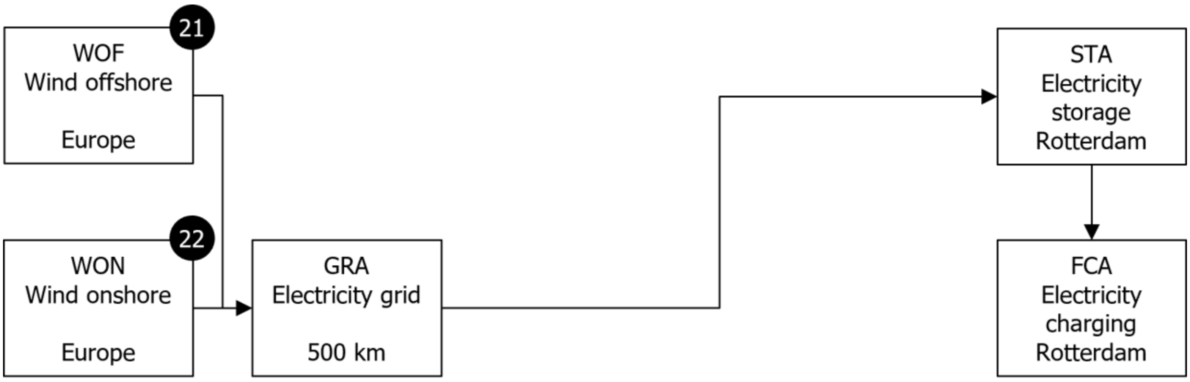

Figure 43: Electricity supply path with electricity from Europe.

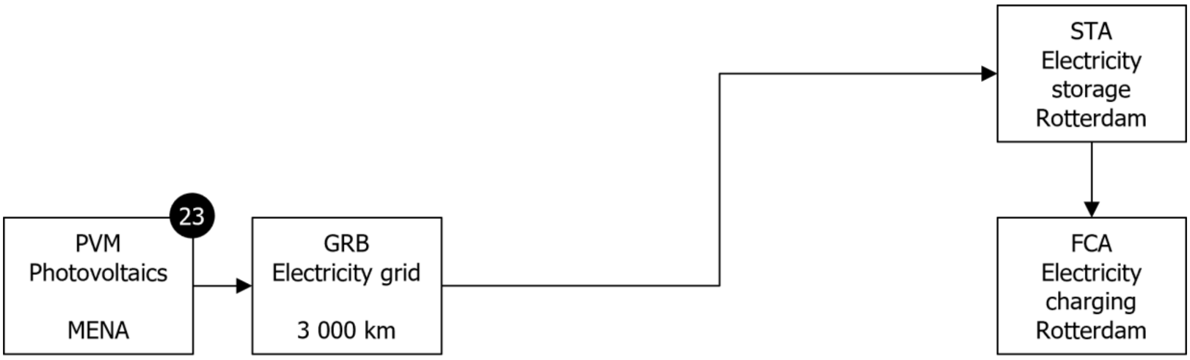

Figure 44: Electricity supply path with electricity from MENA.

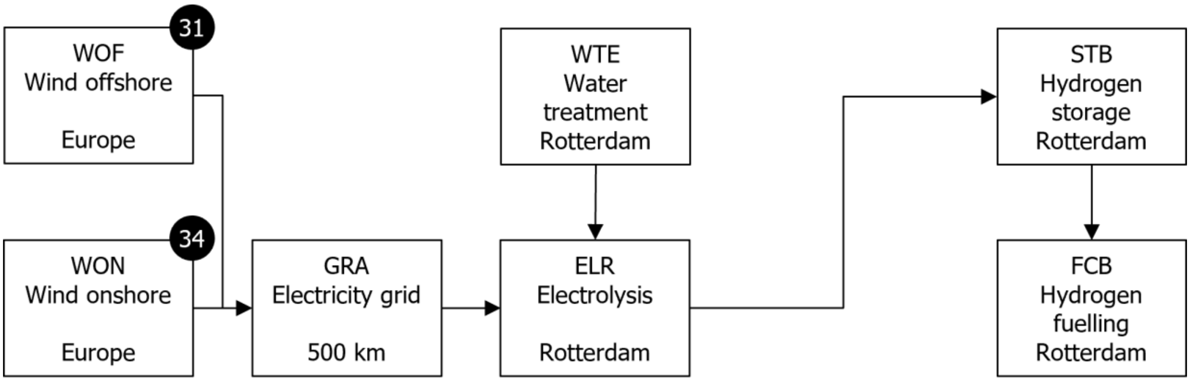

Figure 45: E-Hydrogen supply path with electricity from Europe and a centralised production.

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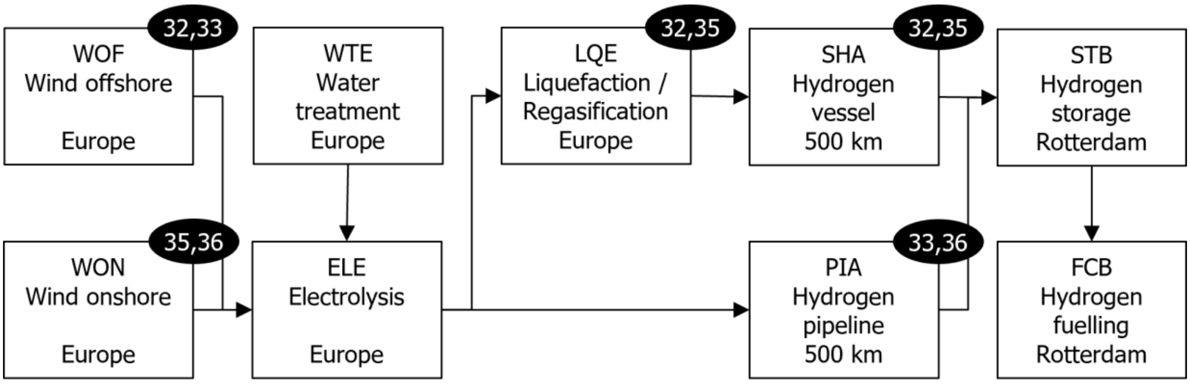

Figure 46: E-Hydrogen supply path with electricity from Europe and a decentralised production.

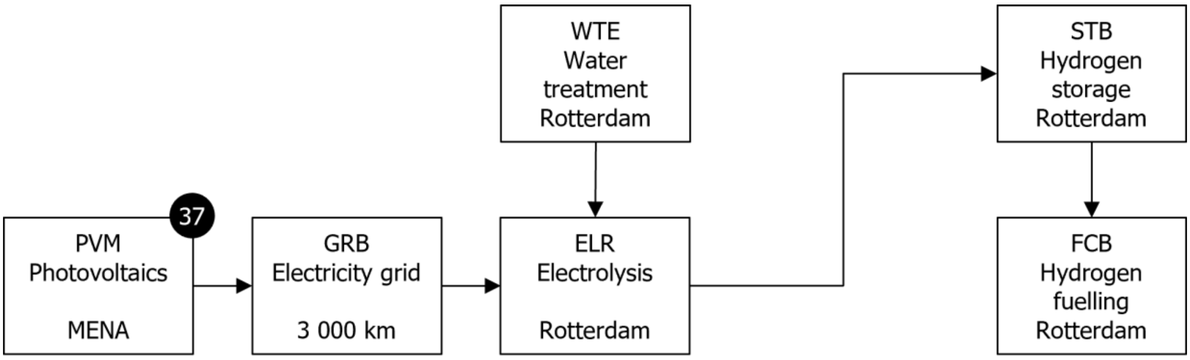

Figure 47: E-Hydrogen supply path with electricity from MENA and a centralised production.

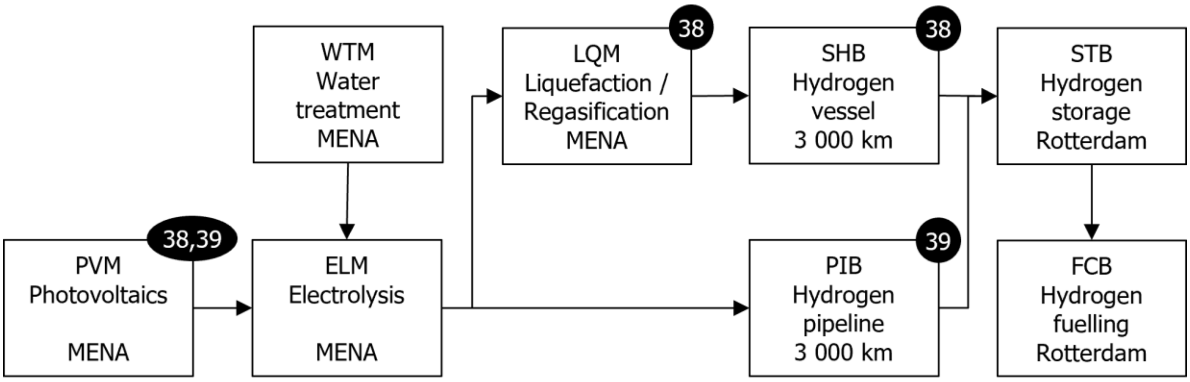

Figure 48: E-Hydrogen supply path with electricity from MENA and a decentralised production.

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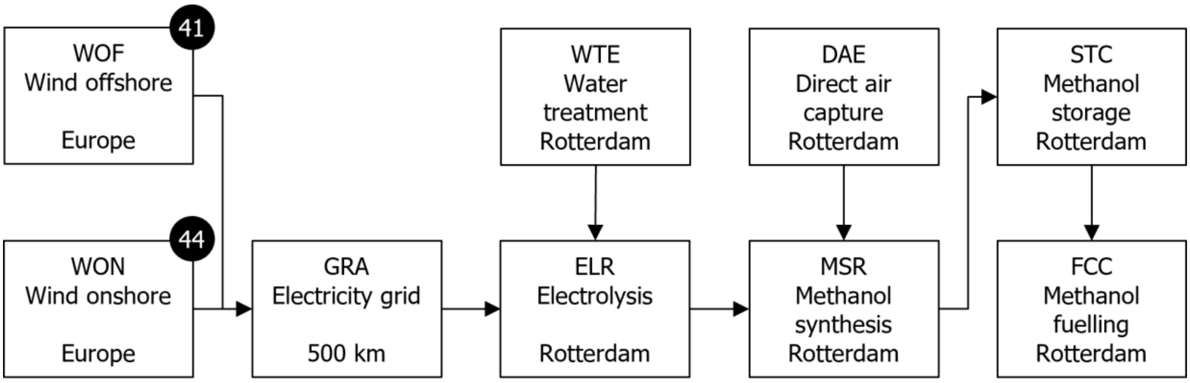

Figure 49: E-Methanol supply path with electricity from Europe and a centralised production.

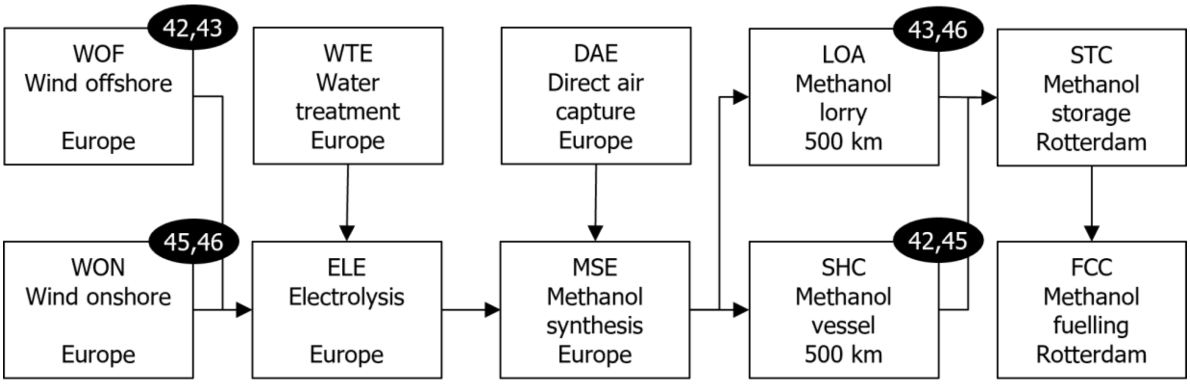

Figure 50: E-Methanol supply path with electricity from Europe and a decentralised production.

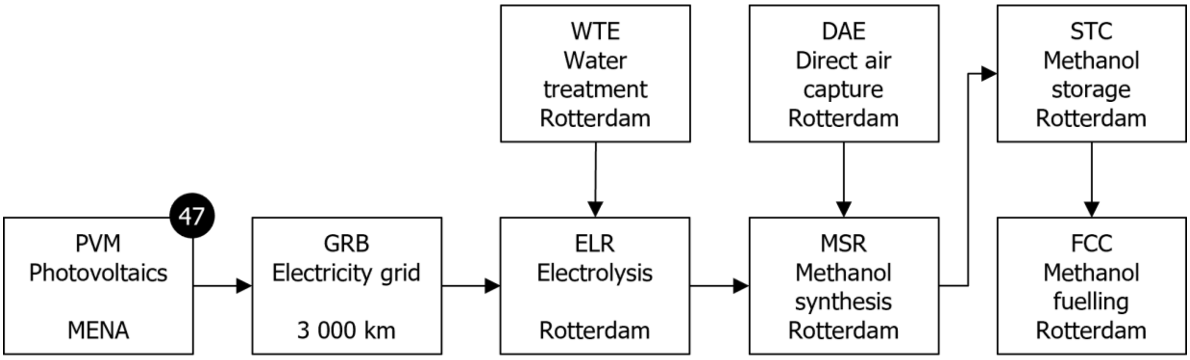

Figure 51: E-Methanol supply path with electricity from MENA and a centralised production.

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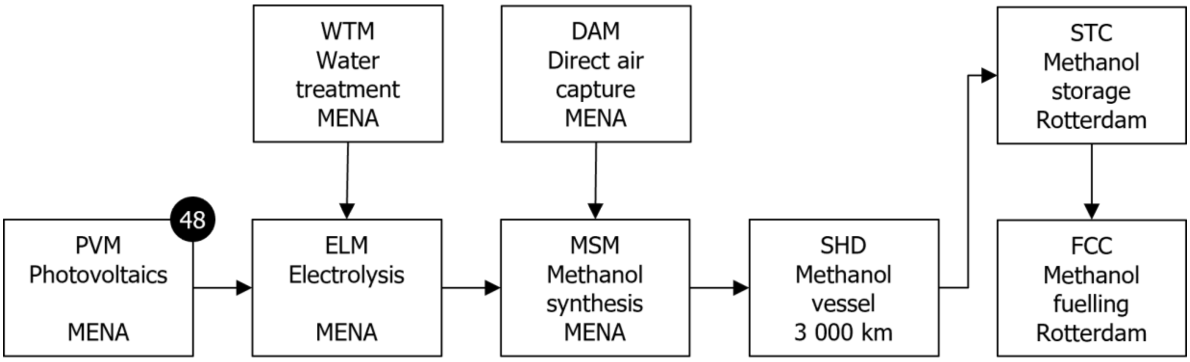

Figure 52: E-Methanol supply path with electricity from MENA and a decentralised production.

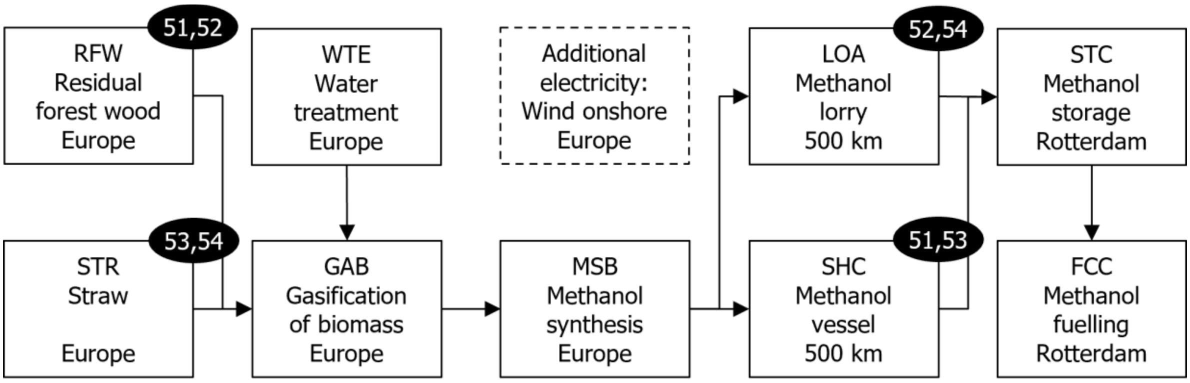

Figure 53: Bio-Methanol supply path with biomass from Europe.

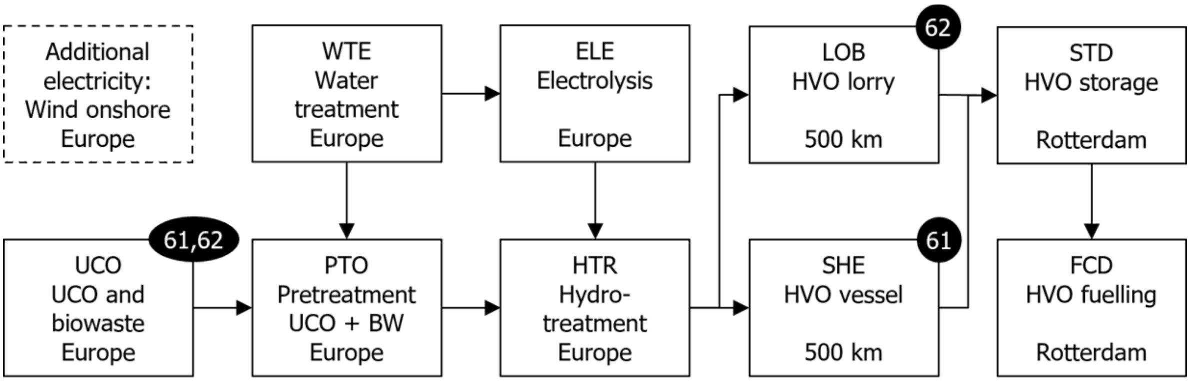

Figure 54: HVO supply path with biomass from Europe.

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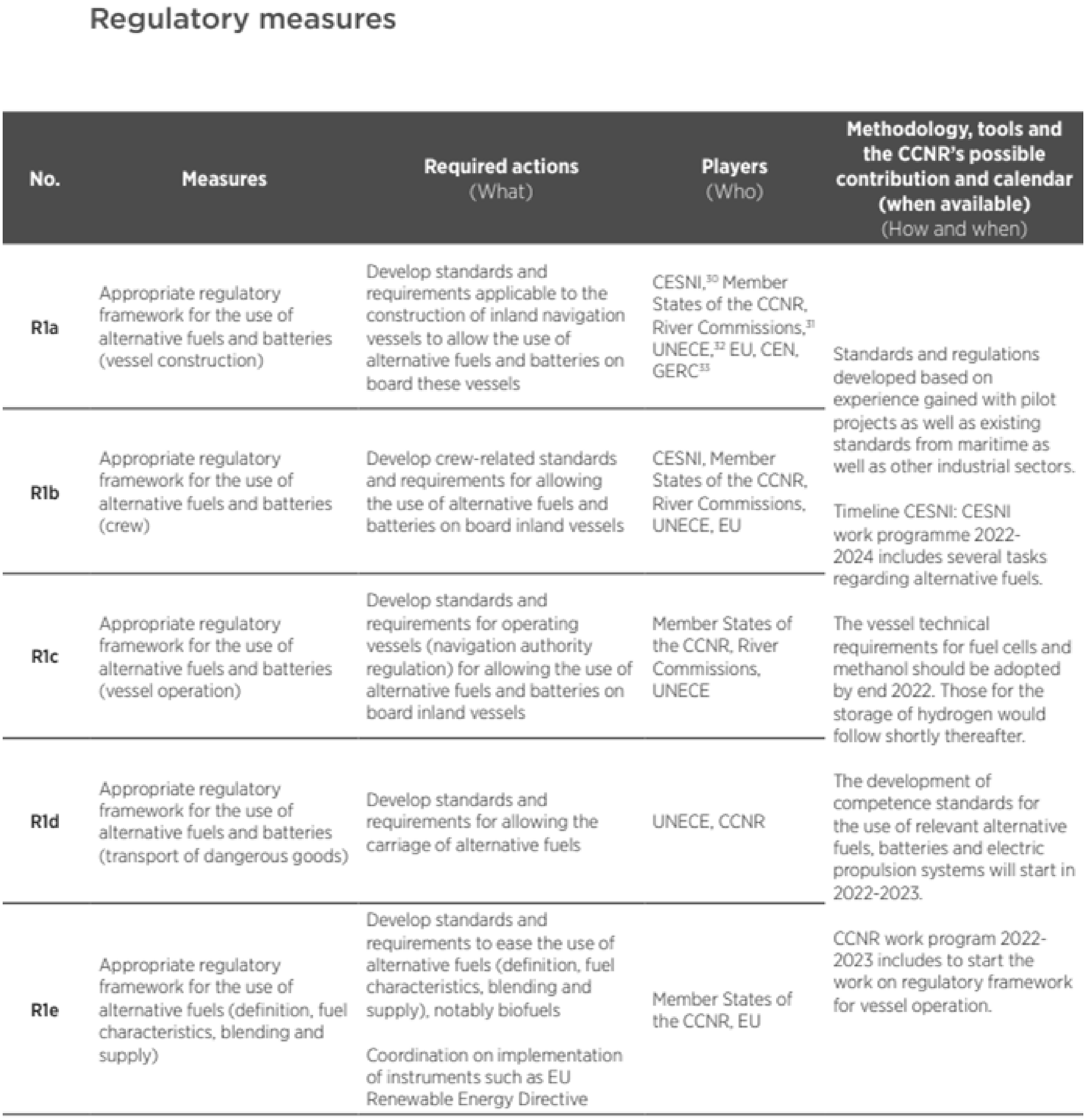
7.2 Measures of the CCNR Roadmap (2022)



Regulatory measures

No.	Measures	Required actions (What)	Players (Who)	Methodology, tools and the CCNR's possible contribution and calendar (when available) (How and when)
R1a	Appropriate regulatory framework for the use of alternative fuels and batteries (vessel construction)	Develop standards and requirements applicable to the construction of inland navigation vessels to allow the use of alternative fuels and batteries on board these vessels	CESNI,[30] Member States of the CCNR, River Commissions,[31] UNECE,[32] EU, CEN, GERC[33]	Standards and regulations developed based on experience gained with pilot projects as well as existing standards from maritime as well as other industrial sectors. Timeline CESNI: CESNI work programme 2022-2024 includes several tasks regarding alternative fuels. The vessel technical requirements for fuel cells and methanol should be adopted by end 2022. Those for the storage of hydrogen would follow shortly thereafter. The development of competence standards for the use of relevant alternative fuels, batteries and electric propulsion systems will start in 2022-2023. CCNR work program 2022-2023 includes to start the work on regulatory framework for vessel operation.
R1b	Appropriate regulatory framework for the use of alternative fuels and batteries (crew)	Develop crew-related standards and requirements for allowing the use of alternative fuels and batteries on board inland vessels	CESNI, Member States of the CCNR, River Commissions, UNECE, EU	
R1c	Appropriate regulatory framework for the use of alternative fuels and batteries (vessel operation)	Develop standards and requirements for operating vessels (navigation authority regulation) for allowing the use of alternative fuels and batteries on board inland vessels	Member States of the CCNR, River Commissions, UNECE	
R1d	Appropriate regulatory framework for the use of alternative fuels and batteries (transport of dangerous goods)	Develop standards and requirements for allowing the carriage of alternative fuels	UNECE, CCNR	
R1e	Appropriate regulatory framework for the use of alternative fuels (definition, fuel characteristics, blending and supply)	Develop standards and requirements to ease the use of alternative fuels (definition, fuel characteristics, blending and supply), notably biofuels Coordination on implementation of instruments such as EU Renewable Energy Directive	Member States of the CCNR, EU	

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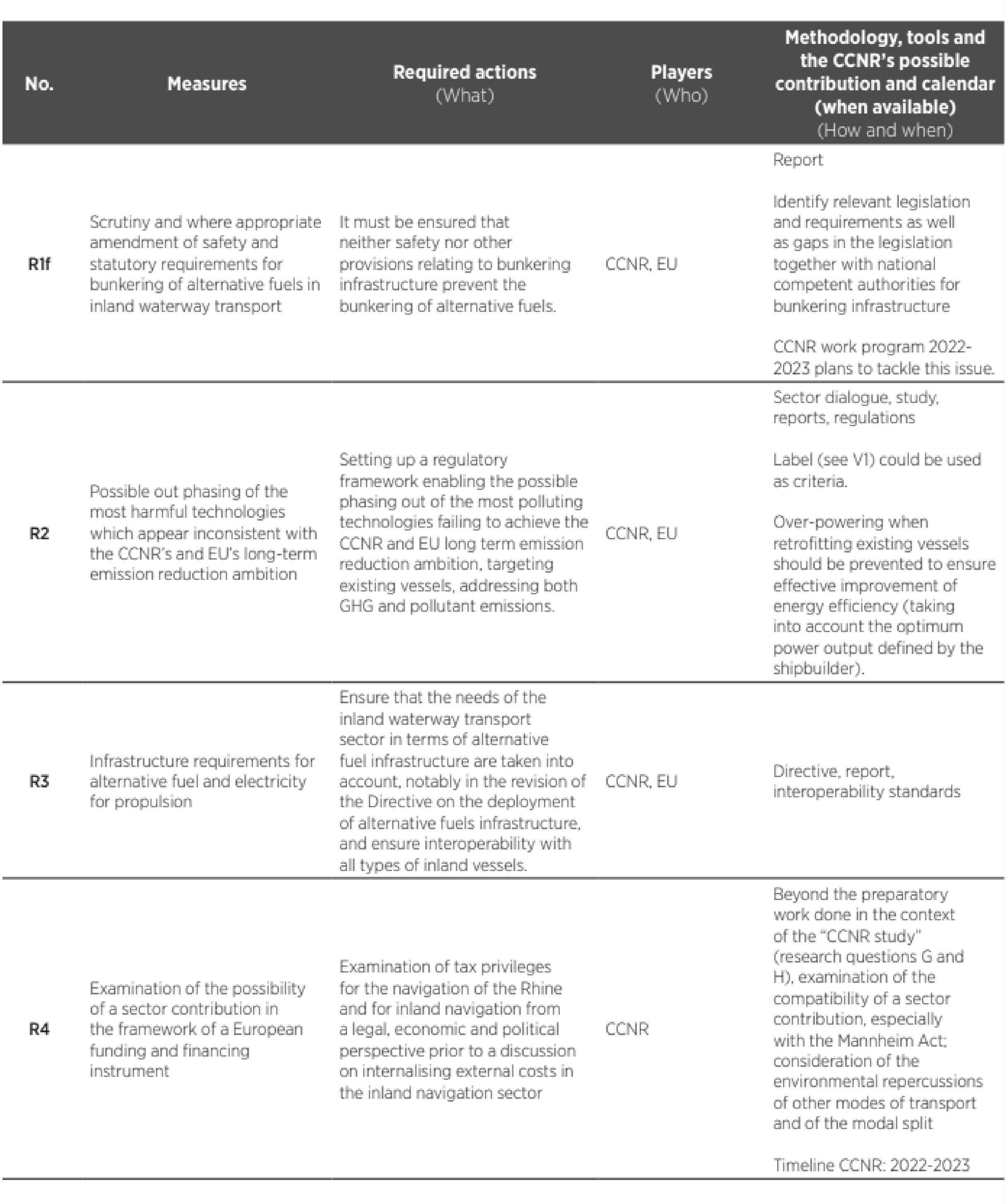

No.	Measures	Required actions (What)	Players (Who)	Methodology, tools and the CCNR's possible contribution and calendar (when available) (How and when)
R1f	Scrutiny and where appropriate amendment of safety and statutory requirements for bunkering of alternative fuels in inland waterway transport	It must be ensured that neither safety nor other provisions relating to bunkering infrastructure prevent the bunkering of alternative fuels.	CCNR, EU	Report Identify relevant legislation and requirements as well as gaps in the legislation together with national competent authorities for bunkering infrastructure CCNR work program 2022-2023 plans to tackle this issue.
R2	Possible out phasing of the most harmful technologies which appear inconsistent with the CCNR's and EU's long-term emission reduction ambition	Setting up a regulatory framework enabling the possible phasing out of the most polluting technologies failing to achieve the CCNR and EU long term emission reduction ambition, targeting existing vessels, addressing both GHG and pollutant emissions.	CCNR, EU	Sector dialogue, study, reports, regulations Label (see V1) could be used as criteria. Over-powering when retrofitting existing vessels should be prevented to ensure effective improvement of energy efficiency (taking into account the optimum power output defined by the shipbuilder).
R3	Infrastructure requirements for alternative fuel and electricity for propulsion	Ensure that the needs of the inland waterway transport sector in terms of alternative fuel infrastructure are taken into account, notably in the revision of the Directive on the deployment of alternative fuels infrastructure, and ensure interoperability with all types of inland vessels.	CCNR, EU	Directive, report, interoperability standards
R4	Examination of the possibility of a sector contribution in the framework of a European funding and financing instrument	Examination of tax privileges for the navigation of the Rhine and for inland navigation from a legal, economic and political perspective prior to a discussion on internalising external costs in the inland navigation sector	CCNR	Beyond the preparatory work done in the context of the "CCNR study" (research questions G and H), examination of the compatibility of a sector contribution, especially with the Mannheim Act; consideration of the environmental repercussions of other modes of transport and of the modal split Timeline CCNR: 2022-2023

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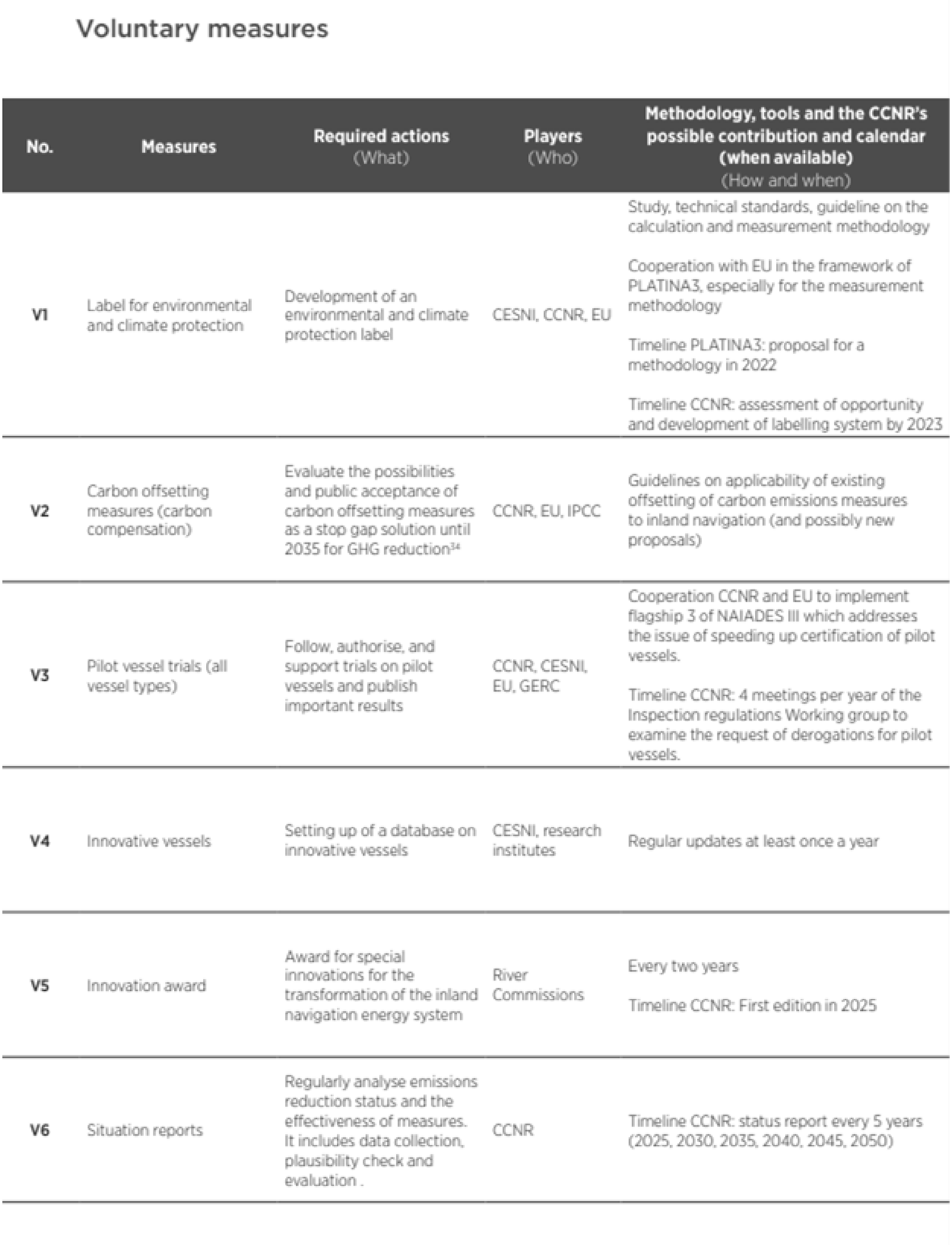

Voluntary measures

No.	Measures	Required actions (What)	Players (Who)	Methodology, tools and the CCNR's possible contribution and calendar (when available) (How and when)
V1	Label for environmental and climate protection	Development of an environmental and climate protection label	CESNI, CCNR, EU	Study, technical standards, guideline on the calculation and measurement methodology Cooperation with EU in the framework of PLATINA3, especially for the measurement methodology Timeline PLATINA3: proposal for a methodology in 2022 Timeline CCNR: assessment of opportunity and development of labelling system by 2023
V2	Carbon offsetting measures (carbon compensation)	Evaluate the possibilities and public acceptance of carbon offsetting measures as a stop gap solution until 2035 for GHG reduction[34]	CCNR, EU, IPCC	Guidelines on applicability of existing offsetting of carbon emissions measures to inland navigation (and possibly new proposals)
V3	Pilot vessel trials (all vessel types)	Follow, authorise, and support trials on pilot vessels and publish important results	CCNR, CESNI, EU, GERC	Cooperation CCNR and EU to implement flagship 3 of NAIADES III which addresses the issue of speeding up certification of pilot vessels. Timeline CCNR: 4 meetings per year of the Inspection regulations Working group to examine the request of derogations for pilot vessels.
V4	Innovative vessels	Setting up of a database on innovative vessels	CESNI, research institutes	Regular updates at least once a year
V5	Innovation award	Award for special innovations for the transformation of the inland navigation energy system	River Commissions	Every two years Timeline CCNR: First edition in 2025
V6	Situation reports	Regularly analyse emissions reduction status and the effectiveness of measures. It includes data collection, plausibility check and evaluation .	CCNR	Timeline CCNR: status report every 5 years (2025, 2030, 2035, 2040, 2045, 2050)

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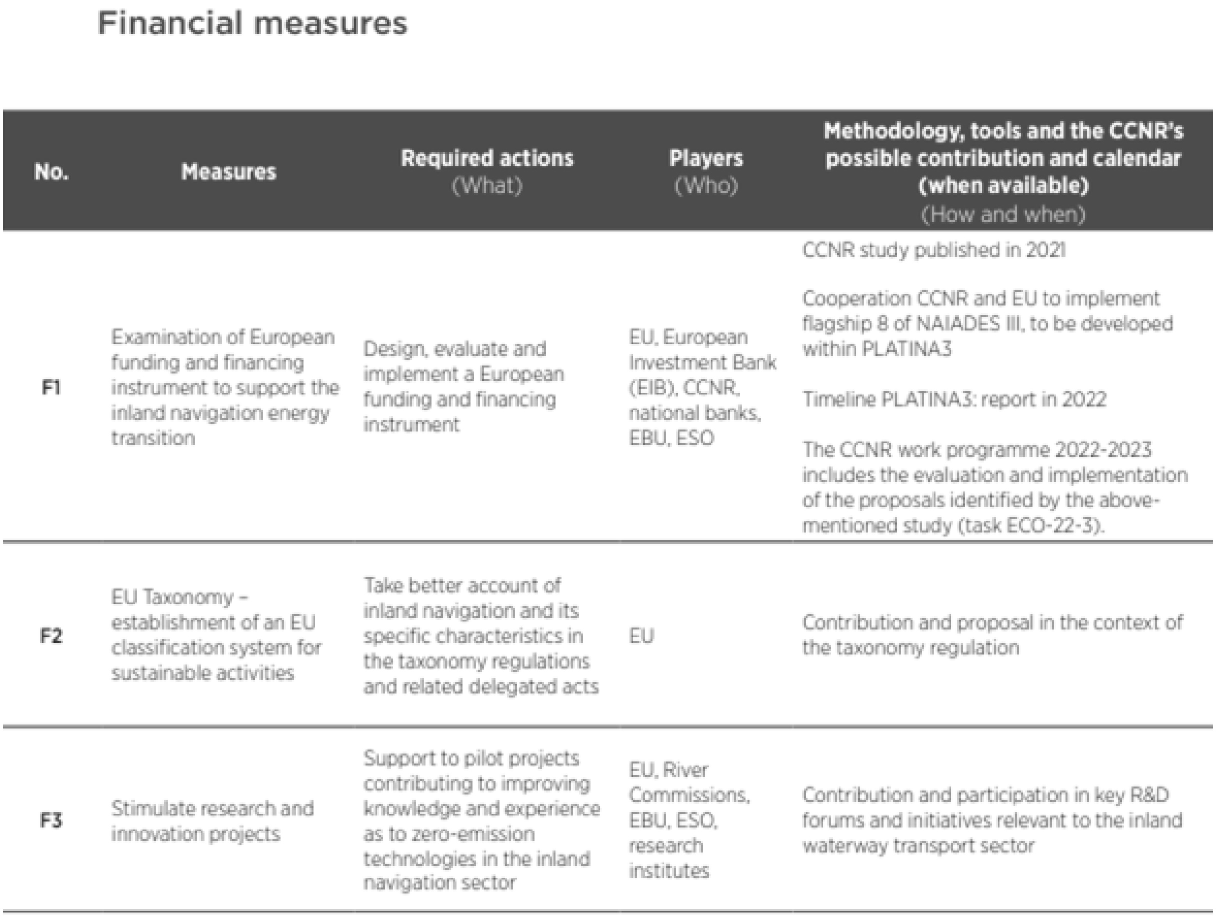

Financial measures

No.	Measures	Required actions (What)	Players (Who)	Methodology, tools and the CCNR's possible contribution and calendar (when available) (How and when)
F1	Examination of European funding and financing instrument to support the inland navigation energy transition	Design, evaluate and implement a European funding and financing instrument	EU, European Investment Bank (EIB), CCNR, national banks, EBU, ESO	CCNR study published in 2021 Cooperation CCNR and EU to implement flagship 8 of NAIADES III, to be developed within PLATINA3 Timeline PLATINA3: report in 2022 The CCNR work programme 2022-2023 includes the evaluation and implementation of the proposals identified by the above-mentioned study (task ECO-22-3).
F2	EU Taxonomy – establishment of an EU classification system for sustainable activities	Take better account of inland navigation and its specific characteristics in the taxonomy regulations and related delegated acts	EU	Contribution and proposal in the context of the taxonomy regulation
F3	Stimulate research and innovation projects	Support to pilot projects contributing to improving knowledge and experience as to zero-emission technologies in the inland navigation sector	EU, River Commissions, EBU, ESO, research institutes	Contribution and participation in key R&D forums and initiatives relevant to the inland waterway transport sector

7.3 Overview of Financial Support Schemes (2024)

Country	Name	Total Budget in €	Funding Rate	Beneficiary	Timespan	Description	Source
Netherlands	Retrofit Binnenvaart	79 Mil	unknown	Companies	2020-2030	Retrofit IWT	URL
	Subsidieregeling Verduurzaming Binnenvaartschepen, SRVB (Subsidy scheme for making inland vessels more sustainable)	76.4 Mil	40% (max. 400000 € per ship)	Companies	2023-2025 (engines only until 2023, catalyst until 2025)	Investment into a new, clean engine or catalytic converter (type SCR)	URL
	Subsidie Duurzame Scheepsbouw, SDS (Subsidy for sustainable shipbuilding)	2.3 Mil (in 2023)	25% (max. 1.25 Mil € per project)	Companies	2023-2024	Subsidy for construction/ conversion of inland vessels, ocean-going vessels and offshore structures (areas: sustainability, emission reduction, alternative fuels and noise reduction)	URL
	Temporary Subsidy Scheme for Electrification	15.1 Mil	40%	Companies	2024	financial incentives to encourage the shift to electric propulsion	URL
	DKTI-transport	37 Mil (in 2021, not only IWT)		Companies, knowledge institutions	2017-2021, may be reopened	CO2 reducing projects in the transport sector (electric driving/ sailing, efficient ships)	URL
	Modal shift	22.5 Mil (15 Mil for road-to-water)		Logistic companies	2023-2025	Facilitate the shifting of existing container and bulk transport from road to water or rail	URL
	Shore power grant (temporary)	6.5 Mil (2023)	35% (max. 5 Mil per project)	Port managers, other investors	2022-2023, Intended follow-up scheme	Support for construction of shore power facilities in seaports (e.g., electricity facility)	URL
	Maritieme innovatieprojecten	7.5 Mil	Max 50% (max. 2 Mil)	Shipping companies (IWT, coastal)	2024-2029	Innovations focussing partly on greening, including research, might include a	URL

Country	Name	Total Budget in €	Funding Rate	Beneficiary	Timespan	Description	Source
						demonstration for the research	
Belgium	Ecologiepremie+		15%-55%	Companies		Contribution to investments in sustainable technologies (topics: cooling, transportation, lighting, heating, water)	URL
	Plan d'aides aux modes de transport alternatifs (Plan Wallonnie) Several aid schemes within this plan		20-50%	Companies (from Walloon)	2021-2025	Contributions to investments in the development and use of less polluting modes of transport (alternative drive systems, systems for reducing pollutant emissions)	URL URL
Luxembourg	Aides publiques en matière de navigation fluviale		30-50%	Private persons domiciled or having their registered office in Luxembourg	Since 2019	Contributions to projects that improve navigation safety, fleet productivity, or environmental protection	URL
	Aide à l'investissement en faveur de la protection de l'environnement		10%-100%	Companies		Aid scheme for eco-technologies or environmentally friendly processes	URL
France	Plan d'Aide à la Modernisation et à l'Innovation (PAMI)	26.2 Mil	20-50%	EU/inland fleet operating in France	2023-2027	4 sections: improve environmental performance of river fleet, better integration of the river connection into logistics chains, Supporting the renewal of stakeholders and the sector, Promoting the development of innovative solution	URL
	Plan d'Aide au Report Modal (PARM)	20 Mil		Companies	2023-2027	Supports companies to integrate waterways into their logistic chains	URL
Germany	Förderprogramm nachhaltige Modernisierung von Binnenschiffen	30 Mil	60-80%	Companies located in Germany under private law as	2024-2024	Equipping new inland waterway vessels and those already in service	URL

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Country	Name	Total Budget in €	Funding Rate	Beneficiary	Timespan	Description	Source
				owner of an inland waterway vessel		with zero-emission propulsion systems (goal: Reduction of air pollutant emissions)	
	Innovativer Schiffbau sichert wettbewerbsfähige Arbeitsplätze		15-50%	Companies registered in Germany	2020-2023, may be reopened	Innovation measures (products or processes) for shipbuilding, ship repair or ship retrofit	URL
	Förderung der nachhaltigen Modernisierung von Küstenschiffen (NaMKü)		30-40%	Companies located in Germany under private law as owner of an inland waterway vessel	2021-30.06.24, may be prolonged until 2025	Engine modernisation, measures to reduce air pollutant emissions, optimised energy efficiency,	URL
	Förderprogramm für Innovative Hafentechnologien (IHATEC II)	65 Mil		Companies (especially working in ports), Institutes, universities	2021-2025	More efficient logistic chains, optimised network of production and logistics	URL
	Beratungs- und Schulungsförderung für Binnenschifffahrtsunternehmen		50-75%	Companies		Consulting in technology and innovation in IWT	URL
	Umweltfreundliche Bordstrom- und mobile Landstromversorgung von See- und Binnenschiffen		40-80%	Natural or legal persons based in Germany	2023	Environmentally friendly on-board and mobile shore power systems for sea-going and inland waterway vessels	URL
	Anschubfinanzierung von regelmässigen Grossraum- und Schwerguttransporten auf Bundeswasserstrassen		50%	Companies registered in Germany	2019-June 2024	Support waterway transport to ease the transition road to water	URL
	Nachrüstung von Emissionsminderungseinrichtungen von Binnenschiffen		60-80% Depending on size of the company	Companies registered in Germany (ship owners)	2024-2026	Support of investments to retrofit emission reduction equipment (engines) in inland waterway vessels	URL

Country	**Name**	**Total Budget in €**	**Funding Rate**	**Beneficiary**	**Timespan**	**Description**	**Source**
	And many more: Link						
Switzerland	Pilot- und Demonstrationsprogramm (BFE – Bundesamt für Energie)	25 Mil/year	40%	Companies, universities, research institutes	From 2020	Innovation projects for energy efficient technologies	URL
	Programm Elektroschiffe		CHF 168 per CO2 reduction certificate	Ship owners	2021-2030	Replacement of diesel engines with electric motors	URL
Austria	Förderprogramm klima- und umweltfreundliche Schifffahrt 2022-2026 (part of Mobilitätsmasterplan 2030)		40-60%	Natural or legal persons based in Austria	2022-2026	Financing measures to increase efficiency and reduce CO2 and air pollutant emissions from IWT vessels	URL
Slovakia	No programs/ incentives available to provide financial support towards zero emission IWT.						
Hungary	No programs/ incentives available to provide financial support towards zero emission IWT.						
Croatia	No programs/ incentives available to provide financial support towards zero emission IWT.						
Romania	No programs/ incentives available to provide financial support towards zero emission IWT.						
Czech Republic	No programs/ incentives available to provide financial support towards zero emission IWT.						
Serbia	No programs/ incentives available to provide financial support towards zero emission IWT.						

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