

# D5.2 Updated Transition Pathways & Landscape of Synergies

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

<b>GRANT AGREEMENT NO.</b>	101096809
<b>DURATION OF THE PROJECT</b>	42 months
<b>DELIVERABLE NUMBER</b>	D5.2
<b>DISSEMINATION LEVEL</b>	Public
<b>DELIVERABLE LEADER</b>	SPB
<b>STATUS</b>	FINAL
<b>SUBMISSION DATE</b>	26-06-2026
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<b>DOI</b>	10.5281/zenodo.20702034

Co-Funded by the European Union. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.



## | Table of Contents

1. Introduction .....	12
1.1 Objectives and scope.....	12
1.2 CCNR study and the transition pathways.....	13
1.2.1 Purpose and Analytical Framework .....	13
1.2.2 Conservative Pathway.....	13
1.2.3 Innovative Pathway .....	13
1.2.4 Complementarity and Policy Implications .....	14
1.2.5 Outlook.....	15
1.3 STEERER and NEEDS Projects .....	15
1.3.1 STEERER .....	15
1.3.2 NEEDS.....	17
1.4 Synergies between projects and initiatives .....	19
IWT Projects Cooperation Platform .....	19
SYNERGETICS WP2 database and showcases .....	20
2. New developments and insights.....	22
2.1 Applicability of technologies and renewable energies .....	23
3. Methodology .....	25
3.1 Approach for updating Transition Pathways for IWT .....	25
3.2 Creating the “landscape of synergies” .....	25
4. NEEDS IWT model application .....	27
4.1 Model description .....	27
4.2 Model development .....	28
4.2.1 Context definition.....	29
4.2.2 Dynamic model .....	29
4.2.3 Post-processing.....	29
4.3 Input parameters and scenarios .....	29
4.4 Temporal development of equipment and integration cost .....	32
4.5 Results: technology shares.....	33
4.4.1 Scenario STEPS – NZE.....	34
4.4.2 Impact of fuel price extremes .....	36
4.4.3 Impact of subsidy .....	37
5. Aggregated views for the inland fleet.....	39

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **2** of **122**



5.1	Model description .....	40
5.1.1	Fleet composition .....	41
5.1.2	Fleet evolution in SYNFEED .....	42
5.1.3	Technologies.....	43
5.1.4	Cost model .....	44
5.1.5	Performance / Emission .....	44
5.2	Input settings and scenarios .....	45
5.2.1	Business-As-Usual scenario .....	45
5.2.2	Conservative pathway.....	46
5.2.3	Innovative pathway .....	46
5.3	Results: emission and economic performance .....	48
5.3.1	Economic results .....	48
5.3.2	Emission results .....	48
5.4	Extrapolated NEEDS Scenarios .....	50
5.4.1	STEPS-MIX scenario .....	50
5.4.2	NZE-MIX scenario.....	51
5.5	SYNERGETICS Expert Scenario.....	53
6.	Landscape of Synergies.....	56
6.1	Hydrogen.....	56
6.2	Methanol .....	58
6.3	Electricity.....	59
6.4	LNG.....	61
6.5	Energy efficiency .....	62
7.	Conclusions .....	64
	Annex I Updated energy price scenarios .....	67
	Introduction.....	69
	Scenarios.....	70
	Stated Policies Scenario .....	71
	Announced Pledges Scenario .....	71
	Net Zero Emissions scenario .....	72
	Energy policy interventions and the price impact .....	73
	Overall prices and comparison.....	74
	STEPS analysis.....	74
	APS analysis .....	78

Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. **| 101096809**

Page **3** of **122**



NZE analysis .....	81
Energy types and the price projections .....	84
Fossil Diesel / MGO .....	84
STEPS.....	85
APS.....	86
NZE .....	87
HVO .....	87
LNG .....	90
Bio-LNG.....	92
Electricity Pay-per-Use.....	98
Fossil and green Methanol .....	101
Fossil and green hydrogen (H2) .....	104
Emission, heating values and efficiency rates .....	107
Price details per energy type .....	107
List of sources.....	111
Annex II NEEDS IWT Model .....	112
Fuel properties and emission factors .....	112
Minimum and maximum for energy carrier, equipment and integration costs .....	114
Temporal development of equipment and integration costs and Readiness and availability levels .....	115
Fuel cost table STEPS scenario .....	117
Fuel cost table NZE scenario .....	118
Energy carrier storage cost table .....	119
Energy system converter cost table .....	120
Energy system integration cost table .....	121
Energy system selection logic.....	122



## **| List of Figures**

1   Technology shares aggregated for all fleet families for the business-as-usual (top), conservative (bottom left) and the innovative transition (bottom right) pathways (source: CCNR roadmap) .....	14
2   NEEDS model overview and three-stage workflow definition: Context definition, Model, Post-processing .....	27
3   Technology share comparison between STEPS and NZE .....	34
4   Fuel price development over time for both STEPS and NZE.....	35
5   Impact of fuel price extremes in the STEPS scenario .....	36
6   Fuel price development over time for fuel price extremes .....	36
7   Impact of CAPEX subsidy for STEPS-min-max scenario, showing ineffectiveness of subsidy with respect to minimum price fossil fuels. ....	37
8   Impact of CAPEX subsidy in NZE-min-max scenario .....	37
9   Impact of CAPEX subsidy on NZE-max-min scenario .....	38
10   Workflow of the SYNFEED model.....	40
11   Gaussian distributions for the fuel consumption and the installed power on tanker vessels with a length of 110 m and more. ....	42
12   Re-calculated business-as-usual pathway of the CCNR-Study .....	45
13   Re-calculated conservative pathway of the CCNR-Study.....	46
14   Re-calculated innovative pathway of the CCNR-Study .....	47
15   Result of the STEPS-MIX scenario calculation in the SYNFEED tool. ....	51
16   Result of the NZE-MIX scenario calculation in the SYNFEED tool.....	52
17   Technology distribution for all fleet families in the SYNERGETCS Expert Scenario .....	54
18   Installed power per technology in the SYNERGETICE Expert Scenario.....	55
19   STEPS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	76
20   STEPS maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	77
21   APS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	79
22   APS maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	80
23   NZE minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	82
24   NZE maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	83
25   STEPS, fossil diesel energy prices euro per GJe, taking into account efficiency of energy conversion .....	86

Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. **| 101096809**

Page **5** of **122**



26 | APS, fossil diesel energy prices euro per GJe, taking into account efficiency of energy conversion ..... 86

27 | NZE fossil diesel, energy prices euro per GJe, taking into account efficiency of energy conversion ..... 87

28 | STEPS, fossil diesel vs HVO, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 88

29 | APS, fossil diesel vs HVO, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 89

30 | NZE, fossil diesel vs HVO, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 89

31 | STEPS, fossil LNG price in euro per GJe, taking into account efficiency of energy conversion .... 90

32 | APS, Fossil LNG price in euro per GJe, taking into account efficiency of energy conversion ..... 91

33 | NZE, fossil LNG price in euro per GJe, taking into account efficiency of energy conversion ..... 91

34 | STEPS, fossil LNG vs Bio-LNG, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 92

35 | APS, fossil LNG vs Bio-LNG, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 93

36 | NZE, fossil LNG vs Bio-LNG, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 94

37 | STEPS, Electricity price in euro per GJe, taking into account efficiency of energy conversion ..... 96

38 | APS, Electricity price in euro per GJe, taking into account efficiency of energy conversion ..... 96

39 | NZE Electricity price in euro per GJe, taking into account efficiency of energy conversion ..... 97

40 | STEPS, PPU price in euro per GJe, taking into account efficiency of energy conversion ..... 99

41 | APS, PPU price in euro per GJe, taking into account efficiency of energy conversion ..... 100

42 | NZE, PPU price in euro per GJe, taking into account efficiency of energy conversion ..... 100

43 | STEPS, fossil methanol vs green methanol, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 102

44 | APS, fossil methanol vs green methanol, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 103

45 | NZE, fossil methanol vs green methanol, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 103

46 | STEPS, fossil hydrogen vs green hydrogen, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 105

47 | APS, fossil hydrogen vs green hydrogen, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 105

48 | NZE, fossil hydrogen vs green hydrogen, price comparison in euro per GJe, taking into account efficiency of energy conversion ..... 106

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **6** of **122**



## | List of Tables

1   Overview of energy types and relevant developments since 2021.....	23
2   SYNERGETICS fleet extrapolation .....	30
3   NEEDS model SYNERGETICS fleet size and route distribution.....	31
4   Overview of carrier, equipment and integration for each system from SYNERGETICS report D4.5	32
5   Capex subsidy.....	33
6   SYNERGETICS scenario inputs .....	33
7   Fleet composition for the SYNFEED model in comparison to previous studies. ....	41
8   Criteria for the determination of the Retrofit-Score.....	43
9   Economic results for all simulated pathways and scenarios .....	48
10   Re-calculated BAU scenario of the CCNR-Study for 2035.....	49
11   Re-calculated BAU scenario of the CCNR-Study for 2050.....	49
12   Emission reduction comparison 2035 in the conservative scenario .....	49
13   Emission reduction comparison 2050 in the conservative scenario .....	49
14   Emission reduction comparison 2035 in the innovative scenario .....	49
15   Emission reduction comparison 2050 in the innovative scenario .....	50
16   WTW emission reduction calculated for the CCNR-Pathways with the SYNFEED tool.....	50
17   PM, NO <sub>x</sub> and CO <sub>2</sub> e emissions in the SYNERGETICS Scenario STEPS-MIX for 2035.....	51
18   PM, NO <sub>x</sub> and CO <sub>2</sub> e emissions in the SYNERGETICS Scenario STEPS-MIX for 2050 .....	51
19   PM, NO <sub>x</sub> and CO <sub>2</sub> e emissions in the SYNERGETICS Scenario NZE-MIX for 2035 .....	52
20   PM, NO <sub>x</sub> and CO <sub>2</sub> e emissions in the SYNERGETICS Scenario NZEMix for 2050.....	52
21   PM, NO <sub>x</sub> and CO <sub>2</sub> e emissions in the SYNERGETICS Expert Scenario for 2035.....	54
22   PM, NO <sub>x</sub> and CO <sub>2</sub> e emissions in the SYNERGETICS Expert Scenario for 2050.....	54
23   CAPEX for conventional and alternative technologies in the SYNERGETICS Expert Scenario.....	55
24   STEPS EU oil and gas prices.....	71
25   APS EU oil and gas prices .....	72
26   NZE EU oil and gas prices .....	72
27   CO <sub>2</sub> prices internalised in the fuel prices for inland navigation and coastal shipping .....	74
28   STEPS minimum range, energy prices euro per GJ (caloric).....	75
29   STEPS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	75
30   STEPS maximum range, energy prices euro per GJ (caloric).....	76
31   STEPS maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	77

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **7** of **122**



32   APS minimum range, energy prices euro per GJ (caloric) .....	78
33   APS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	78
34   APS maximum range, energy prices euro per GJ (caloric) .....	79
35   APS maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	80
36   NZE minimum range, energy prices euro per GJ (caloric) .....	81
37   NZE minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	81
38   NZE maximum range, energy prices euro per GJ (caloric) .....	82
39   NZE maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion .....	83
40   Prices for fossil diesel fuel in euro per m3 for the three scenarios, minimum and maximum .....	85
41   LHV and efficiency rate applied in SYNERGETICS .....	107
42   Fossil diesel. Prices in euro per kg fuel .....	108
43   Fossil LNG. Prices in euro per kg fuel .....	108
44   Bio-LNG. Prices in euro per kg fuel .....	108
45   HVO. Prices in euro per kg fuel .....	108
46   Fossil Methanol. Prices in euro per kg .....	109
47   Green Methanol. Prices in euro per kg .....	109
48   Fossil hydrogen. Prices in euro per kg .....	109
49   Green hydrogen. Prices in euro per kg .....	110
50   Electricity. Prices in euro per kWh .....	110
51   NEEDS model fuel properties and emission factor overview .....	112
52   Equipment cost in €/kW .....	114
53   Integration cost in €/kW .....	114
54   Development over time for equipment and integration of systems .....	115
55   NZE and STEPS scenario development of port availability, social readiness level and technology readiness level .....	116
56   Minimum and maximum fuel cost for STEPS .....	117
57   Minimum and maximum fuel costs for NZE .....	118
58   Minimum and maximum energy carrier costs over time .....	119
59   Minimum and maximum energy converter cost over time .....	120
60   Minimum and maximum system integration cost over time .....	121
61   Ship owner system selection logic for scrapping and retrofit decision making .....	122

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **8** of **122**



## **| Release Approval**

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Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**  
Grant agreement no. **| 101096809**

Page **9** of **122**



## | Executive Summary

This report describes the Updated Transition Pathways & Landscape of Synergies for decarbonizing inland waterway transport (IWT) and coastal shipping. The assumptions and scenarios from the 2021 CCNR Roadmap and related studies are revised and insights from STEERER, NEEDS, and other EU initiatives are integrated. For each technology, the report summarises the latest developments and applies the most recent findings on costs and emission factors. Prices of energy carriers were modelled based on the World Energy Outlook 2024 published by the International Energy Agency. For the analyses reported here, mainly the Stated Policies Scenario (STEPS) and the Net Zero Emissions by 2050 (NZE) Scenario were used. The Announced Pledges Scenario (APS) is described as well, but corresponding results are left out of the report for better clarity. **It must be stressed that the STEPS scenario assumes a certain level of CO<sub>2</sub>e cost internalisation in the fossil fuel prices. This is however not the 'Business as Usual'.** Most of the EU countries did not (yet) decide for ETS-2 opt-in for fuel supply to IWT or coastal vessels. There is a severe risk as well for bunker tourism leading to ineffective policies. With application of STEPS and NZE however, a stable and effective EU binding framework was assumed, in-line with what is needed to reach effective emission reduction in IWT and coastal shipping. Therefore, the STEPS scenario and especially the NZE give an optimistic view on the framework conditions for a fossil free energy use by 2045 and at the same time a largely elimination of air pollutant emissions.

The NEEDS model was used to calculate the development of technology shares for a set of vessels on pre-defined routes. Since the energy prices in each scenario are provided with a bandwidth, the simulations were performed for the STEPS and NZE scenarios with combinations of the minimum prices for conventional fuels and the maximum prices for alternative fuels and vice versa. In addition, the influence of a 60 % CAPEX funding is examined. Neither the scenarios published in the CCNR Roadmap (2021) nor the scenarios produced with the NEEDS model are considered as realistic up-to-date transition pathways. The CCNR scenarios are target scenarios with the strict boundary conditions of achieving the ambitions of the Mannheim Declaration by 2035 and 2050. The NEEDS simulations were performed with updated cost assumptions per technology and price developments for energy carriers. The model allows the conversion of vessels on representative journeys to alternative technologies whenever a positive business case results from the underlying assumptions. Market dynamics of supply and demand and the effect on prices, are not modelled and also the physical and technical limitations are largely left out-of-scope in NEEDS. Accordingly, abrupt changes of technology shares occur in these scenarios. Therefore, the knowledge from existing pilots, TCO modelling and the NEEDS outputs were used to prepare the so-called "SYNERGETICS Expert Scenario". This involved combining the same cost assumptions with well-founded estimates, e.g. based on interviews with vessel owners and operators, regarding technology adoption across the various vehicle families, which were then aggregated again for the entire fleet. However, again here an optimistic assumption is applied for the policy framework, assuming CO<sub>2</sub>e costs internalised in the fossil fuel prices and impactful ETS-2 and RED policies on EU level.

The Landscape of Synergies examines the interdependencies between policy, technology, and infrastructure. It notes that the adoption of hydrogen, methanol, and battery-electric propulsion is influenced by regulatory frameworks, infrastructure availability, and economic factors. For instance, the lack of bunkering facilities for hydrogen and methanol, as well as the need for standardized charging infrastructure for battery-electric systems, are key barriers to their widespread adoption. There is here also a big relation with safeguarding the demand for these renewable energy types. Policy plays a decisive role in creating demand for renewable energy and thus in investments in infrastructure and further developments such as capacity, standards new business models (energy as a service).

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **10** of **122**



The report suggests that a coordinated approach is necessary to address the economic, regulatory, and infrastructure challenges of decarbonization. This includes measures such as introducing carbon pricing, binding targets to use or supply renewable energy, providing financial (and fiscal) incentives (e.g. grant schemes using the revenues from carbon pricing), accelerating infrastructure development, harmonizing regulations, and fostering collaboration among stakeholders.

The report also emphasizes the importance of timely action. Given the long lifetimes of ships and technologies, delays in policy implementation could hinder progress toward the 2050 targets. The latest World Energy Outlook published after the completion of the scenarios reported herein did not include APS but re-introduced the Current Policies Scenario (CPS), which provides a more cautious perspective on the speed at which new technologies are deployed and integrated. This also reflects the general trends and shows that the economic success of most low- and zero-carbon technologies is likely to be further delayed unless regulatory measures are taken. Furthermore, the level playing field in Europe is at risk. Policies implemented in The Netherlands with the ETS-2 opt-in, large grant schemes (240 mln euro) and RED-III may be seen as a blueprint for other EU Member States, but the Dutch policy package would probably miss the target and fail if neighbouring countries do much less or nothing. It seems therefore mainly up to the EU policy makers to take legal actions to ensure a level playing field. Assuming such a stable EU framework for IWT, the SYNERGETICS Expert Scenario demonstrates that, with the right policy mix, the sector can make significant strides toward its decarbonization goals.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**Grant agreement no. | **101096809**Page **11** of **122**

# 1. Introduction

The boundary conditions for the transition towards a more sustainable and future-proof inland waterway transport sector are evolving dynamically. On the one hand, they are driven by technological innovation, regulatory developments, and insights from ongoing research initiatives. On the other hand, economic, societal and political frameworks are changing rapidly. Within this context, Task 5.2 aims to reassess and update existing transition pathways, ensuring they reflect the latest knowledge and developments emerging from the SYNERGETICS project and beyond.

Building on the transition pathways developed in the study on energy transition towards a zero-emission inland navigation sector preparing the CCNR Roadmap in 2021, this task takes stock of new findings generated within SYNERGETICS as well as relevant external initiatives, including results from other EU-funded projects such as STEERER and NEEDS. By integrating these insights, the task seeks to refine and enhance the existing pathways, maintaining their relevance and practical value for stakeholders.

In parallel, Task 5.2 explores the synergies between currently active projects and initiatives. By mapping these interactions and interdependencies, it aims to provide a comprehensive “landscape of synergies” that can support policymakers and other stakeholders in identifying opportunities for collaboration, alignment, and increased impact. Through this dual focus, the task contributes to a more coherent and informed approach to the sector’s transition.

## 1.1 Objectives and scope

The objective of Task 5.2 is to provide an updated and comprehensive understanding of transition pathways in the inland waterway transport sector, incorporating the latest technological, regulatory, and research developments. The task focused on reviewing and refining the transition pathways previously established in the context of the CCNR roadmap, taking into account insights from the SYNERGETICS project and the complementary EU projects STEERER and NEEDS.

In addition, the task examined the synergies between ongoing projects and initiatives, creating a structured “landscape of synergies” that highlights potential areas for collaboration and policy alignment. The scope of Task 5.2 therefore includes both the systematic updating of pathway information and the identification of interactions among initiatives, ensuring that the outcomes provide actionable guidance for stakeholders and support evidence-based decision-making in the sector. The outcomes of task 5.2 are essential for the creation of the scenarios for policy makers, which are outlined in task 5.3 and reported in SYNERGETICS Deliverable 5.3.



## 1.2 CCNR study and the transition pathways

The Central Commission for the Navigation of the Rhine (CCNR) developed, supported by DST and SPB/EICB, a business-as-usual scenario and two distinct but complementary transition pathways (1). The latter are target scenarios with the strict aim to achieve a near-zero-emission inland navigation sector by 2050 (achieving at least 90 % emission reduction in 2050 compared to 2015). These pathways are a central analytical pillar of the CCNR Roadmap adopted in 2021, building on extensive technical, economic, and financing studies conducted since 2019.

### 1.2.1 Purpose and Analytical Framework

The CCNR transition pathways aim to:

- Provide credible trajectories for both new and existing vessels,
- Reflect different levels of technological maturity and risk,
- Support policymaking under conditions of uncertainty,
- Enable progressive tightening of policy measures while safeguarding the competitiveness of inland navigation.

The analysis focused on tank-to-wake (TTW) emissions from propulsion and auxiliary systems, with the understanding that a well-to-wake perspective will be incorporated once sufficiently robust data are available. Similar to the IPCC accounting of GHG emissions, renewable fuels such as biofuels are regarded as 'zero-emission' in the analyses, based on the concept of a closed-loop biogenic carbon cycle.

### 1.2.2 Conservative Pathway

The conservative pathway is based on technologies that are already technically mature or close to market deployment. Its primary objective is to deliver early and cost-efficient emission reductions, especially for the existing fleet.

Key characteristics:

- Strong reliance on incremental improvements to conventional propulsion systems,
- Increased use of low-carbon and alternative fuels compatible with existing engines,
- Emission reductions achieved mainly through retrofits, efficiency improvements, and gradual fleet renewal,
- Lower short-term investment risk, but uncertainty regarding long-term availability and sustainability of fuels.

This pathway is considered essential to ensure near-term emission reductions and to avoid lock-in effects while zero-emission technologies are still under development.

### 1.2.3 Innovative Pathway

The innovative pathway reflects a technological leap towards zero-emission propulsion, particularly relevant for newbuild vessels and specific operational profiles.

Key characteristics:

- Deployment of zero-emission and near-zero-emission technologies that are currently at pilot or early commercial stage,
- Structural changes to vessel design, onboard energy systems, and operational concepts,
- Higher upfront investment costs and regulatory challenges, combined with higher long-term emission reduction potential,
- Strong dependency on the development of energy supply infrastructure, safety regulations, and financing instruments.

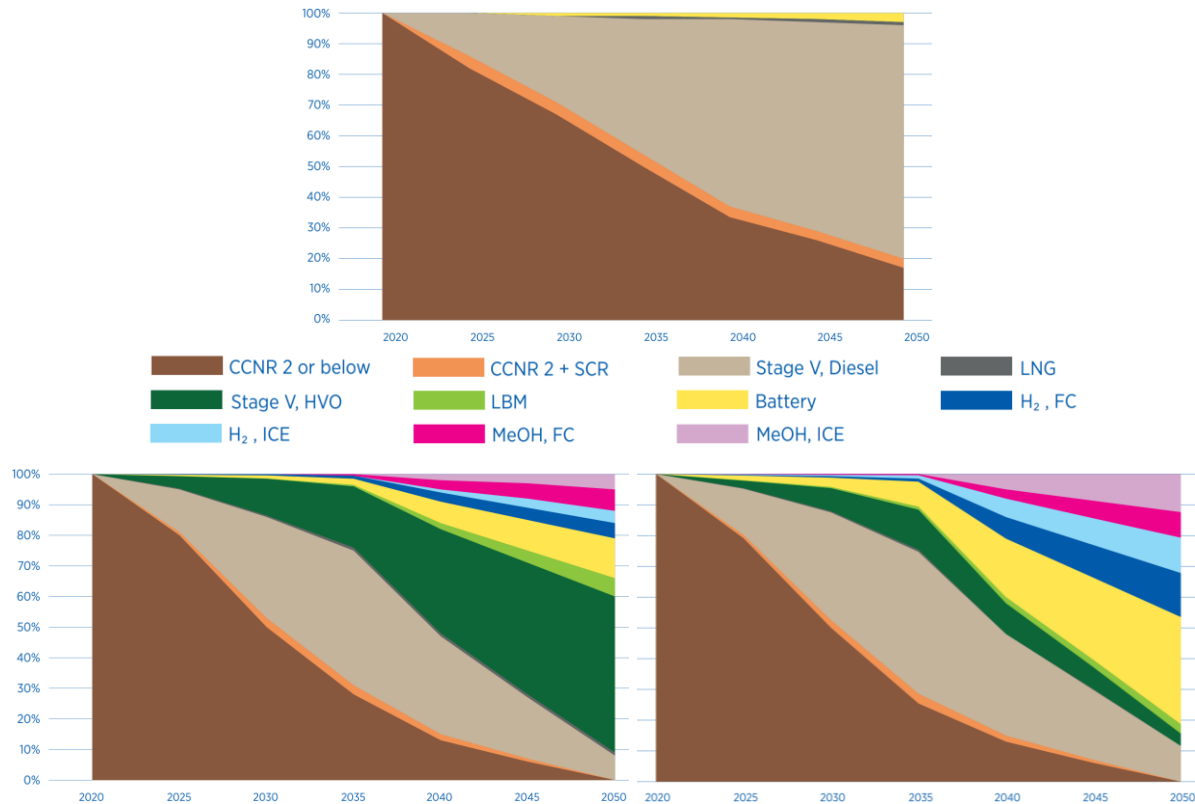
Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **13** of **122**



This pathway is expected to deliver the deep emission reductions required after 2035–2040, once mature technologies and economies of scale are achieved.



1 | Technology shares aggregated for all fleet families for the business-as-usual (top), conservative (bottom left) and the innovative transition (bottom right) pathways (source: CCNR roadmap)

### 1.2.4 Complementarity and Policy Implications

The CCNR does not consider the pathways as mutually exclusive. Instead, they are designed to:

- Co-exist and overlap over time,
- Address different vessel segments and investment cycles,
- Inform a sequenced policy mix combining regulatory certainty, financial support, and innovation incentives.

The CCNR study concludes that both pathways are options to meet the 2050 objectives, and that timely policy intervention is critical to guide investment decisions and to avoid stranded assets.



### 1.2.5 Outlook

Based on the progress assessed in later reports, the CCNR supports a revision of the roadmap<sup>1</sup> and its action plan by 2030, allowing the transition pathways to be updated in line with technological progress and evolving EU climate policy.

## 1.3 STEERER and NEEDS Projects

### 1.3.1 STEERER

The STEERER<sup>2</sup> project (Structuring Towards Zero-Emission Waterborne Transport) was executed between 2019 and 2022; it supported the development of a coherent Strategic Research and Innovation Agenda (SRIA) for zero-emission waterborne transport across maritime and inland modes.

#### STEERER and Inland Waterway Transport

STEERER identifies inland waterway transport as an integral part of the transition towards zero-emission waterborne transport, requiring coordinated action across technology development, policy, and market uptake, aligned with EU climate targets for 2025, 2030 and 2050.

STEERER concludes that decarbonisation pathways must be differentiated by waterborne segment, implying that IWT requires tailored solutions reflecting vessel types, operational profiles, and regional infrastructure conditions rather than one-size-fits-all measures. The STEERER Agenda and Implementation Plan explicitly include:

- assessment of the state of play of decarbonisation across waterborne transport,
- scenarios with quantified emission targets for 2025, 2030 and 2050,
- priority intervention areas and actions, and policy instruments, incentives and business models to accelerate uptake of zero-emission solutions.

These elements are directly relevant for IWT, as they frame how research, innovation and deployment pathways should be organised at EU level. For IWT, STEERER highlights the importance of public policy instruments and supportive frameworks to move from R&I towards deployment, including mechanisms that reduce investment risk and improve business cases for clean vessels and infrastructure.

STEERER produced a carbon-budget assessment for waterborne transport as a whole, designed to align the sector with international and EU climate targets (Paris Agreement, EU Green Deal). The assumption by STEERER is that the IWT greenhouse gas emissions concern a volume of 4.53 MtCO<sub>2</sub> per year (reference year 2017). This is around 0.4 % of the emissions of the overall waterborne sector. For the GHG emission evolution of IWT, STEERER took into account the Renewable Energy Directive and the Fuel Quality Directive and concluded that IWT would miss the Zero Emission by 2050 target by 87 %, clearly stating that additional measures are needed.

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<sup>1</sup> See : [https://www.ccr-zkr.org/files/documents/Roadmap/2025\\_Roadmap\\_en.pdf](https://www.ccr-zkr.org/files/documents/Roadmap/2025_Roadmap_en.pdf)

<sup>2</sup> See for more information about the STEERER project: <https://www.waterborne.eu/projects/coordination-projects/steerer>



## STEERER and coastal vessels

STEERER treats coastal and short-sea shipping as a distinctly important seagoing segment because the vessels:

- operate largely within EU waters,
- contribute disproportionately to air pollution in coastal areas and ports, and
- are earlier exposed to EU climate regulation than deep-sea shipping (e.g. EU ETS, FuelEU Maritime).

Emissions from seagoing ships calling at EU ports are substantial, reinforcing the urgency for action in coastal shipping. STEERER maps EU Green Deal / Fit for 55 trajectories onto all seagoing ship segments, including coastal vessels and aligns them with the vision of zero-emission waterborne transport (ZEWT) by 2050. For coastal shipping this implies:

- strong emission reductions by 2030, consistent with EU maritime policy pathways,
- near-zero / zero GHG emissions by 2050, provided regulatory and technology deployment keeps pace.

STEERER identifies coastal vessels as frontrunners for early decarbonisation, because of their operational profile. Technologies considered particularly suitable are battery-electric and hybrid propulsion, renewable drop-in fuels (e.g. advanced biofuels) and hydrogen- and methanol-based solutions on selected routes. Coastal shipping is advantaged compared to deep-sea shipping due to its

- shorter and more predictable routes,
- frequent port calls,
- easier integration with shore-side electricity and alternative fuel infrastructure.

As a result, STEERER treats coastal shipping as a key testbed for technologies that later scale to wider seagoing fleets.

Ports and infrastructure are decisive factors. STEERER highlights ports and coastal nodes as critical enablers for shore-side electricity (OPS), bunkering of alternative fuels as well as grid connection and energy availability. For coastal vessels, OPS and port-based measures are identified as among the fastest and most cost-effective emission reduction options, particularly for emissions at berth and near populated areas.

STEERER stresses that decarbonisation of coastal shipping depends heavily on EU-level policy coherence. Key instruments affecting coastal vessels:

- EU ETS (maritime extension),
- FuelEU Maritime (GHG-intensity of energy consumption on a well-to-wake basis expressed in grams CO<sub>2e</sub> per MJ of energy),
- AFIR (Alternative Fuels Infrastructure Regulation, port infrastructure for OPS and alternative fuels).

STEERER's conclusion is that coastal shipping will decarbonise earlier than deep-sea shipping, precisely because these EU instruments apply first and most strongly to vessels operating in and around EU ports. However, it needs to be noted here that a large part of the coastal fleet consists of smaller vessels below 5000 GT which are currently not yet subjected to the ETS and FuelEU Maritime regulations. If the scope is not enlarged (e.g. from vessels starting at 400 GT, as currently applied in the MRV Maritime Regulation) the energy transition of the coastal vessels may happen much later for the group of vessels below 5000 GT.

Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. **| 101096809**

Page **16** of **122**



Across D2.2 and related outputs<sup>3</sup>, STEERER's core message for seagoing coastal vessels can be summarised as follows: Coastal shipping is a priority segment for early and deep decarbonisation within the seagoing fleet, capable of reaching near-zero greenhouse gas emissions by 2050 and delivering substantial reductions already by 2030, provided that EU climate regulation, port infrastructure deployment and zero-emission vessel technologies are implemented in a coordinated manner.

### 1.3.2 NEEDS

The NEEDS project<sup>4</sup> was executed during 2022 and 2023. NEEDS stands for NEw sustainable fuel Deployment Scenarios for the European waterborne community. The main objective of NEEDS was to provide a model and methodology to define and assess the most efficient strategies to be deployed for successfully reaching the European target of 90% GHG emission reduction for waterborne activities by 2050, for selected regions. A dynamic techno-economic model was developed in this project and demonstrated for Inland Waterway Transport (Rhine corridor) and also for specific coastal vessel operations in Greece.

### NEEDS and IWT

NEEDS developed a generic dynamic techno-economic model that represents inland waterway transport as an integrated system linking:

- vessels and fleets (existing and future technologies),
- energy carriers and fuel supply chains (conventional and alternative),
- port and inland infrastructure (bunkering, charging, logistics),
- transport demand and network characteristics at regional level.

The model is dynamic in time, allowing scenarios to evolve towards 2050 rather than comparing static end-points. For IWT, the model was applied to a real inland navigation region (Rhine corridor), with region-specific data on fleets, routes, energy demand, and infrastructure. This allows realistic baseline ("business-as-usual") scenarios and alternative decarbonisation pathways to be compared within the same framework. The model supports:

- comparison of different sustainable fuel pathways (e.g. electricity, hydrogen-based fuels, e-fuels),
- variation of key parameters (fuel costs, technology learning rates, infrastructure rollout speed),
- assessment of system responses over time (fleet renewal, energy demand shifts, cost evolution).

The approach is explicitly designed to support policy makers, regional authorities, and sector stakeholders, not only technology developers. Outputs are presented through reports and an interactive dashboard rather than as black-box modelling results.

#### Key findings for inland waterway transport

- No single "winning" fuel pathway: for inland waterways, NEEDS shows that no single alternative fuel or technology dominates across all scenarios. Outcomes strongly depend on: regional energy availability, cost assumptions for low-carbon fuels, infrastructure deployment speed, fleet renewal dynamics.

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<sup>3</sup> See [https://www.waterborne.eu/images/D2.2\\_Scenarios\\_with\\_quantified\\_targets\\_for\\_2025\\_2030\\_and\\_2050\\_-\\_Common\\_stakeholder\\_target\\_scenarios.pdf](https://www.waterborne.eu/images/D2.2_Scenarios_with_quantified_targets_for_2025_2030_and_2050_-_Common_stakeholder_target_scenarios.pdf)

<sup>4</sup> See for more information: <https://www.waterborne.eu/projects/coordination-projects/needs/about-needs>



- Importance of infrastructure synchronisation: the modelling highlights that fleet transition alone is insufficient. Delays or mismatches in: charging infrastructure, bunkering capacity for alternative fuels, port and hinterland energy supply can significantly slow down or undermine decarbonisation trajectories, even if vessel technologies are available.
- Path dependency and timing matter: early decisions strongly influence long-term outcomes:
  - Early investments in certain fuels or infrastructures can create lock-in effects.
  - Gradual, well-sequenced deployment performs better than late, abrupt transitions in terms of system cost and feasibility.

The Rhine IWT case shows that inland shipping can make significant contributions to decarbonisation of the transport sector, but only if energy transition strategies are coordinated with those of ports and energy systems and policy measures are consistent over time and across sectors (transport, energy, industry).

A key meta-finding is methodological: dynamic techno-economic modelling provides more robust policy insights than static comparisons, especially for inland waterways where asset lifetimes are long and infrastructure decisions are capital-intensive.

### **NEEDS and coastal shipping**

For coastal shipping, NEEDS applied its generic dynamic techno-economic model to a real regional case: the Greek coastal shipping network. The model represents coastal transport as an integrated system combining:

- vessel categories (conventional ferries, catamaran ferries, short- and long-route vessels),
- representative routes and sailing profiles,
- ports and energy infrastructure,
- alternative fuels and propulsion technologies.

A comprehensive base-case (BAU) scenario was established using:

- fleet categorisation and operational data for selected vessels,
- realistic route lengths, frequencies and port calls,
- existing and planned port infrastructure,
- creating a robust reference against which transition scenarios are evaluated.

Building on the base case, NEEDS developed and assessed multiple sustainable fuel deployment scenarios (D2.3), exploring combinations of:

- battery-electric propulsion (especially for short routes),
- hybrid configurations,
- Bio-LNG,
- hydrogen-based solutions for longer routes.

Scenarios are “forced” in the sense that specific technology roll-outs are assumed, allowing the model to test system-wide impacts under different policy and investment choices. The modelling tracks how fleet composition, energy demand, emissions and costs evolve over time, rather than comparing isolated static snapshots. This highlights transition dynamics, investment timing and infrastructure constraints.

#### Key findings for coastal vessels

- Route length strongly determines optimal technology. A central finding is the clear differentiation between short and long coastal routes:
  - Electric propulsion performs best on short routes, where energy demand, charging time and battery weight remain manageable.
  - Longer routes require energy-dense fuels, with Bio-LNG and hydrogen-based options emerging in several scenarios.

Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. **| 101096809**

Page **18** of **122**



- No universal solution for the coastal fleet. The coastal fleet is heterogeneous. NEEDS shows that a single fuel or technology pathway is neither realistic nor optimal for all vessel types and routes. Mixed-technology portfolios consistently outperform single-solution strategies in terms of feasibility and cost.
- Infrastructure availability is a decisive bottleneck. Successful decarbonisation of coastal vessels heavily depends on timely deployment of charging and bunkering infrastructure in ports and alignment between fleet upgrades and port investments. Even technically robust vessel solutions underperform if port infrastructure lags behind fleet transition.
- Early policy choices create long-term lock-in. The scenario analysis reveals strong path-dependency:
  - Early commitment to certain fuels (e.g. LNG-based pathways or full electrification of short routes) shapes fleet renewal decisions for decades.
  - Late course corrections increase system costs and reduce achievable emission reductions.
- Coastal shipping can achieve substantial GHG reductions towards 2050, but only if:
  - technology choices are route-specific,
  - infrastructure, energy supply and fleet renewal are coordinated and
  - policies provide stable, long-term signals to operators and ports.

For EU and national coastal shipping policy, NEEDS demonstrates that: route-differentiated regulation is more effective than uniform fuel mandates, port energy infrastructure planning is as critical as vessel technology support and dynamic scenario modelling is essential to avoid costly lock-ins and unrealistic roadmaps.

## 1.4 Synergies between projects and initiatives

### IWT Projects Cooperation Platform

The IWT Projects Cooperation Platform<sup>5</sup> is a European initiative designed to connect, coordinate and amplify the impact of EU-funded research, development and innovation (RD&I) projects in Inland Waterway Transport (IWT). It provides a shared collaboration and dissemination framework for projects addressing the green and digital transition of IWT. Core objectives are:

- To enable synergies between projects by mapping overlaps, complementarities and gaps across technologies, market segments and regions.
- To strengthen knowledge exchange through shared documentation, thematic focus groups and joint events.
- To increase impact and visibility of project results via joint communications, recommendations and stakeholder engagement.
- To support policy uptake by formulating consolidated messages and feedback to EU institutions (e.g. on NAIADES III / post-2027 agenda).

The scope concerns primarily Horizon Europe IWT projects, complemented by CEF, Innovation Fund, INTERREG and LIFE initiatives. Key thematic clusters include:

- Zero-emission waterborne transport
- Digitalisation
- Hydrogen and battery technologies
- Logistics and modal shift
- Skills and human factors

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<sup>5</sup> See for more information: [iwtprojects.eu](http://iwtprojects.eu)



The IWT Projects Cooperation Platform is highly relevant for SYNERGETICS because it directly addresses one of SYNERGETICS' core challenges: fragmentation of greening and retrofit efforts across parallel projects. For SYNERGETICS, the platform:

- Positions its retrofit solutions within the broader European IWT technology landscape, avoiding duplication and improving coherence.
- Enhances dissemination and exploitation of SYNERGETICS outputs (Catalogue, Handbook, Scenarios, Decision Support Tool) through joint channels and events.
- Facilitates structured exchange with complementary projects working on vessels, fuels, infrastructure and policy enablers, strengthening uptake potential.

Technology synergies between SYNERGETICS and other IWT projects are the following:

a) Zero-emission and alternative fuels

The platform clusters projects working on hydrogen, methanol, battery-electric and hybrid solutions for inland vessels. SYNERGETICS contributes retrofit-ready vessel solutions, while other projects address fuel production, bunkering, safety concepts or infrastructure, creating a fuel-to-vessel system perspective.

Synergy: Alignment of onboard retrofit technologies (SYNERGETICS) with upstream fuel and infrastructure development (other ZEWT projects).

b) Energy efficiency & hydrodynamics

Multiple IWT projects address energy efficiency, vessel optimisation and operational improvements. SYNERGETICS specifically demonstrates hydrodynamic retrofit measures on existing vessels.

Synergy: Validation and cross-comparison of hydrodynamic measures across projects, supporting standardisation and broader market confidence.

c) Digitalisation and decision support

Digital tools and data-driven approaches are a recurring theme across the platform. SYNERGETICS delivers decision-support tools, a retrofit catalogue and policy scenarios, directly usable by vessel owners and authorities.

Synergy: Interoperability between digital tools, shared assumptions, and harmonised methodologies for evaluating retrofit and zero-emission options.

d) Policy uptake and regulation

The platform enables joint recommendations to policymakers on removing barriers and enabling deployment of clean technologies. SYNERGETICS explicitly works on regulatory streamlining and policy scenarios for retrofit deployment. [

Synergy: SYNERGETICS' evidence from vessel demonstrations feeds into platform-level policy messages, increasing credibility and impact.

### **SYNERGETICS WP2 database and showcases**

Within Task 2.1 of the SYNERGETICS project a Pilot Database containing pilots with a potential for the project to learn from and/or to interact with (e.g. a (high) learning potential) has been compiled. The database contains approximately 200 identified pilot vessels.

It has been validated by partners and stakeholders through consultation and specific workshops. Furthermore, an assessment has been made to see which of these pilots should be in focus of the SYNERGETICS partners in the framework of follow-up tasks.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **20** of **122**

The SYNERGETICS partners and various stakeholders have assessed all pilots. As a result, around 90 pilot vessel projects are marked with highest ranking as they seem to have a (very) high potential to learn from and/or to cooperate with in order to create synergies. Especially these vessels are relevant also for the landscape of Synergies. Moreover, valuable lessons were identified and presented in WP2 of SYNERGETICS.



## 2. New developments and insights

Since the publication of the CCNR Roadmap and the related transition pathways, several important technological, economic, and regulatory developments have emerged. These developments provide new insights into the feasibility, costs, and emission impacts of different decarbonisation options for inland navigation, highlighting the need to update the original assumptions and projections.

A key area of change is the evolution of zero-emission technologies. The development of some technologies went faster (for example swappable battery technology applications) while others have progressed slower (for example methanol fuel cell applications). Also, the cost estimates for different technologies changed. As a result, the expected technology shares in future scenarios may shift significantly, with a higher potential uptake of battery electric based propulsion systems than originally projected.

The costs of renewable electricity and batteries tend to decrease, improving the economic viability of electrification, particularly for shorter routes in inland navigation. At the same time, uncertainty remains around the future costs of hydrogen and other renewable fuels, influenced by energy market volatility and investment needs in production facilities and infrastructure. These changes suggest that previous cost assumptions in the CCNR pathways may no longer reflect current and future market conditions. Updated costs for different energy carriers are presented in the Annex.

Furthermore, policy and regulatory developments at the European level can accelerate the transition. Initiatives such as stricter emission targets resulting from national implementation of RED-III, carbon pricing mechanisms resulting from national implementation of ETS-2 (opt-in), and accompanying national grant schemes lead to a better outlook for emission reduction and decarbonisation options in some countries. The plans in The Netherlands can be seen as a game-changer for European IWT if these plans are followed as well by other Member States. The planned measures are expected to directly influence both technology adoption rates and economic feasibility, requiring updated modelling assumptions. Therefore, a revised business-as-usual scenario already may assume a certain level of internalisation of emission costs and phasing out of fossil diesel. This is also reflected in the STEPS scenario developed by SYNERGETICS based on the International Energy Agency World Energy Outlook 2024 report.

Overall, these new developments demonstrate that the transition landscape is evolving. Updating the CCNR pathways is therefore necessary to reflect the expected total costs of ownership trajectories. Another major change is a more advanced understanding of emission impacts, with the well-to-wake scope applied in SYNERGETICS. Including also the indications on the well-to-tank emissions for the production and supply of fossil and renewable energy types, ensures that the pathways remain relevant and can effectively support policymakers and stakeholders in making informed decisions towards a sustainable and low-emission shipping sector.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **22** of **122**



## 2.1 Applicability of technologies and renewable energies

In the CCNR pathways a selection of energy types and technologies have been taken into account in the scope to assess the impact on costs and emissions. The following table presents the energy types and presents in the right column the latest developments.

1 | Overview of energy types and relevant developments since 2021.

Technology	Relevant developments since 2021
CCNR 2 and below	No relevant developments
CCNR 2+SCR	It was expected that more engines would be retrofitted with SCR as result of a large Dutch subsidy scheme. However, this did not materialise.
Stage V, Diesel	The Dutch subsidy schemes (until 2025) proved to be rather popular to replace existing engines with Stage V engines. Afterwards, new engines were mainly placed in newbuild ships and fewer upgrades of the existing fleet were done.
Stage V, HVO	The revised Renewable Energy Directive (RED-III) is expected to create a higher demand for HVO and other Drop-in fuels (e.g. FAME) in the 'business as usual scenario'.
LNG	Due to the price levels of LNG versus diesel, especially since the Russian aggression towards Ukraine, the market potential for LNG declined significantly. It even led to existing LNG propelled vessels converted back to diesel fuelled vessels.
LBM	Seen the reduced market demand for LNG the step to start using biomethane as drop-in fuel to replace fossil fuel is expected to be less effective to reduce the emissions of the fleet.
Battery	In the CCNR study only the fixed battery on board concept was assumed. In particular the NEEDS results and also recent results from PLATINA4Action, point towards more favourable business cases for containerised exchangeable batteries. This option therefore needs to be considered and included in the update. Moreover, improvement is expected in the capacity of batteries and also the recharging speeds. A bottleneck could however be the available grid capacity for recharging the batteries.
H <sub>2</sub> FC	The Hydrogen Fuel Cell application is demonstrated in practice but suffers from very high total costs of ownership. Also, the PLATINA4Action report D4.2 points towards quite high costs levels. It seems to be questionable if there will be a significant uptake of H <sub>2</sub> FC in future.
H <sub>2</sub> ICE	The hydrogen combustion option is expected to have lower overall total costs of ownership compared to H <sub>2</sub> FC. In contrast to fuel cell systems or batteries, no rare raw materials are needed for the production of the combustion engine, lifetime is higher and investment costs are lower compared to fuel cell systems. Furthermore, the fuel quality requirements will be less strict, which improves reliability and durability. The legal provisions in the NRMM regulations will also be available on relative short term with the addition of hydrogen as a reference fuel. In addition, there is a subsidy scheme in The Netherlands to support engine manufacturers to certify

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **23** of **122**



hydrogen engines for IWT. Therefore, the outlook for H2ICE is more positive today compared to 5 years ago. Critical is however the price of green H2 which plays a dominant role in the Total Cost of Ownership. The revision of RED-III which sets minimum targets for sales of RFNBO (hydrogen from electrolyses) can support the reduction of the price of H2 for consumption by IWT. A further change compared to the CCNR study from 2021 could be in dual fuel ICE engines, which have a lower fuel-replacement rate but can also use for example HVO100 in case H2 is not available or affordable, as this reduces the investment risk for the vessel owner significantly.

MeOH FC

This option consists of a hydrogen fuel cell that extracts the hydrogen from the methanol using a cracker. An advantage of methanol over hydrogen is that methanol as fuel can be stored in liquid form at ambient temperature and pressure in normal tanks. In 2021 the methanol Fuel Cell option was demonstrated (MS Innogy) and technical regulations for vessels (ES-TRIN) have been prepared. However, there were high costs and problems which led to cancelation of the demonstrator which is now operating on batteries. Since then, though, the German company Freudenberg has made a fresh start to make methanol fuel cells available for ships<sup>6</sup>. The latest activities are in the project zero4cruise<sup>7</sup>.

MeOH ICE

The development of methanol applied for combustion engines was first driven by the ambitions to use methanol in marine engines for seagoing vessels. The long-term focus for seagoing vessels now seems to be more moving towards ammonia as fuel with less attention for methanol. For the application in inland vessels a bottleneck is the required revision of the NRMM Regulation. There are concerns about the formaldehyde emission levels which need to be researched and require an impact assessment before revision of NRMM regulation can take place. It is expected that it will take a few years, though SYNERGETICS demonstrators provided some insights and partners support the process. Additionally, in The Netherlands a subsidy scheme started to support testing and certification of NRMM engines using methanol which can possibly accelerate the revision process. When looking at the price predications of green methanol, it could be an interesting option leading to a relatively low total costs of ownership.

Similar to H2 ICE, a further change compared to the CCNR study could be to assume a dual fuel engine, to reduce the investment risk for the vessel owner.

<sup>6</sup> <https://www.now-gmbh.de/aktuelles/pressemitteilungen/weltweit-erstes-methanolbetriebenes-brennstoffzellen-system-erhaelt-zertifizierung/>

<sup>7</sup> [zero4cruise](#)



## 3. Methodology

### 3.1 Approach for updating Transition Pathways for IWT

First, the pathways for the target scenarios from the CCNR study were recalculated, primarily to test the functionality of the new model, and to identify potential deviations and to assess their impacts. Subsequently, the technology shares from the NEEDS model were simulated, and both costs and achievable emission reductions were determined. These results, together with findings from the CCNR study and recent sector developments, were incorporated into the newly created SYNERGETICS scenario. It is important to emphasize that, unlike the CCNR study, the SYNERGETICS scenario does not aim to meet a specific emission target.

The favourable outcomes in terms of emissions and costs are largely driven by optimistic boundary conditions. In the NEEDS model, a 60 % CAPEX subsidy is assumed, which strongly incentivizes ship-owners to adopt alternative propulsion systems. This assumption is also reflected in the SYNERGETICS scenario. In addition, component costs for alternative propulsion technologies are expected to decrease by up to 30 % by 2050.

Furthermore, the STEPS scenario was used to apply energy price developments. This scenario assumes a positive trend for renewable energy prices, while fossil fuel prices continue to rise, making them increasingly unattractive and further accelerating the transition.

Another key factor is the improvement in energy efficiency. Practical experience shows that most existing inland vessels still offer considerable optimization potential, while new vessel designs are significantly more efficient. It is assumed that this potential will be fully realized by 2050, resulting in a 30 % increase in energy efficiency. This includes both technical improvements and operational measures, such as more energy-efficient navigation and enhanced traffic management.

However, if these assumptions are not fully met, the likelihood of achieving the calculated emission reductions in the SYNERGETICS scenario decreases significantly, potentially to the point of infeasibility. The scenario therefore heavily relies on the realization of these conditions. At the same time, this highlights an important insight: the key factors required for a successful energy transition in inland waterway transport can already be identified and quantified today.

### 3.2 Creating the “landscape of synergies”

To develop a comprehensive and up-to-date landscape of synergies, a structured, multi-step methodology was applied, combining data integration, systematic screening, and thematic clustering. First, the existing IWT projects platform served as the primary data source. This platform provides a structured overview of both ongoing and completed projects as well as participating organizations. It was systematically screened to identify projects relevant to the scope of this analysis, while also mapping existing relationships and collaborations between stakeholders. This initial step ensured a solid baseline, grounded in verified and already interconnected project data.

Second, to enhance completeness and to ensure the inclusion of the most recent developments, this dataset was subsequently complemented with additional projects identified through the SYNERGETICS WP2 database. By integrating this second source, the analysis captured newer initiatives and projects that were not yet reflected in the IWT projects platform, thereby improving both the relevance and the coverage of the overall landscape.

Following the data collection, all identified projects were analysed and grouped using a clustering approach. At the first level, projects were categorized based on their primary technological focus. This resulted in a high-level segmentation across key propulsion and energy pathways, including electricity, hydrogen, methanol, LNG, as well as multi-technology or hybrid solutions. This categorization provided a clear overview of the main technological directions within the sector. At the second level, projects

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **25** of **122**



were further clustered around thematic areas, thus enabling the identification of shared challenges, opportunities, and potential knowledge exchange pathways.

Finally, the clustered dataset was reviewed to highlight potential synergies, with particular attention to overlaps in technological focus, complementary expertise, and opportunities for collaboration among projects and platform members. This step transformed the structured dataset into a more strategic landscape, revealing how individual initiatives can collectively contribute to a more integrated and efficient transition toward sustainable maritime solutions.

Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. **| 101096809**

Page **26** of **122**

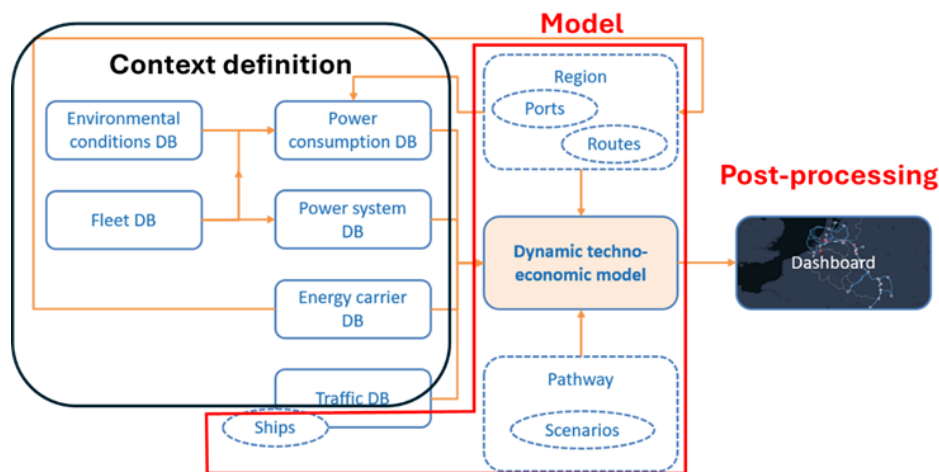


## 4. NEEDS IWT model application

For SYNERGETICS Task 5.2, the NEEDS model was further developed and applied to analyse techno-economic transition pathways for inland waterway transport at fleet level, building on the original Rhine case<sup>8</sup>.

### 4.1 Model description

The NEEDS model follows a three-stage workflow: context definition, dynamic simulation, and post-processing. Within this workflow, four interacting concepts are modelled: the region (Rhine), the fleet (Inland waterway transport ship types and routes), power systems (alternative fuels and technologies), and techno-economic scenario definition such as the stated policies scenario (STEPS), and net zero emissions (NZE).



2 | NEEDS model overview and three-stage workflow definition: Context definition, Model, Post-processing

1. Context definition: defining and initializing data for the model
  - a. Region: Includes ports, generic routes and temporal weather effects from the selected geographic area. This data is used to calculate the power consumption database, which reflects the fuel use of a ship along a selected route over time.
  - b. Fleet & traffic: The fleet DB includes ship parameters of all ships that are included in the simulation, and the Traffic DB includes a collection assigned routes for each ship.
  - c. Power system: Describing potential power and energy system characteristics, including power, fuel use, reduced payload and energy carrier data.
  - d. Scenario: Describing economic and regulatory developments impacting alternative fuel uptake, including capital and operational cost, expected technological and social readiness levels and fuel port availability.

<sup>8</sup> Waterborne Technology Platform, "D3.3 Scenarios for the Inland Region," Waterborne Needs Project. [Online]. Available: <https://waterborne.eu/images/documents/needs/waterborne-needs-d3.3.pdf>



2. Dynamic techno-economic model: using the defined context, the needs model simulates each vessel sailing using discrete events.
  - a. Ship model simulates the ship sailing while considering weather, ship hydrodynamics and the selected power system.
    - i. Ship hydrostatics includes water depth, weather from ERA5<sup>9</sup>, ship particulars (draft, load)
    - ii. Ship decisions: where and when to bunker, whether to retrofit the vessel based on temporal costs, readiness levels and fuel availability
  - b. Port: simulated locations where a ship can bunker fuel, or retrofit
  - c. Region: keeps track of the fleet level developments, including cargo capacity, newbuilds and retrofits
3. Post-processing: During post processing the resulting data from ports, ships and the region is collected and aggregated to build graphs suited for interpretation.

A more extensive description of the model can be found at [NEEDS]. This also includes the adopted decision logic that drives ship decisions. Nevertheless, the system selection logic that directly impacts the results is further explained in the Annex to provide insight into how the ship level retrofit logic considers both cost and technological and social developments.

## 4.2 Model development

Several model developments were required to support the increased fleet size, expanded scenarios, and updated input data; these changes are described below together with their motivation and effect.

- Context definition:
  - o As the fleet is significantly larger than the initial implementation the data initialization needed to be modified.
  - o The scenario data input was improved to support the ability to modify and track many inputs from different sources
- Model:
  - o Initialization: slow for large number of ships
  - o Ports: add shipyard functionality
  - o Ships: update to manage memory issues when running a larger fleet
  - o Region: include stock-fleet to improve fleet cargo capacity balancing through newbuild and retrofit
- Postprocessing:
  - o Added technology share figure
  - o Added fleet family and yearly data aggregation and provided the option to download only the selected data

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<sup>9</sup> H. Hersbach and National Center for Atmospheric Research Staff, "The Climate Data Guide: ERA5 atmospheric reanalysis," Dec. 11, 2025. [Online]. Available: <https://climatedataguide.ucar.edu/climate-data/era5-atmospheric-reanalysis>. [Accessed: May 26, 2026].



#### 4.2.1 Context definition

The traffic and energy carrier databases used to be large tables that were difficult to read, check and modify. To ensure inputs are correct, the initialization now uses the Json data exchange format with input validation. Additionally, the database now works with multiple separated tables to improve readability and modifiability. Lastly, an optional input data summary function was added for reporting purposes.

#### 4.2.2 Dynamic model

To support an increased fleet size and number of scenarios, the model had to be modified to manage computational complexity. The ship model was modified to reduce the memory used by the expanding data stored for each ship, a ship specific history tracker was added to track variables like fuel use and capacity. Additionally, the computational time of the "captain decision mimic", which decides when to bunker, was reduced by decreasing the use of a heavy refuel computation by estimating the expected fuel use from most recent fuel use data. The region model was modified as the increasing result log due to the larger fleet resulted in memory issues. It was solved by periodically saving and removing result data, but this required the use of different file-types, restructuring the model and postprocessing.

Additionally, the fleet behaviour was extended to include a stock fleet functionality. This allows a ship to be stocked (lay-up) when cargo demand is down and re-used on other routes when a ship of that ship type is requested there. This was done through a 2-stage fleet capacity check.

The first stage instantly adds a vessel from the stock fleet to deal with capacity gaps due to retrofit or scrapped vessels. Here it is assumed that shippers find replacement vessels from the stock fleet in advance when planning retrofit or scrapping a vessel.

The second stage occurs in the region level, which controls the fleet size based on cargo capacity demand or lacking stock. The region checks the cargo capacity of the fleet against a "business as usual" cargo capacity benchmark. The cargo capacity can fluctuate when ship payload, speed or number of trips decrease due to the use of alternative energy carriers. To balance the cargo capacity supply along a route, the region adds or removes ships from the stock fleet. A ship is newbuild and placed in the stock fleet if a requested ship-type is not in stock.

#### 4.2.3 Post-processing

First, the post-processing pipeline had to be rebuilt to deal with the new result-data output file-type. Furthermore, the larger fleet data results in large output files, which cannot be read in one step. To deal with this, the post-processing was rebuilt to support streaming of data, so it can be read and processed in chunks. The postprocessing was also added on to calculate the monthly technology share and provide the ability to calculate data for separate ships on a route, or for pre-defined ship-types or fleet families.

Lastly, for sharing data, the NEEDS model outputs results to an online dashboard, which had to be extended to include the technology share graph. Besides this, the download functionality was modified to support the aggregation and download of yearly or monthly data. This works to enable coupling the results to other models (such as the fleet model), the dashboard was updated to output monthly or aggregated yearly data on vessel or fleet level on request.

### 4.3 Input parameters and scenarios

For the inland transport application, the region, power system and fleet of the context definition step were updated with recent data. Additionally, as the initial NEEDS modelled a representative but smaller Rhine inland fleet as a proof of concept, it was decided to extrapolate the fleet. Additionally, new scenarios were defined to reflect NZE and STEPS transition pathways, further extended by investigating

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **29** of **122**



the impact of extreme cost estimates (minimum-maximum) and a 60% subsidy on capital cost. To summarize, compared to the original NEEDS Rhine case, the following context definition updates were made.

- Fleet: Increased fleet size, re-used traffic and fleet definitions, but aggregated ship-types into fleet families as defined in the table below.
- Power systems: Updated energy system selection and properties.
- Region: Re-used Rhine definition and traffic
- Scenarios: Updated scenario input to new CCNR scenarios, also including capex subsidy.

The specific inputs used in the model are described next.

### *Fleet input*

The fleet is extrapolated to approximate the European inland fleet, covering 68% of vessels and representing 84% of dominant energy use patterns.

### 2 | SYNERGETICS fleet extrapolation

Type of vessel	Ship Type in NEEDS	Vessels in the EU fleet	Diesel consumption per year [m <sup>3</sup> ]
<b>Motor cargo vessels (MV) &gt;= 110 m</b>	MVS 110m, MVS 135m	610	206740
<b>Motor tankers (MT) &gt;= 110 m</b>	MTS 110m, MTS 135m	602	83168
<b>Motor cargo vessels (MV) 80-109 m</b>	MVS 105m, MVS 86m	1801	291470
<b>Motor tankers (MT) cargo 80-109 m</b>	MTS 86m	647	153209
<b>Motor vessels (MV) &lt; 80 m</b>	MVS 67m	4463	219456
<b>Push boats with P &gt; 2000 kW</b>	PushB4	36	74520
<b>Coupled convoys</b>	C3L/B	140	78155
<b>Total</b>		8299	1106718
<b>Total in PROMINENT D6.3/D6.5</b>		12262	1323847
<b>Share covered by vessel types</b>		68%	84%

This information is used as input for determining the number of vessels and the proportion of different vessel types within the total fleet. The number of vessels per route is subsequently based on NEEDS Deliverable 1.2, as shown in 3 | NEEDS model SYNERGETICS fleet size and route distribution. The resulting fleet size per vessel type is extrapolated across these routes by distributing the vessels of each type evenly over the routes as shown in the distribution column. Additionally, after initial runs with the full fleet size it was verified that a reduced fleet size as shown in the last column "Reduced fleet size" could be used to manage computational time and increasing the number of tested scenarios, without impacting results.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **30** of **122**



## 3 | NEEDS model SYNERGETICS fleet size and route distribution

Ship Type	Port of origin	Port of destination	NEEDS D1.2 ships	Distribution	EU number per type	SYNERGETICS fleet size	Reduced fleet size
<b>PushB4</b>	Rotterdam	Duisburg	9	9/9	36	36	2
<b>C3L/B</b>	Rotterdam	Antwerp	40	40/84		66	4
<b>C3L/B</b>	Amsterdam	Karlsruhe	17	17/84		28	1
<b>C3L/B</b>	Rotterdam	Basel	9	9/84		15	1
<b>C3L/B</b>	Amsterdam	Antwerp	9	9/84	140	15	1
<b>C3L/B</b>	Rotterdam	Gross Krotzenburg	5	5/84		8	1
<b>C3L/B</b>	Antwerp	Duisburg	4	4/84		6	1
<b>MTS 110m</b>	Rotterdam	Kampen	4	4/35		68	4
<b>MTS 110m</b>	Terneuzen	Rotterdam	3	3/35	602	51	3
<b>MTS 135m</b>	Rotterdam	Karlsruhe	22	22/35		378	23
<b>MTS 135m</b>	Amsterdam	Rotterdam	6	6/35		103	6
<b>MVS 110m</b>	Antwerp	Thionville	16	16/60		162	10
<b>MVS 110m</b>	Cuijk	Breisach	12	12/60		122	7
<b>MVS 110m</b>	Rotterdam	Duisburg	15	15/60		152	9
<b>MVS 110m</b>	Rotterdam	Strasbourg	4	4/60	610	40	2
<b>MVS 110m</b>	Antwerp	Duisburg	3	3/60		30	1
<b>MVS 110m</b>	Antwerp	Düsseldorf	1	1/60		10	1
<b>MVS 110m</b>	Antwerp	Gent (Ghent)	2	2/60		20	1
<b>MVS 135m</b>	Antwerp	Mainz	7	7/60		71	4
<b>MTS 86m</b>	Rotterdam	Ludwigshafen	16	16/16	647	647	40
<b>MVS 105m</b>	Amsterdam	Heilbronn	4	4/17		423	26
<b>MVS 105m</b>	Rotterdam	Alphen a. d. Rijn	10	10/17	1801	1059	66
<b>MVS 86m</b>	Rotterdam	Herne	2	2/17		211	13
<b>MVS 86m</b>	Rotterdam	Duisburg	1	1/17		105	6
<b>MVS 67m</b>	Enkhuizen	Wesel	1	1/1	4463	4463	278
<b>Total</b>			<b>222</b>			<b>8289</b>	<b>518</b>

 Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

 Grant agreement no. | **101096809**

 Page **31** of **122**


The original NEEDS values were updated with estimates for charging/bunkering speed, cost distribution, emission factors and fuel properties from D4.5 chapter 4 and 5 and can be found in table 51 in Annex II.

SYNERGETICS Report D4.5 Chapter 5 is used as input for fuel costs for two potential scenarios STEPS (stated policies scenario) and NZE (net zero emissions). The input includes a minimum and maximum bound to reflect the uncertainty of fuel price development. The values have been converted to euro per kWh using the lower heating value of each fuel. The NEEDS model interpolates the fuel price scenarios over time; the input can be found in Annex II, tables 28 to 39.

Next, the technological readiness, social acceptance and port availability levels for each fuel in different scenarios over time are used to reflect innovation of alternative technologies. The inputs used for each scenario are found in table 56 and table 57 in Annex II.

To describe the energy system capital cost, the system is separated into energy carrier storage, equipment and integration cost. The capital cost includes a minimum and maximum to reflect retrofit cost uncertainty, which is varied as part of another scenario simulation.

4 | Overview of carrier, equipment and integration for each system from SYNERGETICS report D4.5

System	Carrier storage	Equipment	Integration
<b>Battery-electric vessels</b>	Battery	Electric Engine	Battery electric system
<b>MEOH ICE SF</b>		MEOH ICE SF	Methanol system, ICE high-speed
<b>MEOH ICE DF</b>		MEOH ICE DF, DPF&SCR	Methanol system, ICE high-speed
<b>H2 ICE SF</b>	H2-Tank	H2 ICE SF	Hydrogen System, ICE high-speed
<b>H2 ICE DF</b>	H2-Tank	H2 ICE DF, DPF&SCR	Hydrogen System, ICE high-speed
<b>Stage V+, Euro VI</b>		Stage V+ Euro VI ICEs	ICE high-speed, DPF&SCR
<b>H2 FC</b>	H2-Tank	H2 Fuel Cell, Electric Engine, Battery	Hydrogen System, Electric system for FC
<b>MeOH FC</b>		MEOH FC, Electric Engine, Battery	Methanol system, Electric system for FC
<b>LNG ICE</b>		Methane ICE	ICE high-speed, cryogenic fuel storage system

The minimum and maximum carrier storage, equipment and integration cost are used as defined in D4.5 Chapter 5.2. The setup used for each is given in table 4. The cost details can be found in Annex II in the tables 52 to 54

#### 4.4 Temporal development of equipment and integration cost

The capital cost development over time for equipment and integration is reflected using cost development factors shown in table 54 in Annex II

The resulting minimum and maximum cost per kW for equipment and installation and the energy carrier storage cost per kWh for each fuel considered are shown in 56 in Annex II.

Additionally, a 60% subsidy over equipment is also evaluated to investigate how this would affect the inland fleet energy transition. The subsidy is added to all systems that could be used with fuel with significant reduction potential.



## 5 | Capex subsidy

System	CAPEX Subsidy
<b>Battery-electric vessels</b>	60%
<b>MEOH ICE SF</b>	60%
<b>MEOH ICE DF</b>	60%
<b>H2 ICE SF</b>	60%
<b>H2 ICE DF</b>	60%
<b>Stage V+ ICE</b>	0%
<b>H2 FC</b>	60%
<b>MeOH FC</b>	60%
<b>LNG ICE</b>	0%

#### 4.5 Results: technology shares

The scenario runs for SYNERGETICS are shown in table 6, interactive results can be found on the online dashboard<sup>10</sup>. Results are analysed at fleet level, focusing on technology shares over time and differences between STEPS and NZE development scenarios, fuel price uncertainty, capital cost uncertainty and subsidy effects.

## 6 | SYNERGETICS scenario inputs

Scenario name	OPEX, TRL, SRL, PA	Fuel Type	OPEX & CAPEX	CAPEX subsidy
<b>STEPS_min_max</b>	STEPS	LNG & Diesel	Min	
		Renewable	Max	
<b>STEPS_max_min</b>	STEPS	LNG & Diesel	Max	
		Renewable	Min	
<b>NZE_min_max</b>	NZE	LNG & Diesel	Min	
		Renewable	Max	
<b>NZE_max_min</b>	NZE	LNG & Diesel	Max	
		Renewable	Min	
<b>STEPS_min_max_subsidy</b>	STEPS	LNG & Diesel	Min	
		Renewable	Max	60% CAPEX
<b>STEPS_max_min_subsidy</b>	STEPS	LNG & Diesel	Max	
		Renewable	Min	60% CAPEX
<b>NZE_min_max_subsidy</b>	NZE	LNG & Diesel	Min	
		Renewable	Max	60% CAPEX
<b>NZE_max_min_subsidy</b>	NZE	LNG & Diesel	Max	
		Renewable	Min	60% CAPEX

<sup>10</sup> See website: <https://needs.application.marin.nl/dashboard>



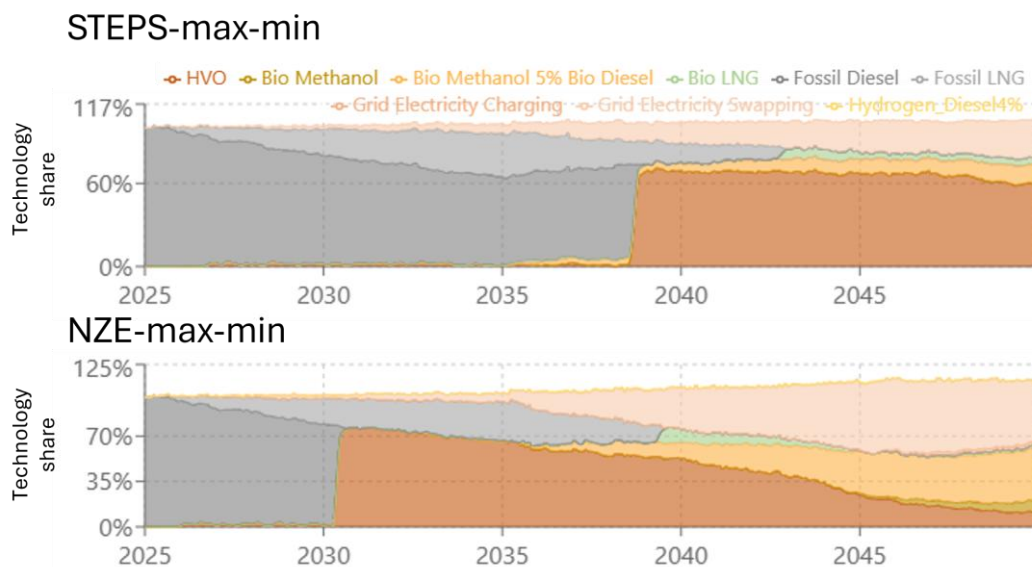
The scenarios are selected to investigate the impact of policy, technological and economical drivers and the results will be discussed along three main topics shown below.

- Impact of NZE versus STEPS
- Impact of extremes: minimum and maximum price developments
- Impact of CAPEX subsidy

This part of the report will mainly focus on the full fleet. For fleet family specific results, the reader is referred to the fleet model chapter.

#### 4.4.1 Scenario STEPS – NZE

The upper bound share for STEPS (STEPS\_MAX\_MIN) is compared with the upper bound share for NZE (NZE\_MAX\_MIN) in Figure 1 below. The colours reflect the different fuel types used.



### 3 | Technology share comparison between STEPS and NZE

In the STEPS scenario with maximum fossil and minimum renewable cost, the costs and readiness of alternative fuels is found to be less attractive when compared to fossil diesel and fossil LNG. Only some vessel types along shorter routes (such as smaller Motor vessels and Motor tanker vessels) start using electricity due to relatively low OPEX in combination with minimum estimated CAPEX. However, most of the fleet only transitions after biofuel alternatives become cheaper than fossil diesel and more accepted and available. A similar effect is found for fossil-LNG, which is phased out for bio-LNG after it becomes more expensive. It should be noted however that the model does not include feedstock limitations. In the model, ships that can directly switch to another fuel are allowed to do so any time it is available against the price set at a port. However, in reality, the transition from fossil diesel would be more gradual due to supply and demand effects compared to the model results. Nevertheless, in the STEPS scenario the fleet sticks to conventional alternatives and combustion engines that suit their operation, including LNG, battery electric and biofuels. As can be seen in below, the moment of transition is mainly influenced by cost. In the figure the monthly fuel price in euro per kWh mirror the major shifts in the fleet technology share for both scenarios.

Similarly, the NZE scenario at the bottom of 3 reflects diesel to become more expensive early on, resulting in biofuel functioning as a transitional fuel early on. Furthermore, the share of alternative fuels

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

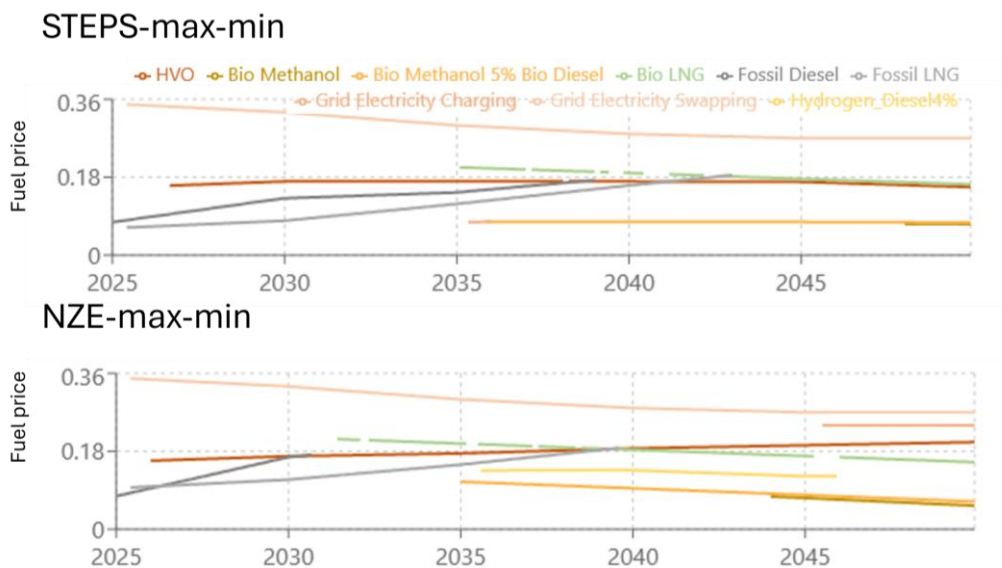
Page **34** of **122**



increases over time due to reduced OPEX and CAPEX and higher fossil fuel costs. However, the technology share of grey or green hydrogen and renewable electricity is lacking, even though technology readiness level (TRL), social readiness level (SRL) and port availability (PA) are improved for these fuels in the NZE scenario. This is because OPEX and CAPEX for hydrogen remain significantly more expensive than the other options, resulting in ships not considering them.

Nevertheless, in the NZE case, the implementation of battery electric power systems picks up significantly when compared to STEPS due to a drop in cost of grid electricity. With the technology share of the total fleet going from 27 % to 50 % making it a go-to retrofit solution for vessels on shorter routes. However, as the inclusion of batteries reduces payload and autonomy, the cargo capacity along these routes also reduces, resulting in the inland fleet increasing in size by 13 % compared to today's fleet. It should also be noted that the NEEDS model primarily considers battery electric swapping due to its reduced CAPEX. This does not consider ADN legislation, which would result in a higher share of battery electric charging for motor tanker vessels.

Besides that, over time, bio-methanol dual fuel is used to replace LNG and the majority of HVO powered vessels, resulting in dual-fuel bio-methanol representing 40 % of the fleet. It is primarily used in coupled convoys, push boats and motor vessels on longer routes, where bio-methanol dual fuel is expected to provide better energy density against lower cost.

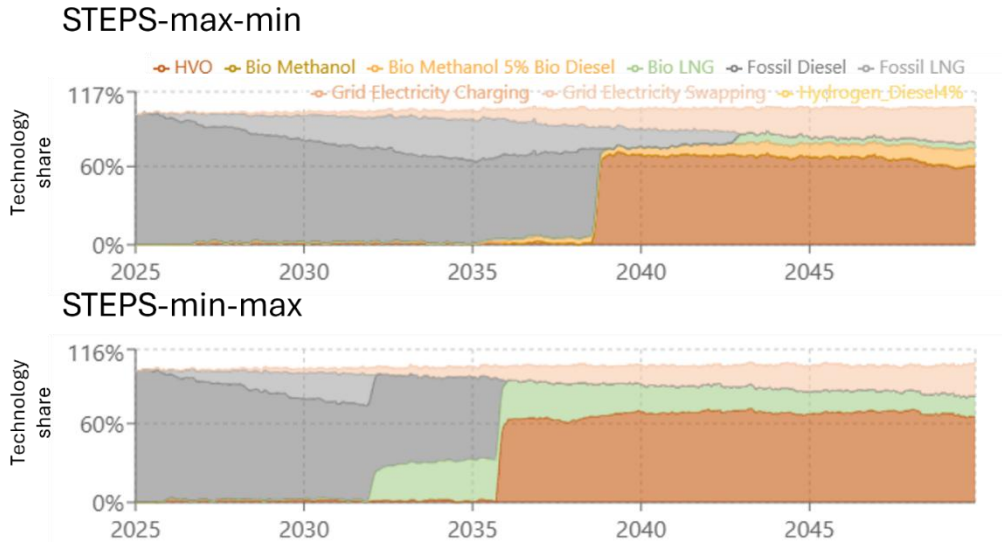


4 | Fuel price development over time for both STEPS and NZE



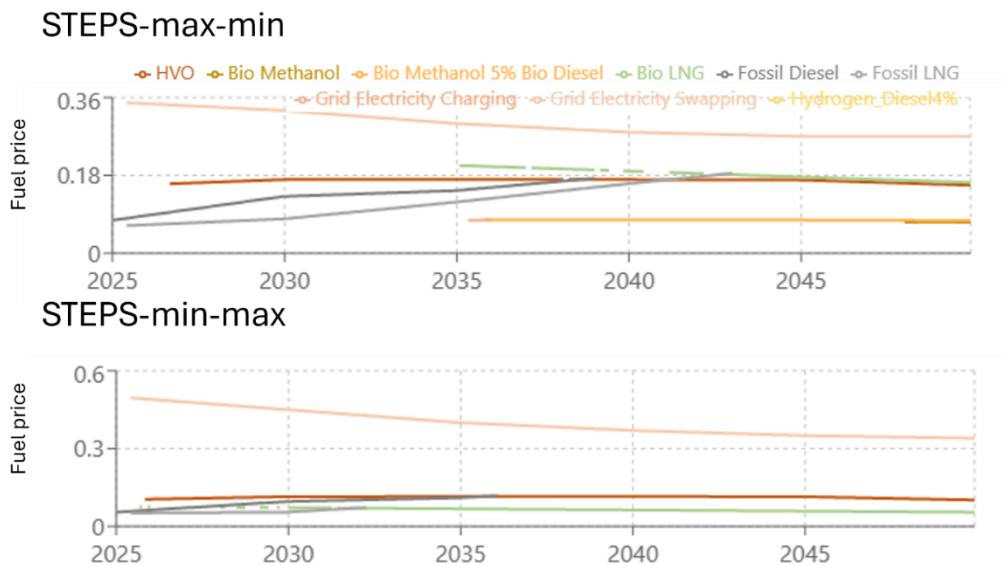
#### 4.4.2 Impact of fuel price extremes

To investigate the impact of fuel price extremes, the simulation was run for both minimum and maximum diesel and LNG costs compared to minimum and maximum alternative fuel costs in 5.



5 | Impact of fuel price extremes in the STEPS scenario

When looking at the minimum conventional– maximum alternative fuel cost combination, only biofuel versions of conventional fuels are used for in combination with a 25 % share of battery electric powered vessels. Interestingly, for maximum conventional – minimum alternative fuel cost combination, despite the introduction of dual fuel methanol, also results in increased bio-fuel costs, which delays uptake. This underlines the importance of transitional fuels. The maximum and minimum bounds for fuel price are shown in 6, which only shows the fuels that were selected by ships during the simulation.



6 | Fuel price development over time for fuel price extremes

Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. **| 101096809**

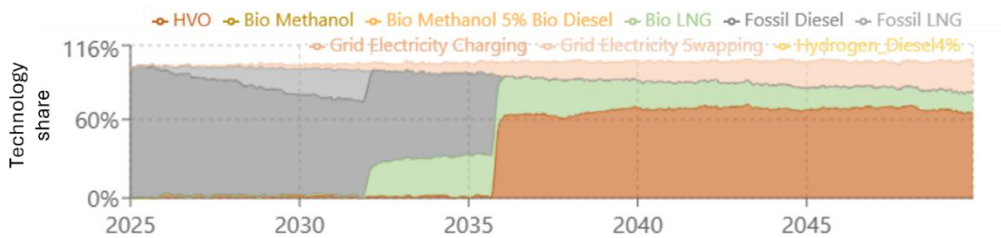
Page **36** of **122**



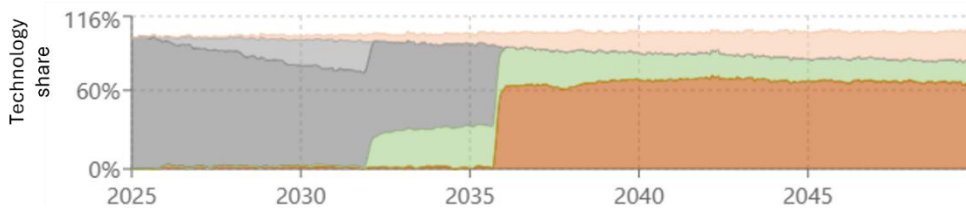
### 4.4.3 Impact of subsidy

To further investigate how CAPEX influences alternative fuel uptake in the model, a 60 % CAPEX subsidy is added to alternative fuels in 7 and 8 for minimum conventional – maximum alternative cost, as this scenario should be impacted most by CAPEX subsidy.

STEPS-min-max



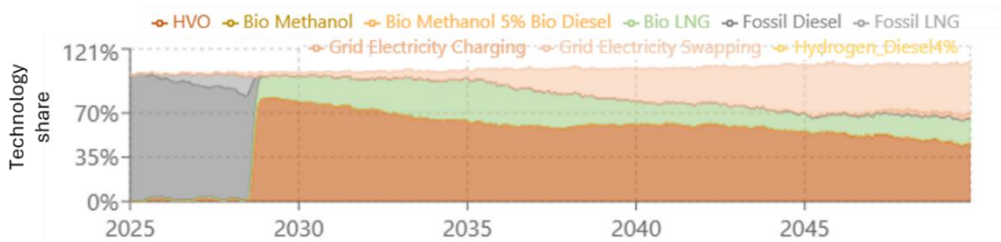
STEPS-min-max-subsidy



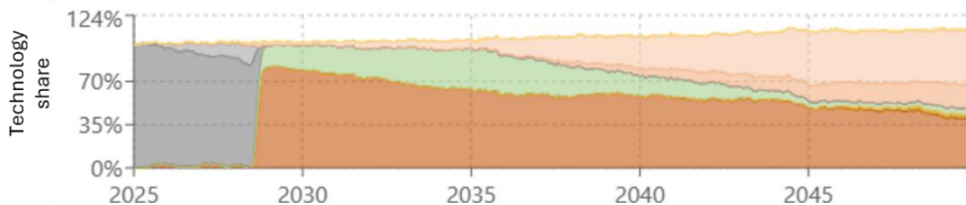
7 | Impact of CAPEX subsidy for STEPS-min-max scenario, showing ineffectiveness of subsidy with respect to minimum price fossil fuels.

Nevertheless, in the STEPS scenario shown in Figure 7, the subsidy has no noticeable impact. However, as can be seen in the results for the NZE scenario in Figure 8, the subsidy results in an increased uptake of capital-intensive alternatives such as fixed batteries instead of Bio-LNG and less use of HVO.

NZE-min-max



NZE-min-max-subsidy



8 | Impact of CAPEX subsidy in NZE-min-max scenario

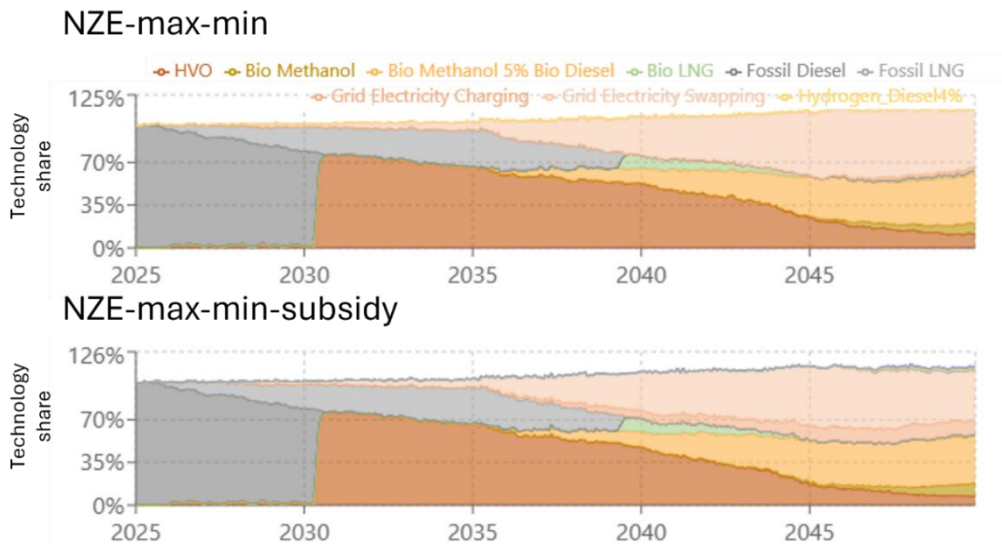
In an extreme scenario, where both alternative fuels experience reduced costs and receive a 60 % subsidy (as shown in Figure 8), vessel owners are incentivised to adopt a broader range of fuel options, including hydrogen, methanol, and electricity. Under these conditions, the share of HVO is reduced to approximately 7 % by 2050. However, in the absence of the 60 % capital expenditure (CAPEX) subsidy,

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**



options such as hydrogen remain economically unviable due to their high costs. These findings indicate that CAPEX subsidies alone are insufficient to significantly influence alternative fuel adoption. To effectively stimulate uptake, reductions in operational expenditure (OPEX), or equivalent OPEX subsidies, are also necessary. This underscores the importance of well-designed subsidy schemes that target specific alternative fuels and address both CAPEX and OPEX components when a particular technology pathway is to be promoted.



9 | Impact of CAPEX subsidy on NZE-max-min scenario



## 5. Aggregated views for the inland fleet

As described in the previous chapters, neither the scenarios published in the CCNR Roadmap nor the scenarios produced with the NEEDS model can be considered as realistic up-to-date transition pathways. Furthermore, the CCNR scenarios are target scenarios with the strict boundary conditions of achieving the ambitions of the Mannheim Declaration by 2035 and 2050. They were produced about five years ago to estimate the financial gap between the BAU scenario and the conservative and innovative pathway fulfilling the emission reduction goals of the CCNR with a mix of different solutions which seemed opportune. Today, it is known, that the BAU scenario was too optimistic regarding the developments in the first five to ten years. The market penetration of Stage V engines is much lower (approx. 5 % compared to predicted 20 %) despite the substantial state aid in a few countries for premature replacements of existing engines. In addition, updated estimates for the costs of technologies and alternative energy carriers may even lead to an increased financial gap.

On the other side, in the past years, regulations have been adopted and are being implemented by some Member States which can make a difference in the near future, with a focus on the reduction of GHG emissions. In particular the planned implementation of RED-III in The Netherlands and Belgium and also the ETS-2 opt-in being implemented in 2028 by The Netherlands and possibly also in Belgium. Such measures can lead to the uptake of renewable fuels as reflected in the conservative or innovative pathway.

The simulations with the NEEDS model were performed with updated cost assumptions per technology and price developments for energy carriers based on the scenarios published by the International Energy Agency which were translated into energy prices for IWT and coastal shipping within the SYNERGETICS project (see Annex I for the full details).

The implemented intelligence allows the conversion of vessels on representative journeys to alternative drivetrain concepts and energy sources whenever the underlying costs lead to a positive business case. Market dynamics, where a significant change in demand which cannot be immediately covered by the supply would lead to a reaction in prices, are not modelled. Dynamic interdependence with alternative fuel and energy infrastructure and competition with the demand of other sectors are not considered as well. However, the minimum and maximum price bandwidth covers these impacts because of competition with other modes.

Accordingly, within the NEEDS model, this leads to projected abrupt changes in technology shares, which could not be handled by equipment manufacturers, ship yards or fuel providers. Therefore, the response should be assumed to develop smoother over time. Furthermore, within NEEDS the simulated vessels and journeys do cover a relevant share of inland waterway transport as the Rhine is the most relevant inland waterway in Europe. However, still a significant share of vessels operating on other transport tasks (e.g. passenger transports) and on other waterways are not covered by NEEDS. Nevertheless, the outcomes of the NEEDS simulations together with the technology shares developed for the CCNR Roadmap provide highly relevant insights on the rationale choices of vessel owners reacting on the economics, feeding into the following SYNERGETICS Transition Pathways.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

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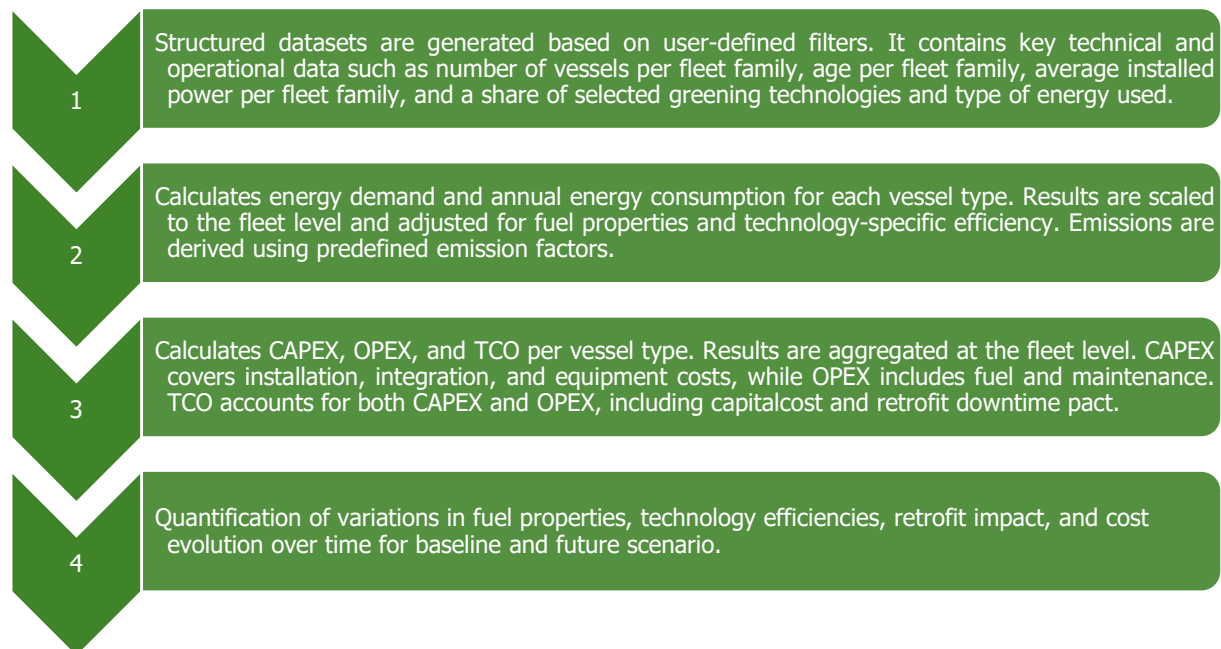
Page **39** of **122**



## 5.1 Model description

For the scenarios published in the CCNR Roadmap a fleet model was developed in 2019 based on Microsoft Excel. In this model, the characteristics of each fleet family were aggregated and factored into the development over time using technology adoption rates, costs, and emission factors. As the scope of the model expanded, it became complicated to use and prone to errors. Therefore, a fundamentally new approach was chosen in SYNERGETICS, which is also intended to form the basis for more complex modelling in the future in the form of a digital twin of the fleet. To identify the model in the text, it was given the name SYNFEED, which stands for “**SYNERGETICS model for Fleet Emission and Energy Development**”.

The SYNFEED model was developed to illustrate the future impact of green technologies on inland waterway transport. The model makes it possible to project the development of the inland waterway fleet at specific points in time up to the year 2050, based on various scenarios. Both emissions and costs are taken into account. The conceptual and detailed description for parts of the model can be found in SYNERGETICS D4.4<sup>11</sup>. Here, only a short summary and the development and changes which were made in the meantime are presented. Figure 10 shows the workflow of the model.



10| Workflow of the SYNFEED model

<sup>11</sup> [https://www.synergetics-project.eu/wp-content/uploads/2025/07/SYNERGETICS\\_D4.4\\_Cost-and-performance-model\\_FINAL.pdf](https://www.synergetics-project.eu/wp-content/uploads/2025/07/SYNERGETICS_D4.4_Cost-and-performance-model_FINAL.pdf)



### 5.1.1 Fleet composition

Fleet families have been defined and analysed already in different projects in the past. In this context, especially the H2020 project "PROMINENT"<sup>12</sup> from 2015 and the CCNR<sup>13</sup> study from 2020 should be mentioned. Apart from the fact that both studies were conducted several years ago, they both contain some aspects that do not meet current requirements. The results from PROMINENT are over 10 years old and all PAX vessels had been grouped together into a single category. Since these vessels vary strongly in size and sailing profile, the compiled data for fuel consumption and emission would not represent the reality. The CCNR study data was given an update with the latest findings<sup>14</sup>. Therefore, the fleet composition was updated based on the studies above and new insights from the IVR (International Association for the representation of the mutual interests of the inland shipping and the insurance and for keeping the register of inland vessels in Europe) database<sup>15</sup>. Table 7 shows the new fleet composition and the differences to the previous studies. In the model the fleet was also given an age distribution. In lack of other data for the whole European fleet, data for vessel age from Belgium, France, Germany, Luxembourg, Netherlands, and Switzerland was taken into account. Vessels with a length between 109 m to 110 m are accounted to the 110 m vessel section. 12 fleet families were identified.

7 | Fleet composition for the SYNFEED model in comparison to previous studies. The definitions of the fleet families can be found in the CCNR study<sup>13</sup>.

Fleet family	SYNERGETICS (2026)	PROMINENT (2015) <sup>12 above12</sup>	CCNR Study (2020) <sup>13</sup>
Large cabin vessels	329	2357 (incl. small)	346
Push boat < 500 kW	855	798	890
Push boat 500 kW - 2000 kW	296	332	520
Push boat ≥ 2000 kW	43	25	36
Motor cargo vessel ≥ 110 m	374	580	610
Motor tankers ≥ 110 m	388	599	602
Motor cargo vessel 80 m - 109 m	1751	1713	1802
Motor tankers 80 m - 109 m	1080	631	647
Motor vessel < 80 m	3525	4285	4463
Coupled convoys	188	140	140
Day trip & small cabin vessels	1505		2207
Ferries	185		103
<b>Sum</b>	<b>10668</b>	<b>11460</b>	<b>12366</b>

<sup>12</sup> [https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015\\_09\\_23\\_PROMINENT\\_D1.1-List-of-operational-profiles-and-fleet-families-V2.pdf](https://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_23_PROMINENT_D1.1-List-of-operational-profiles-and-fleet-families-V2.pdf)

<sup>13</sup> [https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable\\_RQ\\_C\\_Edition2.pdf](https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition2.pdf)

<sup>14</sup> I. Bačkalov et al., Evolution(s) of European Inland Vessel Fleets, [doi.org](https://doi.org/)

<sup>15</sup> <https://www.ivr-eu.com/expertises/ivr-ships-information-system/?lang=en>

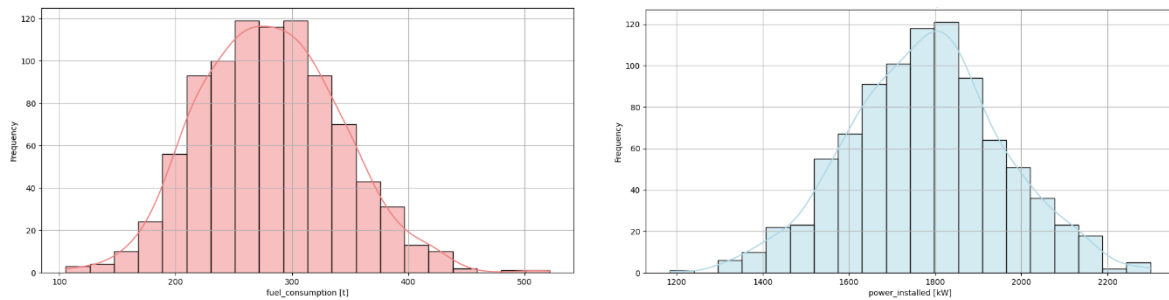
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Grant agreement no. | **101096809**

Page **41** of **122**



In contrast to older studies and models, the performance prediction is not based on the overall average per fleet family but on the contribution and influence of each single vessel. The basic properties for the performance prediction are the fuel consumption, the installed power and the yearly engine hours. These properties were modelled to Gaussian distributions, based on average value, known limits and on available real fleet data. Figure 11 shows some data for tanker vessels with a length of 110 m and more.



11 | Gaussian distributions for the fuel consumption and the installed power on tanker vessels with a length of 110 m and more.

Every vessel in the database has a year of construction and a its own history. The year of construction is based on data from the IVR database, which identifies the decade in which many of the ships currently in service were built. The years of construction within each decade are distributed randomly. The year of construction is used as a criterion for determining the likelihood of vessels being scrapped or retrofitted. The history for each vessel documents retrofitting measures and scrapping up to the year 2050.

### 5.1.2 Fleet evolution in SYNFEED

The evolution of the fleet is restricted by the total number of vessels and the average age of the fleet. Both criteria should not change significantly ( $\pm 1$  vessel,  $\pm 0.1$  years) over the years. An adoption of these criteria is possible and can be implemented if reliable predictions emerge regarding a change in the fleet structure. For example, a rejuvenation, growth or reduction of the fleet. Up to now, no such predictions are known, therefore, the constant fleet approach was chosen.

The evolution of the fleet is depending on the number of newbuilds and scrapped vessels. The criteria for scrapping are given by the age and engine running hours. Vessels older than 50 years and with engine running hours more than 90 000 h are more likely to be removed from database and replaced by a new build. Though many vessels and engines are used longer today, such criteria are required to model the constant average age with balanced newbuilds and scrapping.

Since SYNERGETICS focuses on retrofit, the newbuilt vessels are not automatically given an alternative technology, but start all with a Stage V engine running on diesel or HVO. However, it might be the case, that the vessel is chosen for a retrofit shortly after being built. The implementation of improved and more sophisticated decisions for new ships is foreseen for an upcoming version of SYNFEED.

In the model retrofitting of vessels are foreseen, the probability for retrofitting is determine by a retrofit score. Table 8 shows the criteria and the composition of the score. As criteria, the age of the vessel, the engine running hours and the theoretical number of engines are considered. Each criterion has three categories, assigned to one, two or three points. The higher the score, the more likely a retrofit. The decision which retrofit measure is implemented is based on the target value for 2035 and 2050 and will



be applied linearly. The scenario is predefined and is not aiming for a “digital twin” as indented in the project NEEDS<sup>16</sup>, where greening technologies are chosen based on external influences.

8 | Criteria for the determination of the Retrofit-Score

Age	Older than 50	between 50 and 30	younger than 30
Points	1	2	3
Engine running hours	Less than 30,000	30,000 to 80,000	More than 80,000
Points	1	2	3
Theoretical number of engines	2 and more	1	0
Points	1	2	3

### 5.1.3 Technologies

The technologies that are currently available are the following:

- Battery system (swappable and fixed batteries)
- MeOH ICE (dual and single fuel)
- H2 ICE (dual and single fuel)
- Methanol and hydrogen fuel cell
- Stage V diesel or HVO ICE
- LNG or Biomethane ICE
- Energy efficiency measures

More information on these technologies can be found in D1.1<sup>17</sup> and D5.4<sup>18</sup>. The energy efficiency measures, however, include hydrodynamic improvements, logistics optimisation and the fuel savings generated by smart steaming. As in the CCNR-Study this leads to a reduction of the energy demand per ship by up to 30 % in 2050 in the conservative and innovative pathway and a reduction of 15 % in the BAU pathway.

<sup>16</sup> <https://needs.application.marin.nl/>

<sup>17</sup> [https://www.synergetics-project.eu/wp-content/uploads/2024/09/SYNERGETICS\\_D1.1\\_Relevant-identified-technical-solutions\\_FINAL.pdf](https://www.synergetics-project.eu/wp-content/uploads/2024/09/SYNERGETICS_D1.1_Relevant-identified-technical-solutions_FINAL.pdf)

<sup>18</sup> [https://www.synergetics-project.eu/wp-content/uploads/2026/01/SYNERGETICS\\_D4.5\\_The-Catalogue-of-greening-retrofit-solutions\\_FINAL.pdf](https://www.synergetics-project.eu/wp-content/uploads/2026/01/SYNERGETICS_D4.5_The-Catalogue-of-greening-retrofit-solutions_FINAL.pdf)



#### 5.1.4 Cost model

The model also deals with the costs for the technology transition for the whole fleet. The cost model was developed earlier in the project for individual vessels for the "Decision Support Tool for Ship Owner" [Quelle D5.1]. This model serves as the basis for the cost calculation for the whole fleet. A detailed description of the cost model can be found in D4.3 "*Cost and performance model – Ship*"<sup>19</sup> and D4.4 "*Cost and performance model on fleet level*"<sup>11</sup>.

The fuel cost assumptions are based on three models, namely the STEP (**S**trategic **T**echnologies for **E**urope **P**latform), ASP (**A**nnounced **P**ledges **S**cenario), NZE (**N**et-**Z**ero-**E**mission) model.

#### 5.1.5 Performance / Emission

In order to evaluate the impact of greening technologies on operational performance, the fleet model estimates the annual energy (fuel and electricity) consumption and associated emissions for each vessel type (fleet family). The emission factors used in this model are taken from the EcoTransIt World 2024 for the fossil fuels in Europe and modelled using the ecoinvent database<sup>20</sup> (version 3.9.1) and the internal ifeu<sup>21</sup> refinery model. EcoTransIt World is chosen as a well-documented source with yearly updated factors and reports. The methodology is in line with the approach used within the CLEVER project and expected to be consistent with the announced EU database linked to CountEmissions EU.

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<sup>19</sup> [https://www.synergetics-project.eu/wp-content/uploads/2025/03/SYNERGETICS\\_D4.3\\_Cost-and-performance-model%E2%80%93Ship\\_FINAL.pdf](https://www.synergetics-project.eu/wp-content/uploads/2025/03/SYNERGETICS_D4.3_Cost-and-performance-model%E2%80%93Ship_FINAL.pdf)

<sup>20</sup> <https://ecoinvent.org/>

<sup>21</sup> <https://www.ifeu.de/en/>



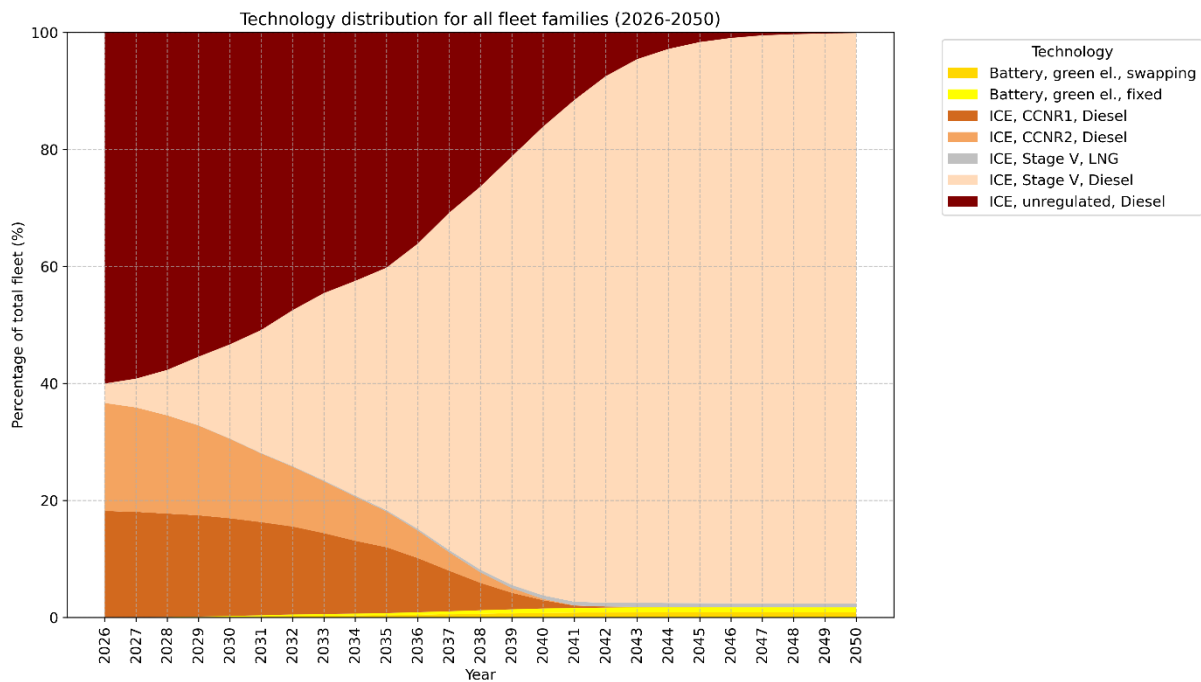
## 5.2 Input settings and scenarios

At first, the three scenarios / pathways of the CCNR-Study were used as test cases to ensure, that the emission reduction calculations of the new tool are comparable to the values published in the CCNR study. The results are presented below. The cost calculations however, are, in many points, based on diverging new figures, so that they are not compared in detail here. A comparison in the order of magnitude for the individual ship was done to ensure that the calculations are correct. The anticipated cost development is the STEPS scenario.

### 5.2.1 Business-As-Usual scenario

“For the BAU scenario only the existing legislative frame-work and existing incentives and drivers have been taken into account, while for the pathways this is still an open discussion, for example concerning regulations and arrangements for new financial instruments as well as more strict emission standards, increased pressure on reporting of carbon footprint in IWT, energy index systems for vessels, emission labels for vessels, stronger incentives by ports (port dues differentiation) as well as a the role of banks to favour green technologies.”<sup>13</sup>

Though the BAU scenario was not completely remodelled based on latest developments in the context of RED III, ETS-2 or CountEmissions EU, some modifications were implemented. For example, the anticipated uptake of Stage V engines took place at a slower pace, and their market share today was adjusted to about 5 %.

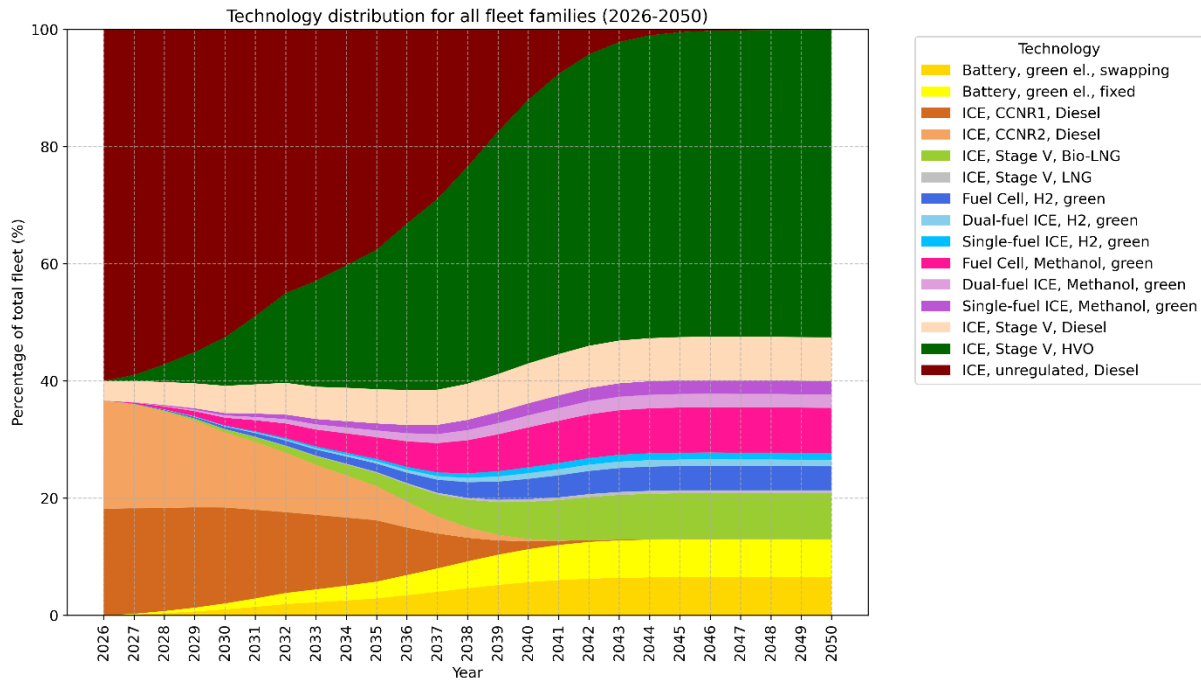


12 | Re-calculated business-as-usual pathway of the CCNR-Study



### 5.2.2 Conservative pathway

„The conservative pathway refers to a pathway in which mainly alternative fuels and techniques are considered which are relatively easy to implement and cost efficient at the short term. This concerns alternatives like advanced biodiesel (in the following summarised as HVO for simplification) that can be used in existing diesel internal combustion engines or LBM that can be used in gas engines. These are called 'drop-in' solutions. These are fuels and techniques which have a high TRL and are already available on the market.“<sup>13</sup>



13 | Re-calculated conservative pathway of the CCNR-Study

### 5.2.3 Innovative pathway

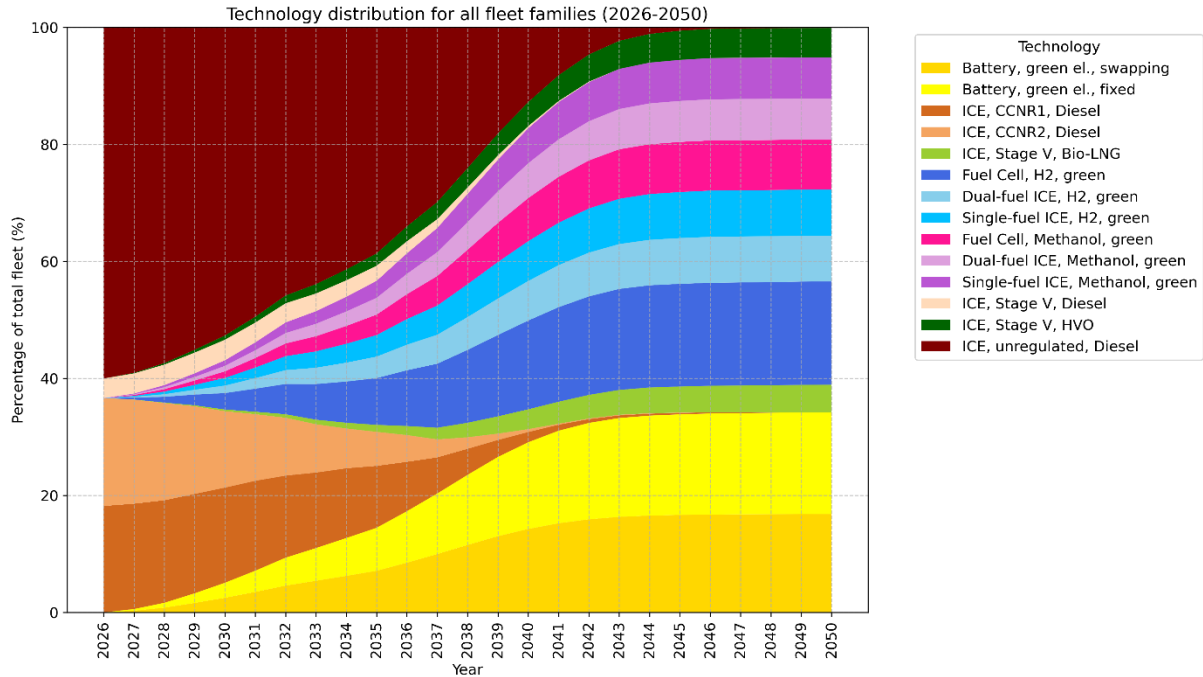
„The innovative pathway takes a more innovative approach with less internal combustion engines into account. The innovative pathway includes fuels and techniques which are currently still in their infancy stage (TRL 5-7) and are significantly more expensive as compared to advanced biodiesel and LBM. These concern alternative technologies with a currently lower TRL like fuel cells and battery-electric propulsion systems. These alternatives perform better though in reducing emissions as compared to drop-in fuels. Also, the business case may become more attractive on the long run, depending on the price scenario. In the short term though, there is no positive business case for most cases. The future economic attractiveness will depend largely on policies to promote and support these alternative fuels in the wider transport sector and European industry as a whole. IWT may then benefit from breakthroughs of technologies and new arising economies, for example for hydrogen fuel cells, batteries and green electricity.“<sup>13</sup>

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **46** of **122**





14 | Re-calculated innovative pathway of the CCNR-Study

In the innovative pathway the uptake from 2035 onwards is seen best in the popular options batteries and hydrogen technologies. Also, the methanol technologies start a broader rollout from this year.

The development appears to be almost complete by 2045. This is because the SYNFEED does not allow for any delays in the development process, but instead allocates a retrofit to the maximum number of suitable ships each year. By 2045, the desired number of retrofits per fleet family will therefore be almost complete. The SYNFEED model does currently not select a 'suitable time', for example based on TCO. For this functionality, a careful distinction would also need to be made between first-movers and shipowners who would wait for costs to fall. Otherwise, in the most extreme case, this would result in a delay in development until 2050: everyone would wait until the most favourable time point identifiable by then.



## 5.3 Results: emission and economic performance

This chapter explains the environmental and economic outcomes of the simulations. It presents the results of the recalculation of the CCNR routes, as well as those of the NEEDS scenarios and the SYNERGETICS scenario. The last three scenarios are explained in more detail in the following chapter.

### 5.3.1 Economic results

The table 9 below shows the economic details for all calculated scenarios, including the Steps Mix, NZE Mixes and SYNERGETICS Expert scenario. The updated numbers for the CCNR study pathways match the dimensions of the former calculations. Differences occur due to the updated figures as well as the alternative fleet composition model described above.

9 | Economic results for all simulated pathways and scenarios

		BAU Pathway	Conservative Pathway	Innovative Pathway	Steps Mix Scenario	NZE Mix Scenario	SYNERGETICS Scenario
CAPEX	M€ min	4,446	8,408	12,683	5,620	5,898	5,800
	M€ max	7,047	12,389	19,663	8,710	9,851	9,148
OPEX	M€ min	34,773	27,155	25,284	25,107	23,223	19,954
	M€ max	45,131	41,570	41,714	37,804	34,935	30,277
TCO	M€ min	45,993	48,285	57,003	39,983	38,444	32,303
	M€ max	62,922	73,005	91,361	61,575	60,536	49,923
Capital Cost	M€ min	4,987	9,525	14,744	6,671	7,138	5,591
	M€ max	7,907	14,169	22,988	10,647	11,904	8,874

### 5.3.2 Emission results

The tables 10 to 15 below show the comparison between the CCNR-Study and the re-calculated pathways in SYNERGETICS of the emission calculation results.

Most of the results reflect, on the one hand, the new assumptions regarding emission factors for climate-relevant and air pollutants. On the other hand, it is evident that if, as in the case of the retrofit logic described above (the prioritisation of suitable vessels), older vessels with unregulated engines remain in the fleet for a relatively long time, this explains the significant delay in reducing air pollutants in the 2035 interim target.

Authors **| D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. **| 101096809**

Page **48** of **122**



## 10 | Re-calculated BAU scenario of the CCNR-Study for 2035

2015, Reference			2035, CCNR-Tool			2035, SYNFEED		
CO <sub>2</sub>	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM
t	t	t	t	t	t	t	t	t
4,426,766	52,169	2,788	3,818,722	22,273	1,000	3,990,020	35,567	1,712
<b>savings</b>			<b>14 %</b>	<b>58 %</b>	<b>63 %</b>	<b>12 %</b>	<b>32 %</b>	<b>39 %</b>

## 11 | Re-calculated BAU scenario of the CCNR-Study for 2050

2015, Reference			2050, CCNR-Tool			2050, SYNFEED		
CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM
t	t	t	t	t	t	t	t	t
4,426,766	52,169	2,788	3,477,350	12,493	462	3,881,226	9,028	213
<b>savings</b>			<b>22 %</b>	<b>76 %</b>	<b>83 %</b>	<b>14 %</b>	<b>83 %</b>	<b>92 %</b>

The diverging between the CCNR study and the SYNFEED model output can be explained by the different fleet development assumptions: in the CCNR study there is a shrinking of the fleet to 9,859 vessels in 2035 whereas the SYNFEED functionality, that aims to keep the average vessel age constant within the fleet families, leads towards a growing fleet of 10,932. However, the approach of bio-blending by 3 % in 2035 and by 7 % in 2050 is included.

## 12 | Emission reduction comparison 2035 in the conservative scenario

2015, Reference			2035, CCNR-Tool			2035, SYNERGETICS-Tool		
CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM
t	t	t	t	t	t	t	t	t
4,426,766	52,169	2,788	2,791,779	15,215	650	2,730,328	34,462	1,670
<b>savings</b>			<b>38 %</b>	<b>73 %</b>	<b>79 %</b>	<b>40 %</b>	<b>34 %</b>	<b>40 %</b>

## 13 | Emission reduction comparison 2050 in the conservative scenario

2015, Reference			2050, CCNR-Tool			2050, SYNERGETICS-Tool		
CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM
t	t	t	t	t	t	t	t	t
4,426,766	52,169	2,788	420,741	5,245	106	239,524	5,774	135
<b>savings</b>			<b>91 %</b>	<b>90 %</b>	<b>96 %</b>	<b>95 %</b>	<b>89 %</b>	<b>95 %</b>

## 14 | Emission reduction comparison 2035 in the innovative scenario

2015, Reference			2035, CCNR-Tool			2035, SYNERGETICS-Tool		
CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM	CO <sub>2</sub> e	NO <sub>x</sub>	PM
t	t	t	t	t	t	t	t	t
4,426,766	52,169	2,788	2,744,304	13,854	585	2,814,818	33,930	1,669
<b>savings</b>			<b>38 %</b>	<b>73 %</b>	<b>79 %</b>	<b>38 %</b>	<b>35 %</b>	<b>40 %</b>

 Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

 Grant agreement no. | **101096809**

 Page **49** of **122**


## 15 | Emission reduction comparison 2050 in the innovative scenario

2015, Reference			2050, CCNR-Tool			2050, SYNERGETICS-Tool		
CO2e	NO <sub>x</sub>	PM	CO2e	NO <sub>x</sub>	PM	CO2e	NO <sub>x</sub>	PM
t	t	t	t	t	t	t	t	t
4,426,766	52,169	2,788	405,491	3,146	65	255,775	2,837	61
<b>savings</b>			<b>91 %</b>	<b>94 %</b>	<b>98 %</b>	<b>94 %</b>	<b>95 %</b>	<b>98 %</b>

Using the SYNFEED tool, it was also possible to calculate the well-to-tank and, consequently, the well-to-wake CO2e emissions. These are shown in the table 16 below. It can be clearly seen here that the CO2e reduction target for the entire supply chain can be comfortably achieved by 2035, but that the target for 2050 is not achievable with the entire supply chain; the aim was a reduction of at least 90 %. It is therefore important to recognise that the upstream supply chain has a significant impact on the actual emissions generated when renewable fuels are used. This is particularly true given that only green alternative fuels were used in all scenarios, and no grey ones.

## 16 | WTW emission reduction calculated for the CCNR-Pathways with the SYNFEED tool

Pathway	Bau2035	Bau2050	Cons2035	Cons 2050	Inno 2035	Inno 2050
CO2e wtw [t]	4,098,493	5,504,127	3,767,778	712,192	3,817,864	1,000,632
Approx. savings CO2e compared to 2015*	<b>11 %</b>	<b>13 %</b>	<b>35 %</b>	<b>82 %</b>	<b>35 %</b>	<b>83 %</b>

\* The wtt CO2e factor used here to calculate the value for 2015 for comparison is 0.966 kg\_CO2e/kg\_fuel, which is described in the literature ten years later. So, the historical correct value may be differing.

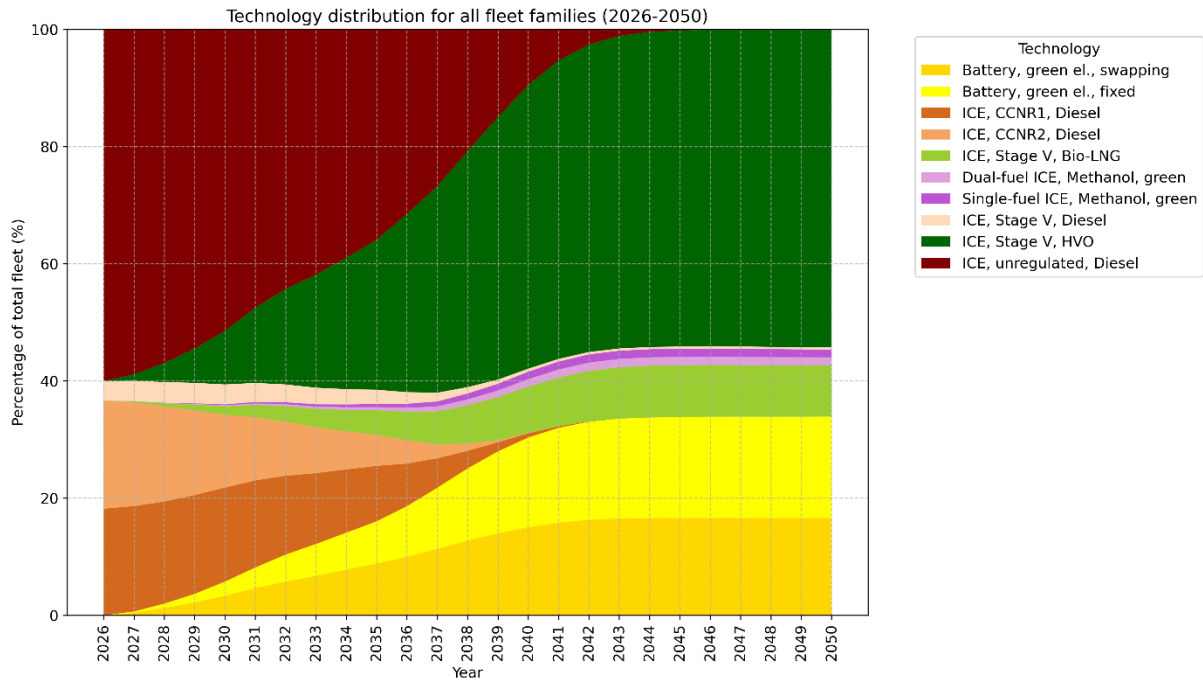
## 5.4 Extrapolated NEEDS Scenarios

The extrapolated NEEDS scenarios were also simulated using the SYNFEED tool. There is one key difference in functionality that leads to divergent development trajectories; although the final outcome in 2050 is the same, there is a difference: namely, the number of retrofits a ship undergoes. In NEEDS, ships can undergo several retrofits by 2050; in the SYNFEED tool, however, only one retrofit is possible. In the NZE-MIX scenario, this means that fossil diesel fuel will continue to be used beyond 2035.

### 5.4.1 STEPS-MIX scenario

The STEPS-MIX scenario represents the average of the NEEDS scenarios "STEPS MIN diesel vs MAX renewable + Subsidy" and "STEPS MAX diesel vs MIN renewable + Subsidy". Underlying this are the decisions made regarding the ships based on the STEPS fuel cost scenario for minimum diesel fuel price and maximum renewable fuel price as well as for maximum diesel fuel price and minimum renewable fuel price. Moreover, a subsidy for the renewable technologies of 60 % on the CAPEX.





15 | Result of the STEPS-MIX scenario calculation in the SYNFEED tool.

17 | PM, NO<sub>x</sub> and CO<sub>2</sub>e emissions in the SYNERGETICS Scenario STEPS-MIX for 2035

2035, STEPS-MIX				
	CO <sub>2</sub> e wtw	CO <sub>2</sub> e ttw	NO <sub>x</sub>	PM
		t	t	t
	3,614,082	2,551,354	32,309	1,574
<b>savings</b>	<b>Approx. 39 % *</b>	<b>44 %</b>	<b>38 %</b>	<b>44 %</b>

18 | PM, NO<sub>x</sub> and CO<sub>2</sub>e emissions in the SYNERGETICS Scenario STEPS-MIX for 2050

2050, STEPS-MIX				
	CO <sub>2</sub> e wtw	CO <sub>2</sub> e ttw	NO <sub>x</sub>	PM
		t	t	t
	1,057,538	267,566	5,723	135
<b>savings</b>	<b>82 %*</b>	<b>94 %</b>	<b>89 %</b>	<b>95 %</b>

\* The wtt CO<sub>2</sub>e factor used here to calculate the value for 2015 for comparison is 0.966 kg\_CO<sub>2</sub>e/kg\_fuel, which is described in the literature ten years later. So, the historical correct value may be differing.

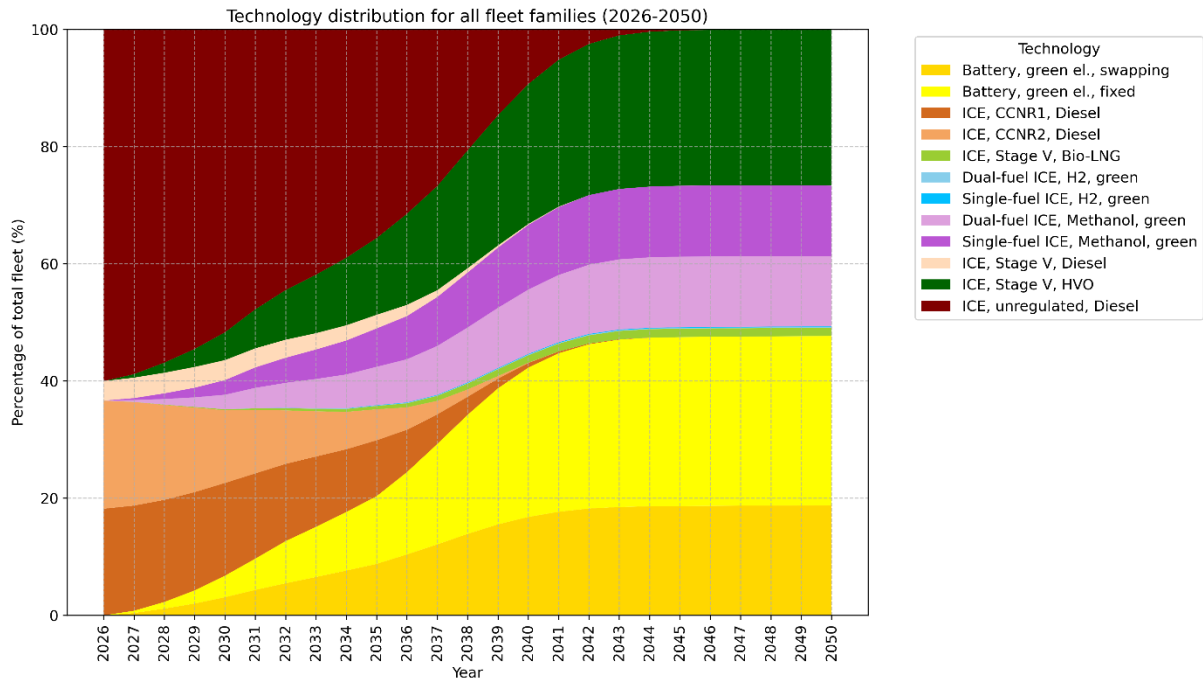
### 5.4.2 NZE-MIX scenario

The NZE-MIX scenario represents the average of the NEEDS scenarios "NZE MIN diesel vs MAX renewable + Subsidy" and "NZE MAX diesel vs MIN renewable + Subsidy". Underlying this are the decisions made regarding the ships based on the NZE fuel cost scenario for minimum diesel fuel price and maximum renewable fuel price as well as for maximum diesel fuel price and minimum renewable fuel price. Moreover, a subsidy for the renewable technologies of 60 % on the CAPEX.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**





16 | Result of the NZE-MIX scenario calculation in the SYNFEED tool.

Table 19 shows the emission reduction in 2035 in the NZE-MIX scenario. It can be seen clearly, that also with the development still using fossil fuels in this year and beyond, the targets of the Mannheim declaration (reduction of both climate-active and pollutant emissions by 35 % in 2035).

19 | PM, NO<sub>x</sub> and CO<sub>2</sub>e emissions in the SYNERGETICS Scenario NZE-MIX for 2035

2035, NZE-MIX				
	CO <sub>2</sub> e wtw	CO <sub>2</sub> e ttw	NO <sub>x</sub>	PM
	t	t	t	t
	3,468,863	2,488,725	31,895	1,559
<b>savings</b>	<b>Approx. 41 % *</b>	<b>45 %</b>	<b>39 %</b>	<b>44 %</b>

20 | PM, NO<sub>x</sub> and CO<sub>2</sub>e emissions in the SYNERGETICS Scenario NZEMix for 2050

2050, NZEMix				
	CO <sub>2</sub> e wtw	CO <sub>2</sub> ee ttw	NO <sub>x</sub>	PM
		t	t	t
	652,842	110,119	4,155	87
<b>savings</b>	<b>Approx. 89 % *</b>	<b>98 %</b>	<b>92 %</b>	<b>97 %</b>

\* The wtt CO<sub>2</sub>e factor used here to calculated the value for 2015 for comparison is 0.966 kg\_CO<sub>2</sub>e/kg\_fuel, which is described in the literature ten years later. So, the historical correct value may be differing.



## 5.5 SYNERGETICS Expert Scenario

The SYNERGETICS Expert Scenario was developed taking into account the findings from the CCNR study, the NEEDS simulations and also the experiences with past and ongoing pilot projects. Notably, this scenario (cf. Figure 17) does not pursue a predefined emission target; instead, its results emerge directly from the assumed framework conditions.

A central boundary condition is the availability of substantial financial and regulatory support. Experience from pilot projects shows that significant funding and regulatory instruments are required to initiate the retrofitting of larger shares of the fleet. At present, pilot applications of alternative propulsion technologies face considerably higher total cost of ownership (TCO) compared to conventional diesel systems, with limited mechanisms available to compensate for this disadvantage. This creates a structural barrier to market uptake that is unlikely to be overcome without strong and sustained policy intervention.

Future regulatory developments are therefore critical, but also uncertain. Instruments such as the ETS-2 opt-in and the RED III are expected to begin influencing the market from 2028/2029 onwards. However, their actual impact will depend on the specific design, implementation, and price signals achieved in practice. The scenario assumes that these instruments will be sufficiently strong to trigger a noticeable acceleration in fleet retrofitting and green newbuilds from around 2030 onwards, which represents a significant but uncertain step change compared to current dynamics.

In addition, technological cost developments play a crucial role. It is assumed that the costs of components for alternative propulsion systems will decrease by up to 30 % by 2050. While such reductions are plausible, they depend on scale effects, supply chains, and continued innovation, all of which are subject to uncertainty. Slower cost declines would directly weaken the competitiveness of alternative technologies.

Energy price developments are another key driver with considerable uncertainty. The STEPS scenario assumes a favourable trajectory for renewable energy prices alongside rising costs for fossil fuels. However, energy markets are inherently volatile and influenced by geopolitical and economic factors. Deviations from these assumptions could significantly alter the relative attractiveness of different propulsion options.

Another important boundary condition is the assumed improvement in energy efficiency. It is expected that both existing vessels and newbuilds will realize significant efficiency gains, leading to a 30 % increase in overall energy efficiency by 2050. While technical and operational improvements are well documented, achieving this level of improvement across the entire fleet requires widespread adoption and consistent implementation, which cannot be taken for granted. If overall energy costs increase in the IWT cost structures, it will be a driver for these optimisations.

Taken together, these boundary conditions create a highly supportive but also rather optimistic framework for the energy transition in inland waterway transport. The scenario illustrates what could be achieved under favourable circumstances, but it also highlights the narrow pathway required to reach these outcomes. If financial support is insufficient, regulatory measures are delayed or weakened, cost reductions do not materialize as expected, energy price trends shift, or efficiency gains fall short, the likelihood of achieving the calculated emission reductions decreases sharply, potentially to the point of infeasibility.

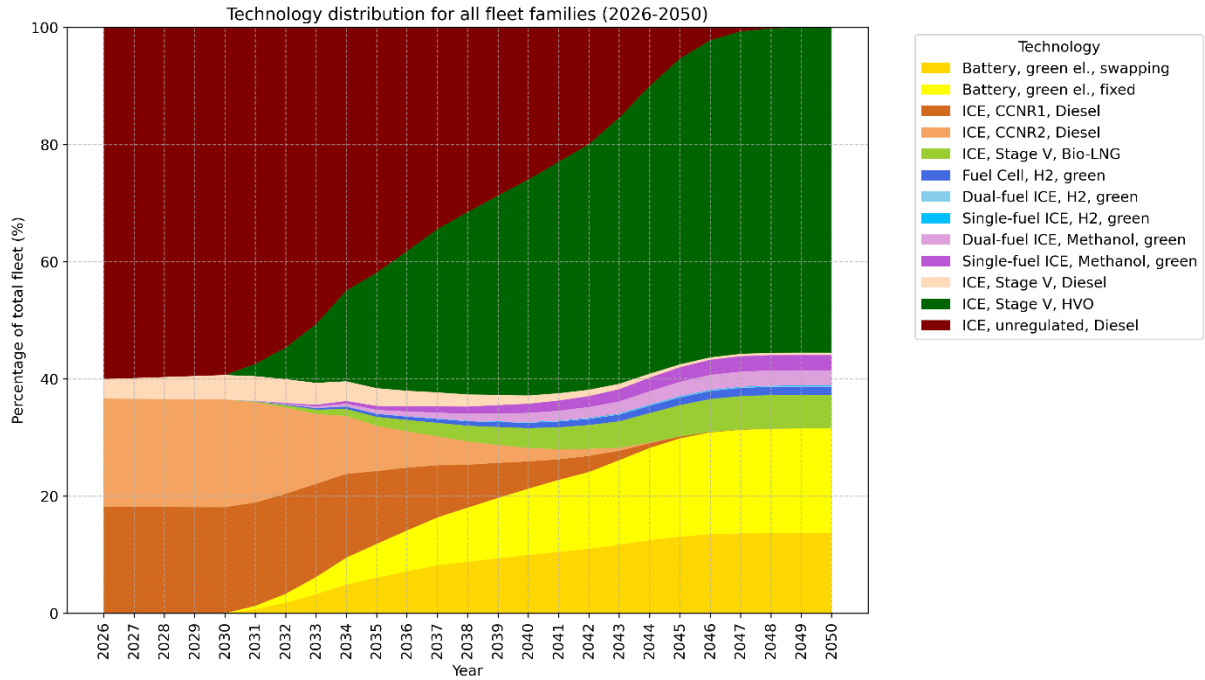
At the same time, this framing provides an important insight: the success of the transition depends on a combination of clearly identifiable and quantifiable conditions. The scenario therefore not only describes a possible future, but also delineates the critical levers and associated risks that must be actively managed to make this future achievable.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **53** of **122**





17 | Technology distribution for all fleet families in the SYNERGETICS Expert Scenario

21 | PM, NO<sub>x</sub> and CO<sub>2</sub>e emissions in the SYNERGETICS Expert Scenario for 2035

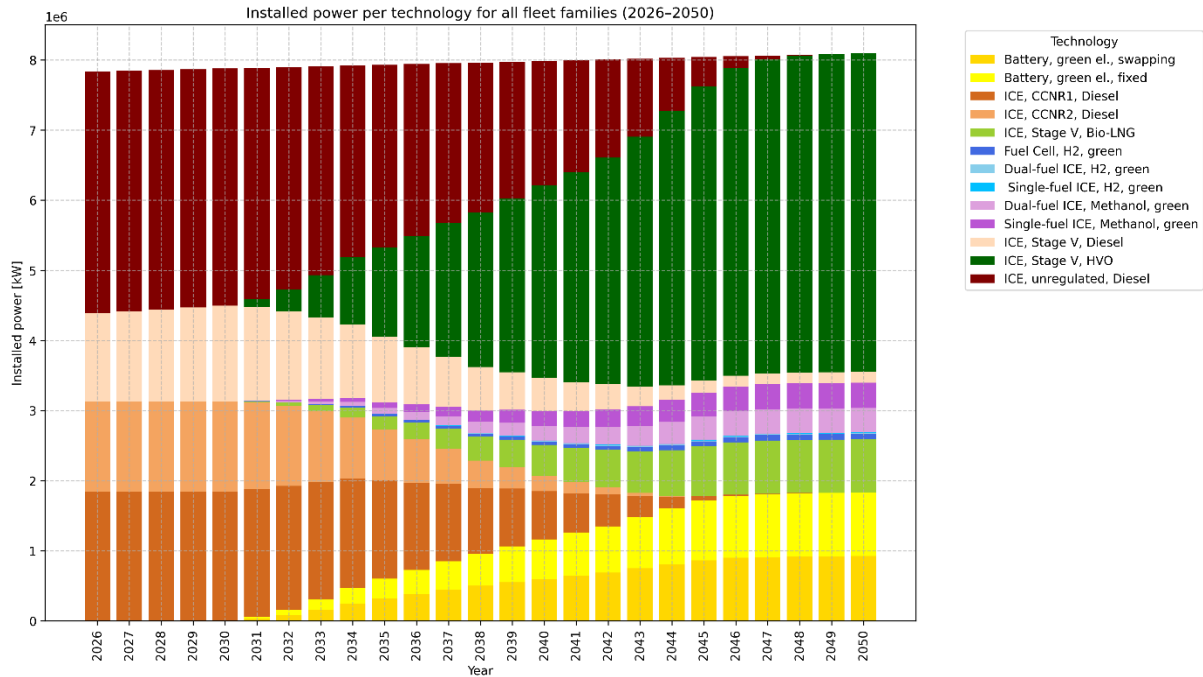
2035, SYNERGETICS Expert Scenario				
	CO <sub>2</sub> e wtw	CO <sub>2</sub> e ttw	NO <sub>x</sub>	PM
	t	t	t	t
	4,135,392	3,000,767	37,352	1,814
<b>savings</b>	<b>Approx. 30 % *</b>	<b>34 %</b>	<b>28 %</b>	<b>35 %</b>

22 | PM, NO<sub>x</sub> and CO<sub>2</sub>e emissions in the SYNERGETICS Expert Scenario for 2050

2050, SYNERGETICS Expert Scenario				
	CO <sub>2</sub> e wtw	CO <sub>2</sub> e ttw	NO <sub>x</sub>	PM
	t	t	t	t
	1,127,787	286,612	6,129	143
<b>savings</b>	<b>Approx. 81 % *</b>	<b>94 %</b>	<b>88 %</b>	<b>95 %</b>

\* The wtt CO<sub>2</sub>e factor used here to calculate the value for 2015 for comparison is 0.966 kg\_CO<sub>2</sub>e/kg\_fuel, which is described in the literature ten years later. So, the historical correct value may be differing.





18 | Installed power per technology in the SYNERGETICE Expert Scenario

By comparing figures 17 and 18, it can be seen, that the batteries are given to smaller units, whereas the other technologies, especially the HVO and the methanol options, are installed on ships with larger engines.

If the SYNERGETICS Expert Scenario is also to include 60 % CAPEX funding for alternative energy converters, the sums can be calculated as shown in the table below. The average annual funding would amount to between approximately €67 million and €115 million.

23 | CAPEX for conventional and alternative technologies in the SYNERGETICS Expert Scenario

	Min [€]	Max [€]
<b>Total CAPEX</b>	5,800	9,148
<b>Conventional technologies CAPEX</b>	3,223	4,771
<b>Alternative technologies CAPEX</b>	2,577	4,377
<b>60 % of CAPEX alternative technologies</b>	1,546	2,626



## 6. Landscape of Synergies

Within the context of the SYNERGETICS project, the landscape of synergies supports a coordinated approach to innovation uptake by clustering and mapping relevant projects and their contributions.

The landscape presents an overview of projects addressing comparable technological developments, clustered by type of technology. In addition, each project is clustered within the technology group by different focus areas of the technology, for example operational vessels, pilot projects, policy or infrastructure systems. Creating an understanding of how innovations and knowledge can be transferred, scaled or jointly implemented across sectors.

### 6.1 Hydrogen

The European hydrogen landscape in the maritime sector shows a clear trajectory from innovation to scale-up, with projects reinforcing each other across technology, infrastructure, and application. Within the hydrogen landscape of synergies, the included projects have been clustered accordingly based on their similarities.

A first group consists of operational vessel projects, where hydrogen technologies are already being demonstrated in real-world maritime operations. Initiatives such as Hydroville, Zemships, Maranda, Hydra, SeaShuttle, and HyEkoTank illustrate the growing technological maturity of hydrogen-powered propulsion systems in inland and short-sea shipping. These projects provide practical experience regarding vessel integration, operational safety, fuel handling, and crew acceptance, thereby reducing uncertainties for future commercial deployment.

A second cluster focuses on concepts, design studies, and demonstration-oriented development projects. Projects including FLAGSHIPS, RESHIP, H2SHIPS, HYSHIP, HyMethShip, Ship-aH2oy, NavHyBus, and H2Watt contribute to the engineering and optimization of hydrogen-powered vessels and associated onboard systems. Their role is particularly important in validating technical feasibility, improving system efficiency, and preparing scalable vessel concepts for broader market adoption.

In parallel, several initiatives address fuel systems and energy-related technologies. Projects such as FPS, GKP7H2, and Jpnh2ydro concentrate on hydrogen production, storage, conversion, and energy management solutions. These developments are essential for overcoming current limitations regarding fuel availability, storage density, and operational reliability.

Another important category consists of infrastructure and ecosystem projects, including RH2IWER, Margreen, and ISHY. These initiatives support the development of hydrogen supply chains, bunkering infrastructure, logistics integration, and port readiness. Their contribution is critical, as the successful deployment of hydrogen-powered shipping depends not only on vessel technology but also on the availability of reliable supporting infrastructure.

Finally, policy and enabling initiatives such as H2MOVE and Grüne Hauptstadt Europas – Essen 2017 contribute by creating favourable regulatory frameworks, fostering stakeholder collaboration, and increasing public and industrial awareness of hydrogen-based mobility solutions.

The main synergy across the hydrogen landscape lies in the interaction between these different project categories. Early operational demonstrations generate practical insights that add into new vessel designs and fuel system innovations, while infrastructure and policy initiatives create the conditions necessary for commercialization and up-scale possibilities. Together, these efforts form an increasingly coherent system that accelerates the transition toward zero-emission maritime transport in Europe.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **56** of **122**



Hydrogen	
<b>Operational vessels</b>	
Hydroville	<a href="#">Pilot Database for external sharing</a>
Zemships	<a href="#">Pilot Database for external sharing</a>
Maranda	<a href="#">Pilot Database for external sharing</a>
Hydra	<a href="#">Pilot Database for external sharing</a>
Fuel Cell Boat	<a href="#">Pilot Database for external sharing</a>
HyEkoTank	<a href="#">Pilot Database for external sharing</a>
Rhenus Mannheim	<a href="#">Pilot Database for external sharing</a>
HTS/MTS Wasserstoffschiff	<a href="#">Pilot Database for external sharing</a>
SeaShuttle	<a href="#">Pilot Database for external sharing</a>
Crew Transfer	<a href="#">Pilot Database for external sharing</a>
<b>Design studies</b>	
FLAGSHIPS	<a href="https://flagships.eu/">https://flagships.eu/</a>
RESHIP	<a href="https://www.reship-project.com/">https://www.reship-project.com/</a>
H2SHIPS	<a href="https://vb.nweurope.eu/projects/project-search/h2ships-system-based-solutions-for-h2-fuelled-water-transport-in-north-west-europe/#tab-3">https://vb.nweurope.eu/projects/project-search/h2ships-system-based-solutions-for-h2-fuelled-water-transport-in-north-west-europe/#tab-3</a>
HYSHIP	<a href="https://hyship.eu/">https://hyship.eu/</a>
HyMethShip	<a href="https://www.hymethship.com/">https://www.hymethship.com/</a>
Ship-aH2oy	<a href="#">Pilot Database for external sharing</a>
NavHyBus	<a href="#">Pilot Database for external sharing</a>
H2Watt	<a href="https://h2watt.eu/nl/">https://h2watt.eu/nl/</a>
<b>Fuel systems</b>	
FPS	<a href="https://futureproofshipping.com/">https://futureproofshipping.com/</a>
GKP7H2	<a href="#">Pilot Database for external sharing</a>
Jpnh2ydro	<a href="#">Pilot Database for external sharing</a>
<b>Infrastructure</b>	
RH2IWER	<a href="https://rh2iwer.eu/">https://rh2iwer.eu/</a>
Marigreen	<a href="#">Pilot Database for external sharing</a>
ISHY	<a href="#">Pilot Database for external sharing</a>
<b>Policy</b>	
Grüne Hauptstadt Europas – Essen 2017	<a href="#">Pilot Database for external sharing</a>
H2MOVE	<a href="https://www.wasserstoff-niedersachsen.de/h2move/">https://www.wasserstoff-niedersachsen.de/h2move/</a>



## 6.2 Methanol

The European maritime methanol landscape demonstrates a gradual transition from early-stage demonstration projects toward commercial implementation and broader policy integration. The ecosystem can be structured around three main categories: operational vessels, pilot and demonstration projects, and policy and enabling initiatives.

The first category consists of operational vessels and commercial deployment projects, where methanol is already being applied in real-world maritime operations. Initiatives such as the Proman–Stena Bulk methanol tanker fleet illustrate the growing maturity of methanol as fuel within the commercial shipping sector. These projects demonstrate the practical feasibility of methanol bunkering, onboard fuel integration, and day-to-day operational reliability. In addition, applications in specialised vessel segments, including chemical tankers, show that methanol can be adapted to different maritime use cases beyond large-scale tanker operations.

A second cluster focuses on pilot and demonstration projects aimed at validating methanol technologies and supporting market inclusion. Projects such as FASTWATER, MENENS, and Mari Boyle & Mali Jone contribute to the technical demonstration of methanol propulsion systems in various maritime contexts, including inland waterways and smaller-scale vessel operations. These initiatives play an important role in reducing technological uncertainty, testing safety procedures, and generating operational experience that can support future scale-up.

The third category consists of policy and enabling initiatives, most notably the EU’s Motorways of the Seas programme. Such initiatives facilitate the development of green shipping corridors, support alternative fuel infrastructure, and strengthen coordination between ports, logistics operators, and shipping companies. Their role is essential in creating the regulatory and infrastructural conditions required for wider methanol adoption across the European maritime sector.

The key synergy within the methanol landscape lies in the interaction between these three categories. Pilot and demonstration projects provide the technical validation needed for commercial confidence, while operational vessel deployments prove economic and operational viability at larger scale. At the same time, policy initiatives create the supporting framework necessary for fuel availability, infrastructure development, and cross-border integration. Together, these interconnected efforts contribute to the progressive integration of methanol into a broader zero- and low-emission maritime ecosystem.

Methanol	
<b>Operational vessels –</b>	
Proman Stena Bulk Methanol Tankers	<a href="https://stenabulk.com">stenabulk.com</a>
Chemicaliëntanker	<a href="#">Pilot Database for external sharing</a>
<b>Pilot projects</b>	
FASTWATER	<a href="https://www.fastwater.eu/">https://www.fastwater.eu/</a>
Mari Boyle & Mali Jone	<a href="#">Pilot Database for external sharing</a>
MENENS	<a href="#">Pilot Database for external sharing</a>
<b>Policy</b>	
Motorways of the Seas	<a href="#">Pilot Database for external sharing</a>

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **58** of **122**



### 6.3 Electricity

The European maritime electrification landscape is developing through a combination of operational deployment, infrastructure development, and pilot initiatives, with two distinct technological approaches emerging in parallel: fixed battery systems and swappable battery systems. Together, these approaches contribute to a broader transition toward zero-emission maritime transport.

The first category consists of operational vessels using fixed battery systems, where batteries are permanently integrated into the vessel and recharged through shore-side charging infrastructure. Projects and vessels such as Havila, NZK Ferries, Oberbillig Ferry, Grüne Flotte Sauerland, M/F Tycho Brahe, MS Wellingdorf, MS Düsternbrook, MS Friedrichsort, MS Insel Mainau, Sento Liner, AURORA AF HELINGBORG, Eilbek, and MS Heisingen demonstrate the growing maturity of this approach. These applications are particularly suited to predictable routes and scheduled operations, such as ferry and passenger services, where charging can be integrated into daily operational cycles. The success of these vessels illustrates that fully electric propulsion is already technically and operationally feasible in regular maritime transport.

A second cluster focuses on operational vessels using swappable battery systems. In this model, batteries function as standardized energy containers that can be exchanged rapidly in ports, minimizing charging downtime and increasing operational flexibility. Projects such as Kotug M-Pusher, Citybarge / Current Direct, and X-Barge demonstrate how battery swapping concepts can support inland shipping and logistics operations where fast turnaround times are essential. This approach aligns closely with container-based logistics systems and offers significant potential for scalability across different vessel types and transport corridors.

Supporting these operational applications are infrastructure and ecosystem initiatives, including ZES and CURRENT DIRECT. These projects focus on developing the charging networks, battery exchange systems, standardization mechanisms, and energy logistics necessary for large-scale electrification. Their contribution is particularly important in enabling operability between vessels, ports, and energy providers, thereby reducing barriers to wider adoption.

Finally, pilot and development projects such as AUTOFLEX, AENEAS, and AB Initio contribute to the optimization and testing of new electrification concepts. These initiatives explore technological innovation, operational efficiency, and smart energy integration, helping to prepare future large-scale deployment of electric maritime transport systems.

The key synergy within the European maritime electrification landscape lies in the complementary nature of fixed and swappable battery approaches. Fixed battery systems demonstrate operational reliability and efficiency on stable routes, while swappable battery systems promote flexibility, rapid turnaround, and scalable energy logistics. At the same time, infrastructure and pilot projects provide the technological and organizational foundations needed to connect these approaches into an integrated zero-emission maritime ecosystem.

Electricity	
<b>Operational vessels – fixed batteries</b>	
Havila	<a href="#">Pilot Database for external sharing</a>
NZK Ferries	<a href="#">Pilot Database for external sharing</a>
Oberbillig Ferry	<a href="#">Pilot Database for external sharing</a>
Grüne Flotte Sauerland	<a href="#">Pilot Database for external sharing</a>
DHL Postboat	<a href="#">Pilot Database for external sharing</a>
E-Spatz	<a href="#">Pilot Database for external sharing</a>
M/F Tycho Brahe	<a href="#">Pilot Database for external sharing</a>

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **59** of **122**



MS Heisingen	<a href="#">Pilot Database for external sharing</a>
Sendo Liner	<a href="#">Pilot Database for external sharing</a>
Missunde III	<a href="#">Pilot Database for external sharing</a>
MS Wellingdorf	<a href="#">Pilot Database for external sharing</a>
MS Düsternbrook	<a href="#">Pilot Database for external sharing</a>
MS Friedrichsort	<a href="#">Pilot Database for external sharing</a>
AURORA AF HELINGBORG	<a href="#">Pilot Database for external sharing</a>
Eilbek	<a href="#">Pilot Database for external sharing</a>
MS Insel Mainau	<a href="#">Pilot Database for external sharing</a>
<b>Operational vessels – swappable batteries</b>	
Den Bosch Max Groen	
Kotug M-Pusher	<a href="#">Pilot Database for external sharing</a>
Citybarge / Current Direct	<a href="#">Pilot Database for external sharing</a>
X-Barge	<a href="#">Pilot Database for external sharing</a>
<b>Charging/ infrastructure systems</b>	
ZES	<a href="#">Home - Zero Emission Services</a>
CURRENT DIRECT	<a href="https://www.currentdirect.eu/">https://www.currentdirect.eu/</a>
<b>Pilot projects</b>	
AUTOFLEX	<a href="https://autoflex-vessel.eu/">https://autoflex-vessel.eu/</a>
AENEAS	<a href="https://www.project-aeneas.eu/">https://www.project-aeneas.eu/</a>
AB Initio	<a href="#">Pilot Database for external sharing</a>



## 6.4 LNG

Liquefied Natural Gas (LNG) has played a pivotal role as a transitional fuel in the decarbonisation of the maritime sector. The current project landscape demonstrates strong synergies across commercial deployment, pilot initiatives, and emerging hybrid technologies, highlighting LNG's function as both a bridging solution and an enabler of future low- and zero-carbon fuels.

At the commercial level, vessels such as AIDAnova and projects like Ecoliner and Ecotanker illustrate the maturity of LNG technology in real-world operations. These initiatives have established critical know-how in fuel handling, onboard storage, and bunkering infrastructure. This operational experience forms a foundation that can be leveraged for the uptake of alternative fuels.

Pilot and demonstration projects, including Breakthrough LNG Deployment in Inland Waterways Transport (IWT) and Swiss LNG, contribute to scaling LNG applications beyond deep-sea shipping into inland and regional contexts. These projects are essential for addressing regulatory, logistical, and economic barriers, while also creating standardisation and cross-border interoperability.

A key area of synergy lies in the overlap between LNG systems and emerging clean fuel technologies. Projects such as ShipFC demonstrate how existing LNG-related expertise, particularly in cryogenic storage, fuel systems, and safety protocols can support the transition towards hydrogen, ammonia, and fuel cell-based propulsion systems. In this sense, LNG infrastructure and knowledge do not become obsolete but instead evolve into critical enablers of multiple alternative energy carriers.

Overall, the LNG project landscape reveals a layered transition pathway: from fossil LNG to bio- and synthetic variants, and ultimately towards zero-emission fuels. The synergies between current deployments, pilot projects, and future-oriented innovations reduce transition risks, optimise investments, and accelerate the maritime sector's alignment with long-term climate targets.

LNG	
<b>Operational vessels</b>	
AIDAnova	<a href="#">Pilot Database for external sharing</a>
Ecoliner	<a href="#">Pilot Database for external sharing</a>
Ecotanker	<a href="#">Pilot Database for external sharing</a>
<b>Pilot demonstration</b>	
Breakthrough LNG Deployment in IWT	<a href="#">Pilot Database for external sharing</a>
Swiss LNG	<a href="#">Pilot Database for external sharing</a>
<b>Hybrid concept</b>	
ShipFC	<a href="#">Pilot Database for external sharing</a>



## 6.5 Energy efficiency

Improving energy efficiency is a key component of the energy transition in the maritime and inland waterway sectors. It not only reduces overall fuel consumption but also plays a crucial role in maintaining the economic viability of vessels as new, often more expensive, energy carriers are introduced. Among other advantages, higher efficiency helps ensure that the operating costs of ships using alternative fuels such as hydrogen, ammonia, or synthetic fuels do not rise excessively. This is especially important during the transition phase, when such energy carriers are expected to be available only in limited quantities and at higher prices compared to conventional fuels.

In the context of climate change, this issue is becoming increasingly urgent. Periods of low water levels are occurring more frequently and lasting longer, especially in major European waterways such as the Rhine. In shallow waters, hydrodynamic resistance increases significantly, leading to a sharp rise in energy requirements for vessel propulsion. As a result, ships must expend more energy to transport the same amount of cargo, which negatively affects both environmental performance and operational costs. Under these conditions, it is vital to optimize vessel operation to achieve the lowest possible energy consumption while still maintaining high transport efficiency. This includes not only technical improvements to hull design and propulsion systems but also smarter operational strategies, such as speed optimization and load management.

Within **SYNERGETICS** the demonstrator vessel *Ernst Kramer* was evaluated for an aft-ship replacement and engine optimization<sup>22</sup>. CFD calculations were used for an automated optimization of the aft-ship form. The redesigned aft-ship features substantial modifications in the transom area, tunnel integration, and hull form below the tunnel, which primarily influence propeller inflow. This results in a efficiency improvement of 30 % in shallow water, with additional saving of 16 % and 22 % in deep and moderate water conditions. The reduction of power demand between 15 % and 30 % was confirmed by model test in the basin of DST.

In 2025, two aft-ship replacement projects were realised with involvement of DST: the *MS Leonie Deymann*<sup>23</sup> and the *MGS Donau*<sup>24</sup>. Both ships were changed from single screw to twin screw power trains and supported with funding from the German subsidy programme<sup>25</sup>. This subsidy programme addresses modal shift by means of Digitalisation and Automation to improve safety and/or environmental performance (Art. 2.1), energy efficiency (Art. 2.2) and optimisation to improve low-water resilience by at least 15 cm (Art. 2.3) including aft-ship or bow replacement or retrofitting of a flexunnel. Article 2.4 covers adaptation of cargo holds for new markets and modal shift. Funding intensity can be up to 80 % of eligible costs for all categories, low-water resilience even for big shipping companies.

The RESHIP<sup>26</sup> project focused on investigating energy-saving devices and measures with the aim of promoting the use of new hydrogen technology through energy savings. One aspect was the investigation of compatibility of conventional ESD with hydrogen technology, cf. findings by *Stark et al.*<sup>27</sup>. Another

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<sup>22</sup> [https://www.synergetics-project.eu/wp-content/uploads/2025/07/SYNERGETICS\\_D3.15\\_Evaluation-report-aft-ship\\_FINAL.pdf](https://www.synergetics-project.eu/wp-content/uploads/2025/07/SYNERGETICS_D3.15_Evaluation-report-aft-ship_FINAL.pdf)

<sup>23</sup> [MS Leonie Deymann](#)

<sup>24</sup> [MGS Donau](#)

<sup>25</sup> <https://www.elwis.de>

<sup>26</sup> <https://www.reship-project.com/>

<sup>27</sup> <https://www.mdpi.com/2077-1312/10/3/388>



aspect was tubercle-assisted propulsion, including the investigation of tubercle ducts and tubercle propellers. For inland vessels, the use of a flow separation plate, the modification of the stern and the use of tubercle ducts were investigated in model tests. For seagoing vessels, the demonstrator vessel Fortuna Crane was retrofitted with tubercle propellers and significant savings in power demand of more than 15 % were confirmed in sea trials.

In addition to the hydrodynamic and propulsion measures used in inland waterway transport, coastal vessels also have the option of harnessing the wind for propulsion. The Flettner rotor is a particularly notable example of this.

Two studies have also recently been published. The first deals with the techno-economic analysis of decarbonisation pathways for a deep-sea container vessel <sup>28</sup>. It found that speed reduction, air lubrication and hull maintenance are the most cost-efficient measures. The second study <sup>29</sup> analysed ships over 400 GT calling at German ports in terms of their ability to meet the required future EEDI, EEXI and CII values. The key measures identified here are engine power limitation (EPL), retrofitting to LNG, or replacing the ship.

Further projects and vessel, that are addressing energy efficiency have been identified in the SYNERGETICS project and are listed in the Pilot Database:

Energy efficiency	
<b>Engine efficiency</b>	
Vinotra 10	<a href="#">Pilot Database for external sharing</a>
Bravenes	<a href="#">Pilot Database for external sharing</a>
<b>Wind assisted</b>	
Conoship CIP 3600	<a href="#">Pilot Database for external sharing</a>
MV Ankie	<a href="#">Pilot Database for external sharing</a>
Copenhagen	<a href="#">Scandlines</a>
Berlin	<a href="#">Scandlines</a>
<b>Hull design/aft-ship replacement</b>	
Zr.Ms. Groningen	<a href="#">Pilot Database for external sharing</a>
Rhenus Duisburg	<a href="#">Pilot Database for external sharing</a>
Stolt Ludwigshafen	<a href="#">Stolt</a>
Mannheim	<a href="#">Pilot Database for external sharing</a>
Hirschhorn / Leonie Deymann	<a href="#">Deymann</a>

<sup>28</sup>I.Sontakke et al., Techno-economic analysis of decarbonization pathways for a deep-sea container vessel - <https://doi.org/10.1080/09377255.2025.2585247>

<sup>29</sup>M. Bergström et al., A Simulation-Based Approach for Evaluating Merchant Fleet Decarbonization Strategies - <https://doi.org/10.1115/OMAE2023-102401>



## 7. Conclusions

This report presents the Updated Transition Pathways & Landscape of Synergies for decarbonising mainly inland waterway transport (IWT) but also coastal shipping. This was done for IWT by revising and enhancing the transition pathways initially developed for the CCNR Roadmap by integrating the latest technological, economic, and regulatory insights based on SYNERGETICS research work. Drawing on the outcomes of EU-funded projects such as STEERER and NEEDS, as well as updated cost assumptions provided by technology suppliers and integrators and energy price projections from the International Energy Agency's World Energy Outlook 2024, this analysis provides a robust and contemporary foundation for stakeholders to navigate the complexities of the energy transition. The report underscores that the decarbonisation of the waterborne sector is not only a technical challenge but it is much more a systemic challenge, requiring coordinated action across policy, infrastructure, and market dimensions.

Especially the economic gap between using fossil fuels or renewable energy types is a crucial barrier which prevents roll-out. This gap can only be closed by means of strong policy measures which need to safeguard the level playing field between countries at the same time. As a result, it seems most appropriate to take measures at EU level. Examples of options are for example providing binding regulations to energy suppliers to add ETS-2 for fuel suppliers to IWT, to set specific CO<sub>2</sub> reduction targets for energy supply to IWT and/or to set specific CO<sub>2e</sub> reduction targets for vessel owner/operations, such as a FuelEU for inland waterway vessels (similar to FuelEU Maritime for seagoing vessels above 5000GT).

One key component of the work was the application of the NEEDS model to simulate the evolution of technology shares for a representative fleet operating on predefined routes within the Rhine corridor. By incorporating minimum and maximum cost scenarios for both conventional and alternative fuels, as well as the impact of a 60 % CAPEX subsidy, the model offered valuable insights into the economic and operational drivers of technology adoption. However, the results also revealed the limitations of such simulations. The NEEDS model, while dynamic and techno-economic, does not account for market supply-demand dynamics, physical limitations of vessels to accommodate energy storage on board, infrastructure constraints, or the gradual scaling of production capacities. As a result, the simulations often produce abrupt shifts in technology adoption, which are unlikely to occur in reality due to industrial, logistical, and economic inertia. Similarly, the CCNR pathways—though pioneering in their ambition—were designed as target scenarios to meet the goals of the Mannheim Declaration by 2035 and 2050, rather than as realistic projections of market-driven transitions.

To address these gaps, the SYNERGETICS Expert Scenario was developed, combining the latest cost assumptions with well-founded estimates based on practical experiences from pilot projects and interviews with vessel owners and operators. Unlike the CCNR pathways, this scenario does not pursue a predefined emission reduction target. Instead, it emerges from a set of boundary conditions that reflect current and anticipated developments based on energy policies and prices according to the WEO STEPS scenario. This includes substantial financial and regulatory support, expected reductions in the costs of alternative technologies, internalised CO<sub>2e</sub> cost in fossil fuels and favourable renewable energy price trends, and significant improvements in energy efficiency. Under these conditions, the scenario demonstrates that the IWT sector can make substantial progress toward the decarbonisation goals as presented in Mannheim declaration and EU policy documents.

However, the analyses also highlight the precarious nature of this progress: the results are highly sensitive to energy policies such as ETS-2 and RED-III. In a Business As Usual scenario, they may fail to be effective because of bunker tourism due to lack of level playing field between EU member states. The result is that financial incentives are insufficient, cost reductions fail to materialise. The likelihood of achieving the calculated emission reductions diminishes sharply because of no return on investment for vessel operators to invest in clean technologies and usage of renewable energy.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **64** of **122**



The Landscape of Synergies further illustrates the interdependencies between policy, technology, and infrastructure that underpin the transition. The key driver today is the policy, especially policy on EU level with a level playing field impact. Policy needs to set the right framework conditions to create a business case for vessel owners to invest in clean energy and usage of renewable energy. A solid business case for the users, backed by clear and stable long term policy regulations, will also give confidence to energy and infrastructure providers of renewable energy to invest in developing the network. Preferably, this will be done on corridor level to mitigate a 'chicken-egg' dilemma by pooling the supply and demand. With mass in volume, the technology can also further develop and economies of scale can be utilised, for example leading to more rapid standardisation, new business models and modular concepts (e.g. energy as a service').

Especially, the adoption of hydrogen, methanol, and battery-electric propulsion is not solely a function of technological maturity but mainly depends on regulatory frameworks (both technical regulations and energy regulations (ETS, RED), infrastructure availability, and economic factors. The lack of bunkering facilities for hydrogen and methanol, as well as the need for standardised charging infrastructure for battery-electric systems, remain significant barriers to their widespread adoption. However, no one will invest in a network of renewable energy if there is no secured demand. Demand will only be triggered if there is policy which ensures the demand for renewable energy or which makes it more attractive compared to fossil diesel by means of economic incentives.

The economic viability of alternative fuels is heavily influenced by their production costs, which are shaped by broader energy market trends and policy instruments such as carbon pricing. The report emphasises that a coordinated approach is necessary to address these challenges, combining measures such as the introduction of carbon pricing, specific targets to ensure renewable fuel use, the provision of financial and fiscal incentives, the acceleration of infrastructure development, the harmonisation of regulations, and the fostering of collaboration among stakeholders. However, today these elements are largely missing or expected to be ineffective in the field of energy supply to European IWT and smaller coastal vessels (below 5000 GT). Some countries like The Netherlands plan ETS-2 and RED-III but there is a big threat that these policies will be undermined by their neighbouring countries which do not follow or lag behind. The result is that there is an 'escape' for many vessel owners and operators, because they are often operating cross border, and can easily avoid bunkering in The Netherlands and can move their bunkering operations to Antwerp or Duisburg instead.

The analysis also underscores the urgency of timely action. Given the long lifespans of ships and propulsion technologies—often exceeding 30 to 50 years—delays in policy implementation or infrastructure deployment can lead to lock-in effects, where fossil-based systems remain dominant due to the inertia of existing assets. The report notes that the latest World Energy Outlook, published after the completion of the scenarios, re-introduced the Current Policies Scenario (CPS), which suggests a more cautious perspective on the speed of new technology deployment. This aligns with the observation that, without decisive regulatory intervention, the economic success of most low- and zero-carbon technologies is likely to be delayed. The SYNERGETICS Expert Scenario demonstrates that, with the right policy mix, the sector can make significant strides toward its decarbonisation goals. However, it also serves as a reminder that the window for action is narrowing, and that the next decade will be critical in determining whether the sector can align with the EU's long-term climate objectives for a 90% reduction of greenhouse gas emissions to be achieved in 2050 and to contribute to cleaner air for people.

The report identifies several key levers that must be activated to ensure a successful transition. First, carbon pricing mechanisms and the internalisation of external costs are essential to create a level playing field between fossil and renewable fuels. The gradual phasing out of tax exemptions for fossil diesel, as seen in some Member States, is a step in the right direction but needs to be expanded and harmonised across Europe to avoid market distortions. Second, financial incentives are crucial to offset the higher upfront costs of alternative technologies and reduce the investment risk for vessel owners. The analysis shows that CAPEX subsidies alone are insufficient to drive significant adoption; OPEX support or

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**Grant agreement no. | **101096809**Page **65** of **122**

equivalent measures are very much necessary to make technologies like hydrogen economically viable in the short to medium term. Third, infrastructure development must keep pace with fleet renewal to avoid bottlenecks. The successful deployment of alternative fuels depends on the timely outlook on demand for renewable energy resulting in investments and thus availability of bunkering and charging infrastructure, as well as the alignment of port and energy supply systems with fleet transition plans. Finally, harmonised regulations and standardised frameworks are indispensable to ensure interoperability, reduce uncertainty for investors, and facilitate cross-border cooperations and minimise time loss for bunkering/recharging. Seen the lower energy density of many renewable energy solutions compared to diesel, the speed and availability of bunkering/recharging facilities is getting more important for competitiveness of IWT and coastal shipping.

In addition to these measures, collaboration among stakeholders—including vessel owners, technology providers, ports, energy suppliers, and policymakers—is indispensable to align efforts, share knowledge, and collectively address the challenges of the energy transition. Initiatives such as the IWT Projects Cooperation Platform and the SYNERGETICS WP2 database exemplify how structured cooperation can amplify the impact of individual projects, avoid duplication of efforts, and accelerate the scaling of technologies and providing clear recommendations to policy makers on EU and national level. By leveraging these platforms, the sector can foster a more integrated and efficient approach to innovation uptake, ensuring that lessons learned from pilot projects and feasibility studies are widely disseminated and applied and taken into account.

In conclusion, this report provides a realistic yet ambitious vision for the decarbonisation of inland and coastal shipping. It demonstrates that achieving the sector's climate targets is feasible but requires a coherent, proactive, and collaborative approach that addresses economic, regulatory, and infrastructural barriers in parallel. The Updated Transition Pathways and the Landscape of Synergies offer valuable tools for policymakers, industry stakeholders, and researchers to navigate the complexities of the energy transition. The SYNERGETICS Expert Scenario, in particular, highlights the critical levers and associated risks that must be actively managed to make a sustainable future for IWT achievable. However, the success of this transition ultimately hinges on the willingness of all stakeholders to act decisively and collaboratively, ensuring that the necessary conditions for change are put in place without further delay. As the sector stands at a pivotal moment, the insights and recommendations presented in this report can serve as a roadmap for aligning economic competitiveness with the EU's climate and energy ambitions, paving the way for a sustainable, competitive, resilient and future-proof waterborne transport system.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**Grant agreement no. | **101096809**Page **66** of **122**

## Annex I Updated energy price scenarios

### | Executive Summary

The inland navigation and coastal shipping sector in the European Union is facing a significant challenge as it must align economic competitiveness with the EU's climate and energy policies. Energy costs are central to this transition, directly shaping both the operating environment for shipping companies and the effectiveness of regulatory measures introduced by policymakers.

Currently, inland navigation in Europe relies predominantly on fossil diesel fuel. This fuel is currently still attractive due to its low cost, tax exemptions, well-established infrastructure, high energy density, and low safety risks, making it the most beneficial option for operators today.

However, the EU's green agenda is accelerating the shift towards renewable and low-carbon alternatives, gradually phasing out fossil fuels. Options include Hydrotreated Vegetable Oil (HVO) and other advanced biofuels, bio-LNG, green methanol, green hydrogen, and battery-electric propulsion. Each of these alternatives presents advantages in terms of emission reductions but currently comes with substantially higher costs compared to fossil diesel.

To understand how policy and market developments could shape future fuel costs, three scenarios are assessed, aligned with the **World Energy Outlook publication (2024)**. Under the **STEPS scenario**, which reflects the current trajectory of existing policies and announced measures, fossil fuel prices are expected to rise steadily through 2050 due to increasing fuel and carbon costs. This gradual increase makes fossil-based energy carriers such as diesel, LNG, and grey hydrogen progressively more expensive. In contrast, renewable alternatives, including green hydrogen and green methanol, are projected to become significantly cheaper after 2030, driven by ongoing technological progress, declining renewable electricity costs, and scaling effects in production. By 2040–2050, the cost gap between fossil and green fuels narrows substantially, indicating that low-carbon fuels will become increasingly competitive. Nevertheless, between 2025 and 2035, fossil fuels are likely to remain the more economical choice in the absence of stronger policy incentives or carbon taxation. Overall, STEPS depicts a moderate energy transition in which current policies drive some progress toward decarbonization, but not yet at the pace required to achieve enough emission reductions.

The **APS scenario** explores the potential impact if all announced national energy and climate pledges, including net-zero targets, are fully implemented. In this case, fossil fuels continue to increase in price but retain competitiveness until around 2040. During this period, green and bio-based fuels, such as HVO and Bio-LNG, gradually gain cost efficiency and are expected to play a larger role in sectors where direct electrification remains technically or economically challenging. Electricity prices remain relatively stable throughout the projection period, highlighting the strong potential of electrification as a cost-effective pathway to decarbonization. Around 2040, the prices of fossil and renewable fuels converge, marking a crucial turning point for the maritime sector and other transport industries. From this point onward, shifting towards cleaner propulsion technologies and low-carbon fuels becomes not only environmentally desirable but also economically rational. The APS scenario therefore represents a slower, more predictable transition in which fossil fuels maintain short-term relevance but gradually lose their cost advantage over cleaner alternatives.

The **NZE scenario** outlines the path required to achieve global net-zero emissions by 2050, consistent with limiting global warming to 1.5°C. In this scenario, fossil fuel prices rise steadily due to stringent CO<sub>2</sub> emission pricing, increasing resource constraints, and inflationary pressures. At the same time, green fuels, particularly green hydrogen and green methanol, become increasingly competitive as technological innovation and large-scale deployment drive down production costs. Electricity prices remain stable, positioning electrification as the most cost-effective and scalable energy solution in the long

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Grant agreement no. | **101096809**

Page **67** of **122**

term. Biofuels such as HVO and Bio-LNG continue to play an important complementary role in sectors where electrification is less feasible. By 2050, renewable and low-carbon energy carriers are expected to be fully cost-competitive or even cheaper than fossil fuels, confirming the economic viability of deep decarbonization under an ambitious climate policy framework.

Across all three scenarios, a number of consistent trends emerge. Fossil fuel prices rise structurally over time, while the costs of renewable energy carriers decline significantly after 2030. Internalising the CO2 costs and imposing strict limits on emission levels (ETS) acts as a key driver in closing the cost gap between fossil and green fuels, making it a decisive factor in the competitiveness of low-carbon technologies. Electricity remains the most stable and, over time, the least expensive energy type, reinforcing its central role in the transition toward a decarbonized energy system. A critical tipping point is expected between 2040 and 2050, when price parity between fossil and renewable fuels is reached in most sectors.

In conclusion, the analysis shows that while the energy transition may advance gradually under current and pledged policies, the economic and regulatory momentum will increase renewable and low-carbon fuels over time. For shipowners, energy suppliers, and policymakers, the coming decades, particularly the 2030s and 2040s, represent a decisive period to plan and invest in cleaner energy solutions that align with long-term competitiveness and sustainability goals.

This report serves as basis for further analyses on the Total Costs of Ownership of propulsion systems of inland and coastal vessels.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **68** of **122**



## Introduction

The inland navigation and coastal shipping sector in the European Union are facing a significant challenge as it must align economic competitiveness with the EU's climate and energy policies. Energy costs are central to this transition, directly shaping both the operating environment for shipping companies and the effectiveness of regulatory measures introduced by policymakers.

Currently, inland navigation in Europe relies predominantly on fossil diesel fuel. This fuel benefits from low costs, no taxation, well-established infrastructure, widespread availability, a very high energy density and low safety risks making it the most beneficial option for operators today. However, prices for fossil fuels remain highly volatile. They are tied to international oil markets and influenced by factors such as global supply and demand, geopolitical tensions, and disruptions in refining and distribution. Such volatility creates uncertainty for shipping companies. In parallel, the EU's current green agenda is accelerating the push towards renewable and low-carbon alternatives and to gradually phase out the fossil fuels. Options for renewable fuels include:

- Hydrotreated Vegetable Oil (HVO) and other advanced biofuels, which are technically compatible with existing engines but currently cost 50–100% more than conventional fossil diesel, due to feedstock costs and processing costs. On longer term, possibly also e-diesel can be an option, which requires green hydrogen and sustainable CO<sub>2</sub>.
- Bio-LNG which can be made from bio-mass or feedstock such as wet manure, and can achieve very high reduction rates of GHG emissions, even beyond 100% as it prevents methane to be emitted directly to the air. On longer term, possibly also e-methane can be an option, which requires green hydrogen and sustainable CO<sub>2</sub>.
- Green methanol, produced from renewable sources like biomass or captured CO<sub>2</sub> and green hydrogen, is emerging as a low-carbon fuel option for inland shipping due to its easier storage and handling compared to hydrogen.
- Green hydrogen, powered by renewable electricity. Currently, supply chains and bunkering infrastructure remain underdeveloped.
- Battery-electric propulsion, viable at the moment for short-range or port-based operations, but constrained by limited energy density and high upfront infrastructure costs. The concept of swappable batteries and the further development of battery technologies can mitigate the limitations.

The economic gap between fossil and renewable energy sources remains the most significant barrier to adoption. This is illustrated by the Total Cost of Ownership calculations, in which the energy costs have a dominant share and are much higher than additional capital costs. For many shipping companies, switching to renewable energy would currently increase operating costs while the customers are not (yet) willing to pay for the benefits on the emission performance. As a result, operation using fossil diesel is most beneficial for the vessel owner/operator.

For policymakers, this divergence highlights the need for a robust regulatory and supporting framework. Subsidies, tax reductions, reduction targets for energy suppliers, carbon pricing, and targeted funding and financing for innovation and infrastructure need to result in the level playing field between fossil and renewable energy for inland navigation and coastal shipping. This is however a process of many years but eventually the impact of policies will be reflected in the energy prices, creating a business case for renewable solutions compared to fossil options.

For shipping companies, the challenge lies in balancing immediate cost and competitiveness pressure with long-term strategic positioning. Investments in dual-fuel engines, retrofits, or pilot projects with hydrogen and batteries are ongoing, but these require long term commitments from clients, clear signals on future fuel availability, pricing, and regulatory certainty to convince vessel owner/operators and other stakeholders to step in such a transition.

Bridging the gap between costlier renewable energy and cheaper fossil fuels is therefore critical for the future of inland navigation and coastal shipping in Europe. Scaling up renewable energy production,

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **69** of **122**



developing bunkering and charging infrastructure along key waterways and in ports, and ensuring regulatory stability and support will be essential to enable a gradual, economically viable transition. Policy-makers and industry stakeholders alike must collaborate closely to align incentives, mitigate risks, and ensure that inland navigation and coastal shipping continue to be both a competitive transport mode and a driver of the EU's climate ambitions.

## Scenarios

Given the scope of the SYNERGETICS project and its specific focus on the European inland waterways and coastal vessels, it has been decided to work with a minimum and maximum price range per fuel / energy type specific for the European energy prices.

Fuel / energy prices have a varying bandwidth that is broadly applicable across the majority of the EU countries. To ensure comparability, the following price components have been taken into account:

- Wholesale prices for each fuel / energy type reflecting the production price of energy/fuel
- Price impacts from regulations, such as impacts from Renewable Energy Directive (RED), Energy Taxation Directive (ETD) and the EU Emissions Trading System (ETS)
- Distribution costs per fuel / energy type including handling costs, infrastructure, storage

Where possible, a distinction has also been made between fossil and renewable energy sources in order to enhance the quality and relevance of the comparison between the different energy types.

In this report, the focus is on current fuel/energy prices and the future prognoses. For the future prices different scenarios are described to see what could happen to the inland shipping industry with a different set of regulatory rules and implementations.

The scenarios are based on the scenarios used in the World Energy Outlook 2024 (WEO 2024), published by the International Energy Agency (hereafter IEA)<sup>30</sup> with specific values for Europe. In the WEO 2024 there are three scenarios which are:

- Stated Policies Scenario (STEPS)
- Announced Pledges Scenario (APS)
- Net Zero Emissions (NZE)

The Stated Policies Scenario is a kind of business-as-usual scenario which takes into account the planned and confirmed policy measures. The Announced Pledges Scenario takes it a step further in terms of ambitions and uses the climate targets of countries as basis for the forecasts of energy prices. The Net Zero Emissions Scenario is the most ambitious one regarding the climate mitigation and assumes that the global warming will not exceed 1.5 degrees Celsius, which requires higher targets than foreseen in the APS.

This report was developed throughout 2025 using the World Energy Outlook 2024 as its primary reference. Since then, the World Energy Outlook 2025 has been published, introducing an updated methodological approach and revised scenario framework. These changes have been reviewed and taken into consideration. However, for the purposes of consistency and comparability, it was decided to continue using the 2024 scenarios. A comparison of the scenarios that are present in both editions, such as the Stated Policies Scenario (STEPS) and the Net Zero Emissions by 2050 Scenario (NZE), indicates that the differences between the 2024 and 2025 versions are minimal. Therefore, the 2024 data remains sufficiently robust for use in this analysis.

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<sup>30</sup> [World Energy Outlook 2024](#)



## Stated Policies Scenario

The Stated Policies Scenario (STEPS) provides a projection of the global energy system based on current policy measures and officially announced policy intentions. For Europe, this concerns policies such as the revised RED III Directive and the revised EU-ETS. This scenario reflects the direction the energy system is likely to take under existing policies, without assuming that all announced targets will be fully achieved on time. Under STEPS, global energy demand is expected to grow by 0.7% per year between 2023 and 2030, about half the growth rate of the past decade. This slower growth is driven by improvements in energy efficiency, electrification, and the accelerated deployment of renewable energy. Electricity demand is projected to grow faster than total energy demand, driven by factors such as electrification of transport, data centres, and air conditioning. Renewable energy, particularly solar and wind, will contribute most to electricity generation growth, with a global market share exceeding 40% by 2035 and nearly 60% by 2050. Meanwhile demand for oil, gas, and coal is expected to peak before 2030, though the decline varies by fuel. In table 24 the expected wholesale prices for the coming years are shown. It needs to be noted however that this does not include any CO<sub>2</sub> costs. It can be seen that the oil prices are declining, as result of less demand for fossil crude oil due. The reducing demand is the result of policies to mitigate climate change and thus to phase-out fossil fuels. For the two other scenarios, the APS and NZE, the decline of the whole sale price is much larger (compare table 1 with tables 2 and 3).

24 | STEPS EU oil and gas prices

STEPS	2030	2040	2050
IEA crude oil (\$/barrel)	79	77	75
Natural gas (\$/MBtu)	6.5	7.6	7.7

The STEPS scenario serves as a reference for the other two main scenarios in the World Energy Outlook 2024: the Announced Pledges Scenario (APS), which assumes full and timely implementation of all national energy and climate targets, and the Net Zero Emissions by 2050 Scenario (NZE), which outlines a pathway to net-zero emissions by 2050 to limit global warming to 1.5°C.

## Announced Pledges Scenario

The Announced Pledges Scenario (APS) assumes that all current national energy and climate pledges made by governments including net-zero goals are met in full and on time. Under APS, policy ambition increases beyond what is already law or currently implemented (as in the Stated Policies Scenario), leading to deeper emissions reductions, faster deployment of renewable energy, and greater uptake of technologies like electric vehicles, efficiency improvements, and clean power generation.

While APS offers a more optimistic outlook than STEPS, it still falls short of the path required for limiting global warming to 1.5 °C. It shows what could happen if governments live up to their declared commitments, but also highlights the gap between ambition and what is needed for the most ambitious climate goals. Table 25 shows that in the APS the EU oil prices are expected to decrease even more, compared to the STEPS. Nature gas will decrease even further, although not as significant as the oil prices.



## 25 | APS EU oil and gas prices

APS	2030	2040	2050
IEA crude oil (\$/barrel)	72	63	58
Natural gas (\$/MBtu)	6.0	5.2	5.2

### Net Zero Emissions scenario

The Net Zero Emissions (NZE) Scenario outlines a pathway in which global CO<sub>2</sub> emissions fall to net zero by 2050, consistent with limiting global warming to around 1.5 °C. This scenario assumes that countries not only deliver on their existing pledges but also take additional actions, including a rapid scale-up of renewables, large-scale electrification, major efficiency improvements, and a sharp reduction in the use of fossil fuels.

In the NZE, electricity demand grows significantly, while total energy demand declines thanks to efficiency measures. Renewables, especially solar and wind, alongside nuclear, hydropower, and bioenergy, provide the bulk of the power mix. The use of unabated fossil fuels is almost entirely phased out, while technologies such as carbon capture, utilization and storage (CCUS) and clean hydrogen play a crucial supporting role. Due to the phasing out of fossil fuels, the wholesale price of crude oil will reach an all-time low, which is also shown in table 26. Natural gas will also be at one of the lowest prices, although the price difference in 2050 within all three scenarios is not as significant as for crude oil.

## 26 | NZE EU oil and gas prices

NZE	2030	2040	2050
IEA crude oil (\$/barrel)	42	30	25
Natural gas (\$/MBtu)	4.4	4.1	4.0



## Energy policy interventions and the price impact

Currently, the European Taxation Directive is still under revision which makes it yet unclear if there will be minimum excise duties to be applied for fuels and energy used by coastal vessel and inland vessels and, if implemented, which differentiation there will be between fossil fuels and renewable energy types. The framework for taxing energy and providing subsidies and creating binding targets for usage of renewable fuels or achieving carbon emission reductions in the energy sector is at a crossroads, shaped by climate objectives, the energy crisis, and pressure to ensure fairness.

Despite commitments to phase out environmentally harmful subsidies, fossil fuels still receive substantial support in the EU because the external costs of climate mitigation are not internalised by means of taxation of Emission Trading Schemes. The 2024 Report on Energy Subsidies shows fossil fuel subsidies in 2023 amounted to about €111 billion, although this represents a decline (18%) from the 2022 level.

Most of these subsidies take the form of tax reductions or exemptions, or income support to shield households and industries from high fuel prices. Many of these are crisis-related measures (e.g. during the energy price spikes) rather than long-term structural subsidies. However, the situation of the tax exemptions on fuels for inland navigation and coastal shipping is of structural character. Between countries along the Rhine River there is even an agreement from 1952 between the CCNR countries not to impose any taxes on fuel used for inland navigation.

Renewable energy continues to be supported through subsidies, although the nature and amount of support vary significantly between countries and over time. In 2023, subsidies for renewables and clean electricity were still considerable but showed signs of stabilization or modest decline compared to peak levels during the height of energy market volatility.

To close gaps and make tax and subsidy policy more coherent with climate targets, the European Commission is pursuing several policy reforms:

- Revising the Energy Taxation Directive to ensure minimum tax rates are more closely linked to environmental performance, thus introducing also minimum tax levels for fuels supplied to inland navigation and coastal vessels.
- Phasing out fossil fuel subsidies, especially those that prolong use of high-emission fuels, with the target year of 2050 frequently cited.
- Tightening state aid rules to ensure subsidies go to green investments rather than propping up fossil fuel infrastructure.

In this sub-report (Annex to D5.2), we distinguish different scenarios. However, the base scenario STEPS already takes into account the measures such as RED-III and the revised EU-ETS which do have an impact on prices of energy. However, in the two more ambitious scenarios, we do assume higher impacts as result of policies required to realise the ambitions for the scenarios.

As an example, the EU-ETS revision introduces the "ETS-2 system" with the opt-in for fossil fuel supply to inland navigation. Originally it was planned that by 2027 the CO<sub>2</sub> emission costs are internalised, but the introduction has been postponed to 2028. A price of 45 euro per ton of CO<sub>2</sub>, as expected by the European Commission in their impact assessment study, would lead to a price increase of fossil diesel fuel of 12 cents per litre. Next to that the revision of the Renewable Energy Directive (RED-III) and the target to reduce the CO<sub>2</sub> emissions per MJ of energy supplied by 14.5% is estimated to lead to a price increase of 13 cents per litre of fuel by 2030. This price increase is reflecting the compensation to supply the required amounts of renewable fuels such as HVO, FAME, hydrogen and electricity into the energy mix for inland navigation.

Therefore, the current policies RED-III and ETS-2 opt-in already lead to a price increase of 25 cents per litre of fuel, while the current market price is around 55 cents per litre. Consequently, the policy measures RED-III and ETS-2 already lead to a price increase of 45% between 2025 and 2030.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **73** of **122**

Towards 2045 the available emission tickets for fossil fuels will be reduced to zero. As a result, the prices for CO<sub>2</sub> are expected to increase significantly, resulting in renewable alternatives becoming a cost competitive option instead of using fossil diesel. For example, drop-in fuels such as HVO, e-diesel are expected to become competitive as result of these policy measures.

## Overall prices and comparison

### STEPS analysis

The Stated Policies Scenario (STEPS) provides a sense of the energy sector’s direction based on the situation seen in 2024 taking into account the market data, technology costs and in-depth analysis of the prevailing policy settings in countries around the world and in Europe. The STEPS also provides the backdrop for the upside and downside sensitivity cases.

The current policies that have been announced by the European Union are for example the RED-III and the option for Member States to also activate ETS 2 for fossil fuel supply to inland navigation. There is no universal approach how or if to implement the ETS2 in the European inland shipping sector. It depends if Member States themselves decide to expand the scope of the ETS2 to include also the fuel supply to inland navigation or to leave it out.

However, to compare the expected prices, in the STEPS-scenario, seen the decision of The Netherlands with a share of 70 % of fuel supply in IWT, we have chosen to internalise an inclining CO<sub>2</sub> costs tax of EUR 0.25/kg per 5 years from 2040 onwards for fossil fuels (base is diesel). For the ETS 2 we have based the figures on the data published in the World Energy Outlook 2024, in which, it sees a base the EU ETS CO<sub>2</sub> price for power generation rise to just under USD 160/tonne CO<sub>2</sub> in 2050. From 2030 to 2050 an increased CO<sub>2</sub> price value was assumed and these costs were internalised the energy prices based on the carbon intensity of the respective fossil fuel. The following table presents the total CO<sub>2</sub> prices which have been applied on the fossil fuel for IWT:

27 | CO<sub>2</sub> prices internalised in the fuel prices for inland navigation and coastal shipping

	STEPS		APS		NZE	
	minimum	maximum	minimum	maximum	minimum	maximum
<b>2025</b>	0	0	0	0	0	0
<b>2030</b>	€ 96	€ 136	€ 104	€ 144	€ 236	€ 276
<b>2035</b>	€ 112	€ 152	€ 250	€ 290	€ 392	€ 432
<b>2040</b>	€ 189	€ 229	€ 396	€ 436	€ 548	€ 588
<b>2045</b>	€ 266	€ 306	€ 542	€ 582	€ 704	€ 744
<b>2050</b>	€ 343	€ 383	€ 688	€ 728	€ 860	€ 900

Under the STEPS, the cost evolution of various energy carriers shows a widening gap between fossil-based and renewable alternatives. While grey hydrogen, LNG, diesel, and other fossil fuels experience a steady cost increase through 2050, driven by higher fuel and carbon prices, green hydrogen and green methanol show a significant decline in cost after 2030. This reflects technological progress, lower renewable electricity costs, and gradual market scaling. Despite these improvements, fossil-based options remain cheaper in the near term (2025–2035). However, by 2040–2050, the cost difference narrows considerably, suggesting that low-carbon fuels will become increasingly competitive, especially in sectors where decarbonization policies intensify.

Overall, the STEPS scenario indicates a transitional phase: current policies drive moderate efficiency gains and cost reductions for green fuels, but not yet at a pace sufficient to fully replace fossil on the short term.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **74** of **122**



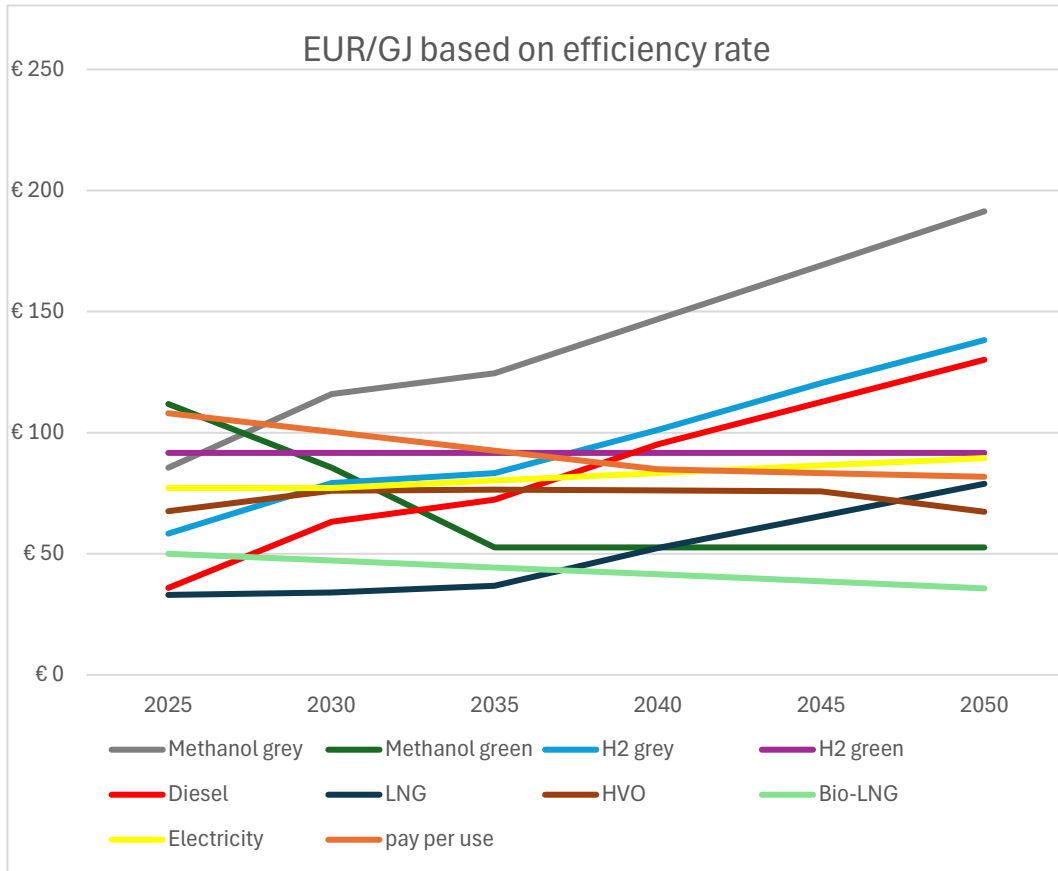
28 | STEPS minimum range, energy prices euro per GJ (caloric)

Min	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 33	€ 43	€ 29	€ 46	€ 15	€ 13	€ 28	€ 20	€ 69	€ 97
<b>2030</b>	€ 44	€ 33	€ 40	€ 46	€ 27	€ 14	€ 32	€ 19	€ 69	€ 90
<b>2035</b>	€ 47	€ 20	€ 42	€ 46	€ 30	€ 15	€ 32	€ 18	€ 72	€ 83
<b>2040</b>	€ 56	€ 20	€ 51	€ 46	€ 40	€ 21	€ 32	€ 17	€ 75	€ 76
<b>2045</b>	€ 64	€ 20	€ 60	€ 46	€ 47	€ 26	€ 32	€ 15	€ 78	€ 75
<b>2050</b>	€ 73	€ 20	€ 69	€ 46	€ 55	€ 32	€ 28	€ 14	€ 81	€ 74

29 | STEPS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion

Efficiency min	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 86	€ 112	€ 58	€ 92	€ 36	€ 33	€ 68	€ 50	€ 77	€ 108
<b>2030</b>	€ 116	€ 86	€ 79	€ 92	€ 63	€ 34	€ 76	€ 47	€ 77	€ 100
<b>2035</b>	€ 125	€ 53	€ 83	€ 92	€ 72	€ 37	€ 76	€ 44	€ 80	€ 93
<b>2040</b>	€ 147	€ 53	€ 101	€ 92	€ 95	€ 52	€ 76	€ 42	€ 83	€ 85
<b>2045</b>	€ 169	€ 53	€ 120	€ 92	€ 113	€ 66	€ 76	€ 39	€ 86	€ 83
<b>2050</b>	€ 191	€ 53	€ 138	€ 92	€ 130	€ 79	€ 67	€ 36	€ 90	€ 82





19 | STEPS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion

30 | STEPS maximum range, energy prices euro per GJ (caloric)

Max	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 43	€ 108	€ 100	€ 175	€ 21	€ 16	€ 43	€ 60	€ 89	€ 139
<b>2030</b>	€ 58	€ 83	€ 115	€ 175	€ 36	€ 20	€ 47	€ 57	€ 89	€ 125
<b>2035</b>	€ 62	€ 51	€ 117	€ 150	€ 40	€ 21	€ 47	€ 53	€ 92	€ 111
<b>2040</b>	€ 70	€ 51	€ 126	€ 117	€ 50	€ 27	€ 47	€ 50	€ 94	€ 103
<b>2045</b>	€ 79	€ 51	€ 135	€ 100	€ 57	€ 32	€ 47	€ 46	€ 97	€ 97
<b>2050</b>	€ 87	€ 51	€ 144	€ 83	€ 64	€ 38	€ 44	€ 43	€ 100	€ 94

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

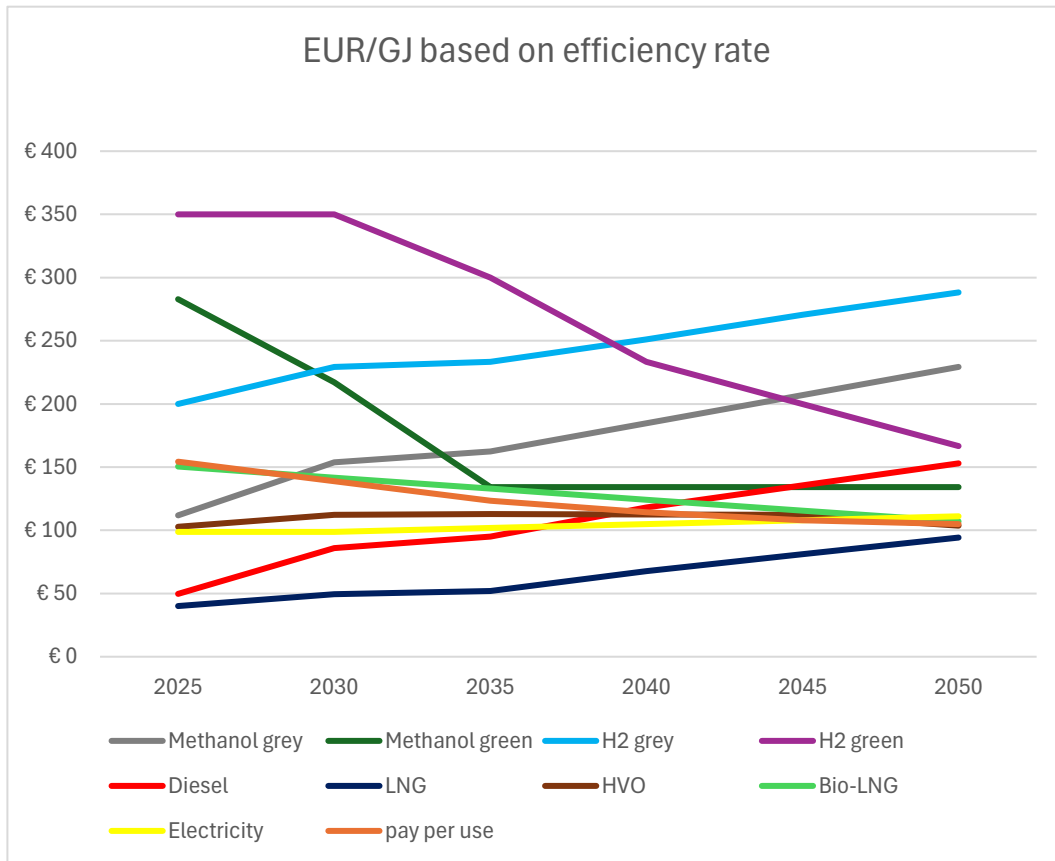
Grant agreement no. | **101096809**

Page **76** of **122**



31 | STEPS maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion

Efficiency max	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	pay per use battery
<b>2025</b>	€ 112	€ 283	€ 200	€ 350	€ 50	€ 40	€ 103	€ 150	€ 99	€ 154
<b>2030</b>	€ 154	€ 217	€ 229	€ 350	€ 86	€ 49	€ 112	€ 142	€ 99	€ 139
<b>2035</b>	€ 162	€ 134	€ 233	€ 300	€ 95	€ 52	€ 113	€ 133	€ 102	€ 123
<b>2040</b>	€ 185	€ 134	€ 251	€ 233	€ 118	€ 68	€ 113	€ 124	€ 105	€ 114
<b>2045</b>	€ 207	€ 134	€ 271	€ 200	€ 136	€ 81	€ 112	€ 116	€ 108	€ 108
<b>2050</b>	€ 229	€ 134	€ 288	€ 167	€ 153	€ 94	€ 104	€ 107	€ 111	€ 105



20 | STEPS maximum range, energy prices euro per GJe, taking into account efficiency of energy conversion

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **77** of **122**



### APS analysis

The Announced Pledges Scenario (APS) examines what would happen if all national energy and climate targets made by governments, including net zero goals, are met in full and on time.

In the Announced Pledges Scenario (APS), fuel prices reflect a gradual transition where conventional fossil fuels such as diesel and LNG steadily increase due to resource constraints and carbon costs. Electricity remains relatively stable, highlighting its potential as a cost-effective option for decarbonization. Green fuels like hydrogen and methanol remain more expensive than their grey counterparts throughout the period, indicating that their adoption will likely be slower under current policy pledges. Biofuels, including HVO and Bio-LNG, show moderate price increases, maintaining a role in sectors that are difficult to electrify.

Overall, the APS scenario suggests a slower energy transition compared to more ambitious pathways, with fossil fuels retaining significant economic competitiveness and limited pressure on rapid decarbonization. Around 2040 most energy type prices cross each other where the alternative options become more cost effective than the fossil fuels. This will become as crucial point for shipowners to consider the transition of their fleet to an alternative mode.

32 | APS minimum range, energy prices euro per GJ (caloric)

Min	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 33	€ 43	€ 29	€ 46	€ 15	€ 13	€ 28	€ 20	€ 69	€ 97
<b>2030</b>	€ 55	€ 35	€ 42	€ 46	€ 24	€ 14	€ 31	€ 19	€ 69	€ 90
<b>2035</b>	€ 73	€ 30	€ 59	€ 46	€ 37	€ 23	€ 33	€ 18	€ 69	€ 83
<b>2040</b>	€ 90	€ 25	€ 75	€ 42	€ 51	€ 33	€ 36	€ 17	€ 69	€ 76
<b>2045</b>	€ 107	€ 20	€ 92	€ 42	€ 64	€ 43	€ 38	€ 16	€ 69	€ 75
<b>2050</b>	€ 124	€ 15	€ 108	€ 42	€ 77	€ 53	€ 42	€ 14	€ 69	€ 74

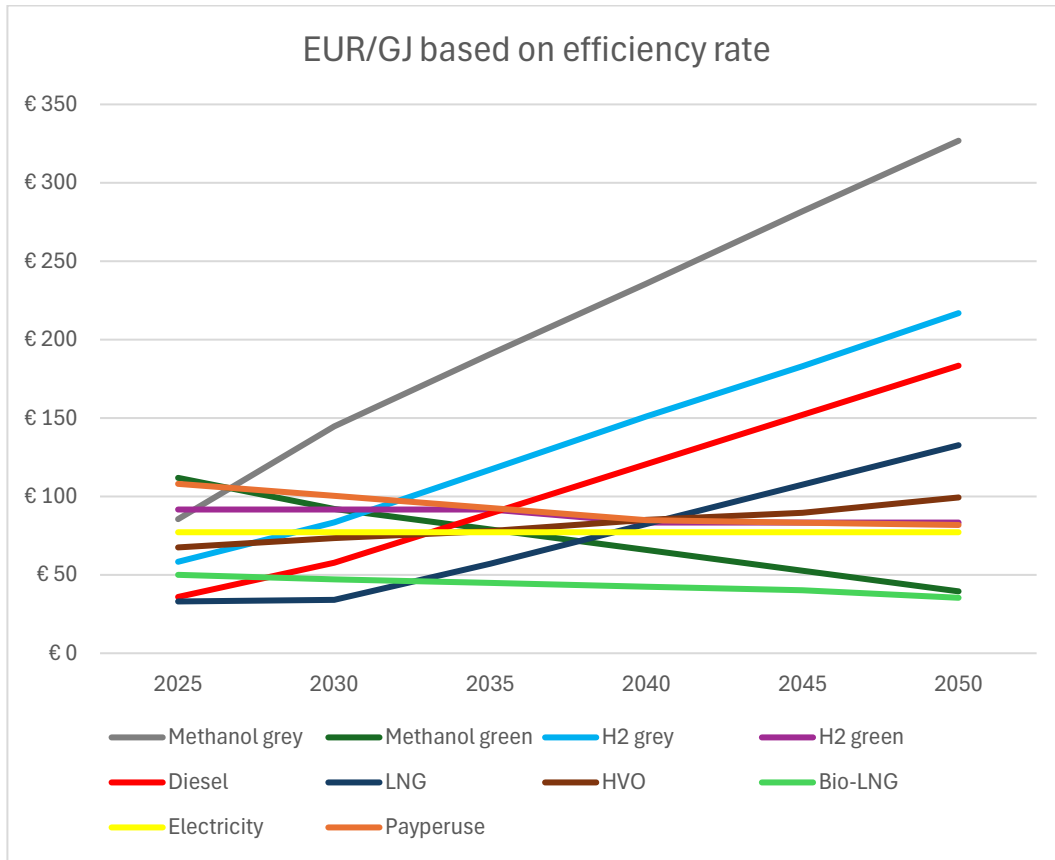
33 | APS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion

Efficiency min	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 86	€ 112	€ 58	€ 92	€ 36	€ 33	€ 67	€ 50	€ 77	€ 108
<b>2030</b>	€ 145	€ 92	€ 83	€ 92	€ 58	€ 34	€ 73	€ 47	€ 77	€ 100
<b>2035</b>	€ 191	€ 79	€ 117	€ 92	€ 89	€ 57	€ 78	€ 45	€ 77	€ 93
<b>2040</b>	€ 236	€ 66	€ 151	€ 83	€ 121	€ 82	€ 85	€ 42	€ 77	€ 85
<b>2045</b>	€ 282	€ 53	€ 183	€ 83	€ 152	€ 108	€ 89	€ 40	€ 77	€ 83
<b>2050</b>	€ 327	€ 39	€ 217	€ 83	€ 183	€ 133	€ 99	€ 35	€ 77	€ 82

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Grant agreement no. | **101096809**





21 | APS minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion

34 | APS maximum range, energy prices euro per GJ (caloric)

Max	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 43	€ 108	€ 100	€ 175	€ 21	€ 16	€ 43	€ 60	€ 89	€ 139
<b>2030</b>	€ 69	€ 60	€ 117	€ 75	€ 34	€ 20	€ 46	€ 56	€ 89	€ 125
<b>2035</b>	€ 87	€ 55	€ 134	€ 75	€ 47	€ 29	€ 48	€ 52	€ 86	€ 111
<b>2040</b>	€ 104	€ 50	€ 150	€ 71	€ 60	€ 39	€ 51	€ 48	€ 86	€ 103
<b>2045</b>	€ 122	€ 45	€ 167	€ 71	€ 73	€ 50	€ 53	€ 44	€ 83	€ 97
<b>2050</b>	€ 139	€ 40	€ 184	€ 71	€ 87	€ 60	€ 56	€ 41	€ 83	€ 94

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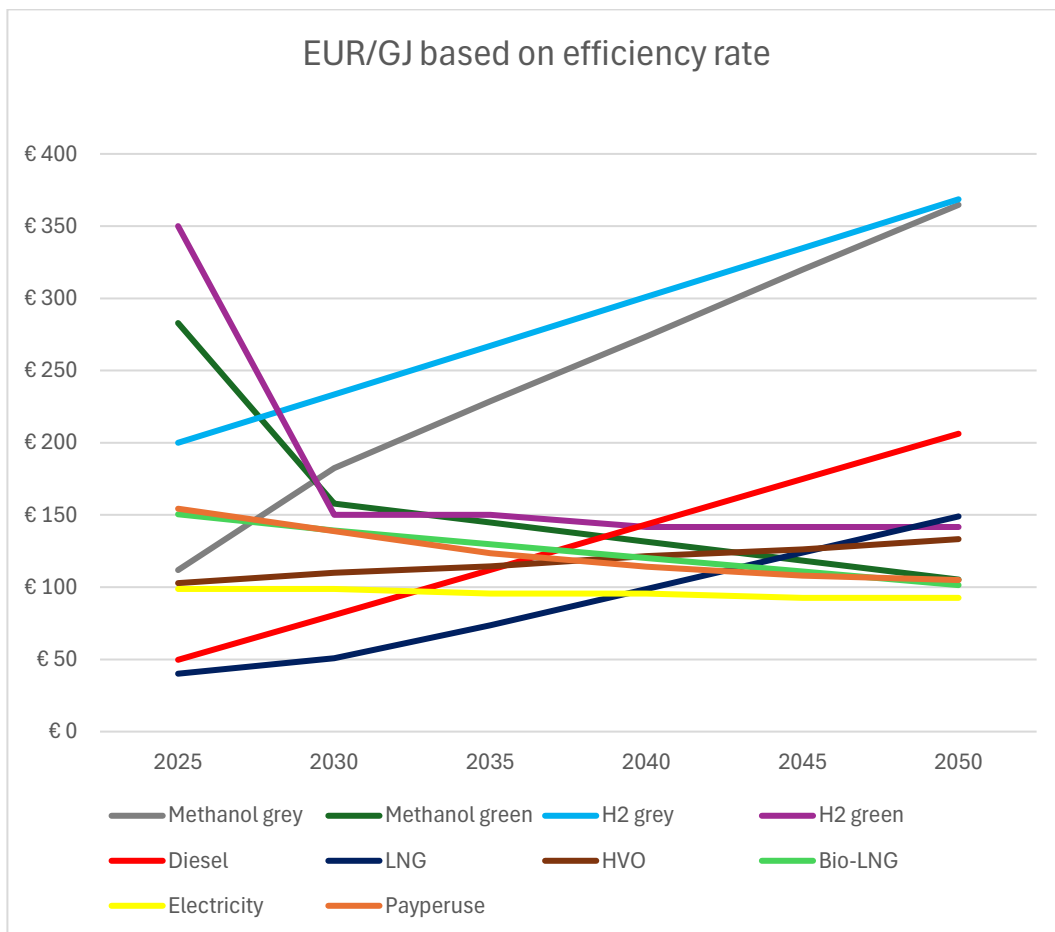
Grant agreement no. | **101096809**

Page **79** of **122**



35 | APS maximum range, energy prices euro per GJ, taking into account efficiency of energy conversion

Efficiency max	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 112	€ 283	€ 200	€ 350	€ 50	€ 40	€ 103	€ 150	€ 99	€ 154
<b>2030</b>	€ 182	€ 158	€ 233	€ 150	€ 81	€ 51	€ 110	€ 139	€ 99	€ 139
<b>2035</b>	€ 229	€ 145	€ 267	€ 150	€ 112	€ 74	€ 114	€ 130	€ 96	€ 123
<b>2040</b>	€ 274	€ 132	€ 301	€ 142	€ 143	€ 99	€ 122	€ 120	€ 96	€ 114
<b>2045</b>	€ 320	€ 118	€ 335	€ 142	€ 175	€ 124	€ 126	€ 111	€ 93	€ 108
<b>2050</b>	€ 365	€ 105	€ 369	€ 142	€ 206	€ 149	€ 133	€ 101	€ 93	€ 105



22 | APS maximum range, energy prices euro per GJ, taking into account efficiency of energy conversion

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Grant agreement no. | **101096809**

Page **80** of **122**



## NZE analysis

The Net Zero Emissions by 2050 (NZE) Scenario maps out an increasingly narrow path to reach net zero emissions by mid-century in a way that limits global warming to 1.5 °C.

The data indicate clear trends in the evolution of fuel prices over the next three decades. Conventional fossil fuels, such as diesel and LNG, are expected to gradually increase in cost, reflecting anticipated resource constraints, carbon pricing, and general inflation. In contrast, electricity prices remain relatively stable, highlighting the potential cost-effectiveness of electrification for transport and industry.

Green alternatives, including hydrogen and methanol, start out more expensive than their grey counterparts but become rapidly competitive over time as technological improvements and economies of scale reduce production costs. Grey fuels may initially be cheaper, but they carry long-term environmental and economic risks due to associated carbon emissions. Biofuels such as HVO and Bio-LNG show moderate price increases and remain an important option for sectors that are difficult to electrify.

Overall, the projected €/GJ prices underscore a strong economic incentive to transition toward renewable energy carriers and electricity. While green fuels may require higher upfront investment, their competitiveness is expected to improve significantly by 2050, supporting the broader goal of achieving a low-carbon, sustainable energy system.

36 | NZE minimum range, energy prices euro per GJ (caloric)

Min	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 33	€ 43	€ 29	€ 46	€ 15	€ 13	€ 28	€ 20	€ 69	€ 97
<b>2030</b>	€ 71	€ 35	€ 55	€ 50	€ 36	€ 21	€ 31	€ 19	€ 69	€ 90
<b>2035</b>	€ 91	€ 30	€ 73	€ 38	€ 50	€ 33	€ 33	€ 18	€ 69	€ 83
<b>2040</b>	€ 110	€ 25	€ 91	€ 38	€ 63	€ 42	€ 37	€ 17	€ 67	€ 76
<b>2045</b>	€ 127	€ 20	€ 108	€ 33	€ 76	€ 53	€ 39	€ 16	€ 67	€ 75
<b>2050</b>	€ 145	€ 15	€ 126	€ 33	€ 90	€ 64	€ 41	€ 14	€ 67	€ 74

37 | NZE minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion

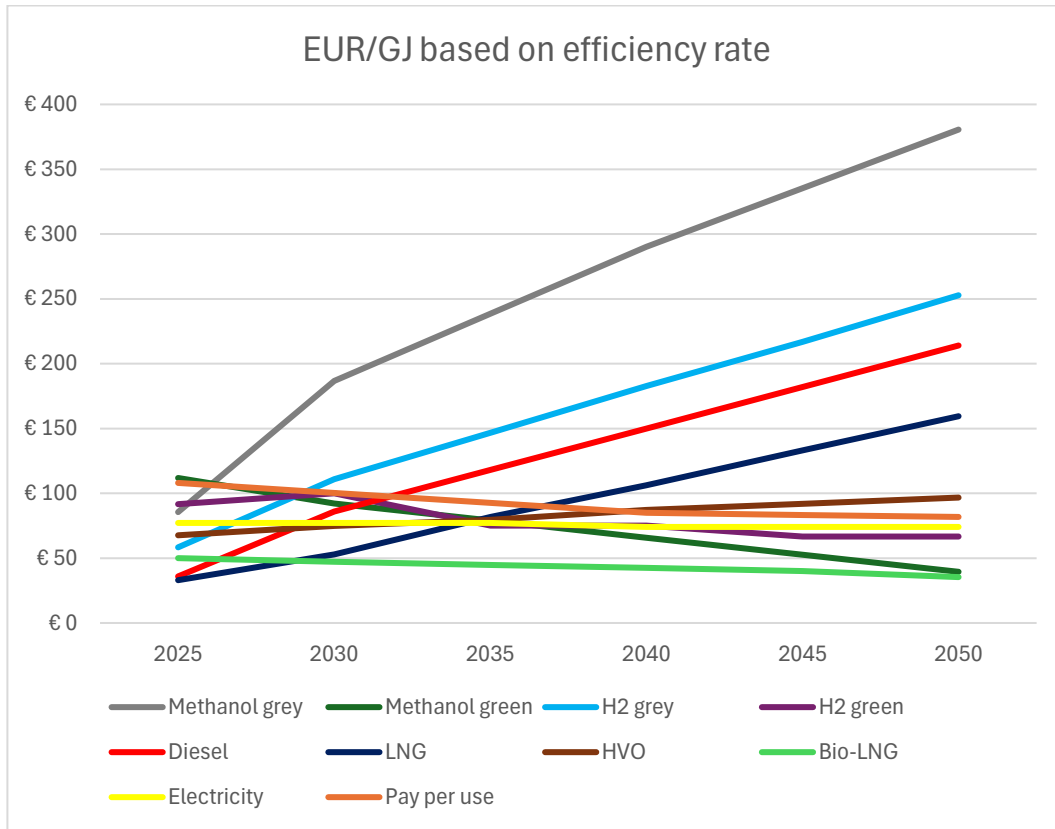
Efficiency min	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 86	€ 112	€ 58	€ 92	€ 36	€ 33	€ 68	€ 50	€ 77	€ 108
<b>2030</b>	€ 187	€ 92	€ 111	€ 100	€ 86	€ 53	€ 75	€ 47	€ 77	€ 100
<b>2035</b>	€ 238	€ 79	€ 147	€ 75	€ 118	€ 82	€ 80	€ 45	€ 77	€ 93
<b>2040</b>	€ 290	€ 66	€ 183	€ 75	€ 150	€ 106	€ 87	€ 42	€ 74	€ 85
<b>2045</b>	€ 335	€ 53	€ 217	€ 67	€ 182	€ 133	€ 92	€ 40	€ 74	€ 83
<b>2050</b>	€ 381	€ 39	€ 253	€ 67	€ 214	€ 159	€ 97	€ 35	€ 74	€ 82

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Grant agreement no. | **101096809**

Page **81** of **122**





23 | NZE minimum range, energy prices euro per GJe, taking into account efficiency of energy conversion

38 | NZE maximum range, energy prices euro per GJ (caloric)

Max	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 43	€ 108	€ 100	€ 175	€ 21	€ 16	€ 43	€ 60	€ 89	€ 139
<b>2030</b>	€ 85	€ 60	€ 130	€ 75	€ 46	€ 29	€ 47	€ 56	€ 89	€ 125
<b>2035</b>	€ 105	€ 55	€ 148	€ 71	€ 59	€ 38	€ 49	€ 52	€ 83	€ 111
<b>2040</b>	€ 125	€ 50	€ 166	€ 71	€ 73	€ 49	€ 52	€ 48	€ 83	€ 103
<b>2045</b>	€ 142	€ 45	€ 184	€ 67	€ 86	€ 60	€ 54	€ 44	€ 78	€ 97
<b>2050</b>	€ 159	€ 40	€ 202	€ 67	€ 99	€ 71	€ 56	€ 41	€ 78	€ 94

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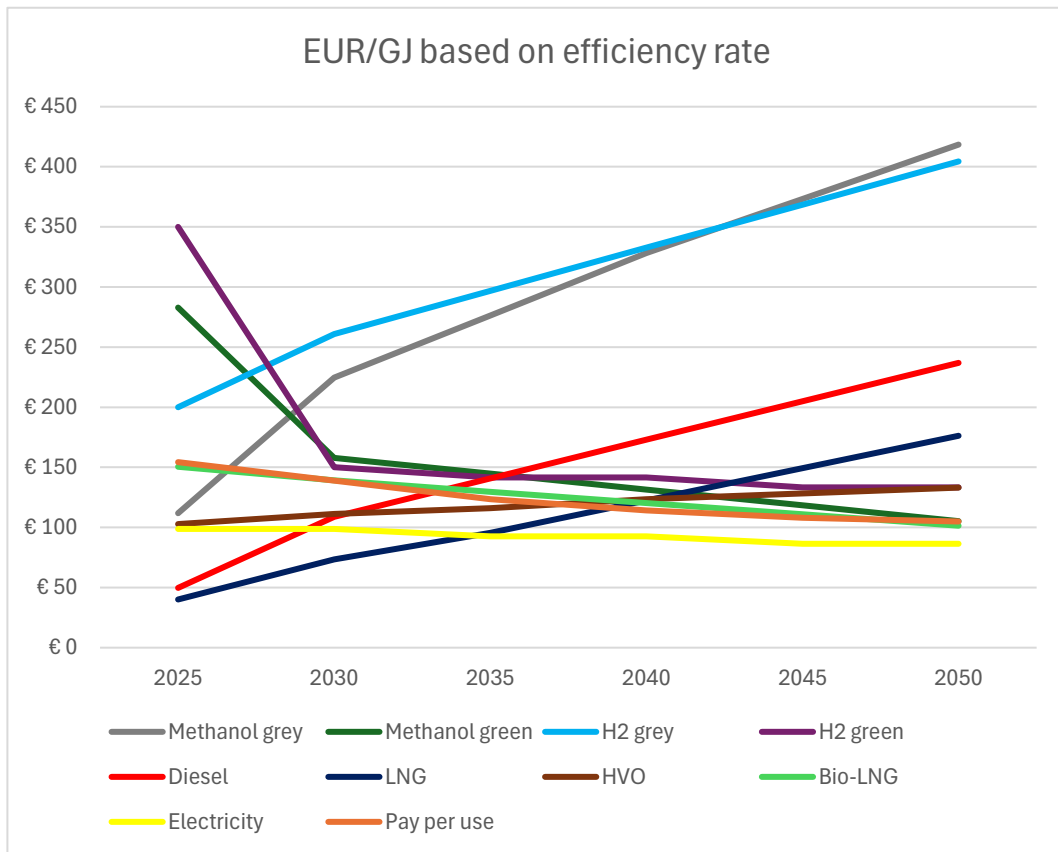
Grant agreement no. | **101096809**

Page **82** of **122**



39 | NZE maximum range, energy prices euro per GJ, taking into account efficiency of energy conversion

Efficiency max	Methanol grey	Methanol green	H2 grey	H2 green	Diesel	LNG	HVO	Bio-LNG	Electricity	Pay per use battery
<b>2025</b>	€ 112	€ 283	€ 200	€ 350	€ 50	€ 40	€ 103	€ 150	€ 99	€ 154
<b>2030</b>	€ 225	€ 158	€ 261	€ 150	€ 109	€ 73	€ 111	€ 139	€ 99	€ 139
<b>2035</b>	€ 276	€ 145	€ 297	€ 142	€ 141	€ 96	€ 116	€ 130	€ 93	€ 123
<b>2040</b>	€ 328	€ 132	€ 333	€ 142	€ 173	€ 123	€ 124	€ 120	€ 93	€ 114
<b>2045</b>	€ 373	€ 118	€ 369	€ 133	€ 205	€ 149	€ 128	€ 111	€ 86	€ 108
<b>2050</b>	€ 418	€ 105	€ 404	€ 133	€ 237	€ 176	€ 133	€ 101	€ 86	€ 105



24 | NZE maximum range, energy prices euro per GJ, taking into account efficiency of energy conversion

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Grant agreement no. | **101096809**

Page **83** of **122**



## Energy types and the price projections

In the coastal and inland shipping sector, fuel costs remain one of the most significant components of operational expenses. Looking further ahead, the energy transition will reshape the landscape entirely. By 2050, the ambition is a climate-neutral inland fleet. Green hydrogen, electrification, and advanced biofuels are being positioned as the energy types of the future. As these alternatives gain ground, fossil diesel may become less dominant and more expensive for the end-user due to taxation and other policy measures. In particular the impact of binding legislations such as the CO<sub>2</sub>e reduction targets from Renewable Energy Directive and the reduction of emission rights in the ETS system, lead to the situation that fossil diesel will become scarce on the market. The STEPS scenario already assumes the impact of ETS-2 which results in a phase out of fossil fuels by 2044 for inland vessels. For shipowners who continue to rely solely on diesel, this could mean operating at a growing disadvantage compared to early adopters of renewable fuels and alternative propulsion systems.

In order to compare the prices between the different energy types, they are all expressed in terms of euro per GJ. Furthermore, also the efficiency of the energy convertor is taken into account in energy prices, to better reflect the operational fuel costs for the vessel operator.

### Fossil Diesel / MGO

Today, 14 October 2025, the price of diesel is around 550 euro per m<sup>3</sup>. Taking into account the density of 0.84 kg/m<sup>3</sup>, this corresponds to 655 euro per metric ton (MT). In order to calculate the price in terms of euro per GJ caloric value of the fuel, the heating value of diesel needs to be used, which is 43.1 MJ/kg<sup>31</sup>. This leads to a price of 15.2 euro per GJ (caloric value). However, a large part of the caloric energy is lost in the combustion process because of the heat losses, also called thermal loss of the engine. The net efficiency of diesel to convert between caloric value to mechanical energy is assumed at 42% for new Diesel engines (Stage V). But it can also be higher or lower, e.g. 33% for older engines or engines which are mainly operated at relatively low power compared to their maximum power. When assuming the 42%, the net price is therefore effectively 36 Euro per GJ mechanical output at today's price of 550 euro per m<sup>3</sup>.

The price range for 2025 for diesel is set between 546 and 756 euro per m<sup>3</sup> of diesel for the end-consumer. As diesel prices vary considerably across the European Union, data from multiple countries have been incorporated to capture this range.<sup>32</sup> This price also depends on the place where and how the diesel is bunkered and at what volume. Logistic costs can vary, depending on the location in Europe. Furthermore, economy of scale discounts are applicable when it concerns large fuel delivery contracts and high volumes of energy transferred per bunker operation.

When expressing this in terms of the price per GJ<sub>e</sub>, this results in a range for the year 2025 between EUR 36/GJ<sub>e</sub> and EUR 50/GJ<sub>e</sub> in 2025, based on efficiency (hereafter "GJ<sub>e</sub>").

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<sup>31</sup> See also the Annex I for the details on the heating values and the efficiency rates for the different energy types

<sup>32</sup> [Slurink - Slurink](#)

[World Energy Outlook 2024](#)

NL Diesel EN590 10ppm EURO 5 price in Netherlands [28.05.2025]



In the years towards 2050, diesel prices in the inland shipping sector are expected to remain under upward pressure, shaped by climate and energy policies. The overall trend points toward steadily increasing prices, reflecting the additional costs of complying with increasingly stringent environmental regulations. Factors such as carbon taxation, CO<sub>2</sub>e reduction targets (RED III) and the expansion of CO<sub>2</sub> pricing mechanisms (ETS-2) will further elevate overall fuel costs. In the APS and NZE scenarios the impact of price increases is higher compared to the expectations under STEPS.

Although diesel is expected to remain an essential fuel for inland shipping in the short to medium term, its economic competitiveness will decline over time. Consequently, diesel's share in the energy mix is projected to gradually decrease as the sector transitions toward cleaner and more sustainable alternatives. This is also illustrated by the comparison between prices for fossil diesel and HVO. In NZE scenario the prices are expected to reach the same level already relatively soon, while for the STEPS scenario the prices are the same at a later stage.

The following tables presents the expected fuel prices for fossil diesel in euro per m<sup>3</sup>, which is the usual price indicator for the fuel.

40 | Prices for fossil diesel fuel in euro per m<sup>3</sup> for the three scenarios, minimum and maximum

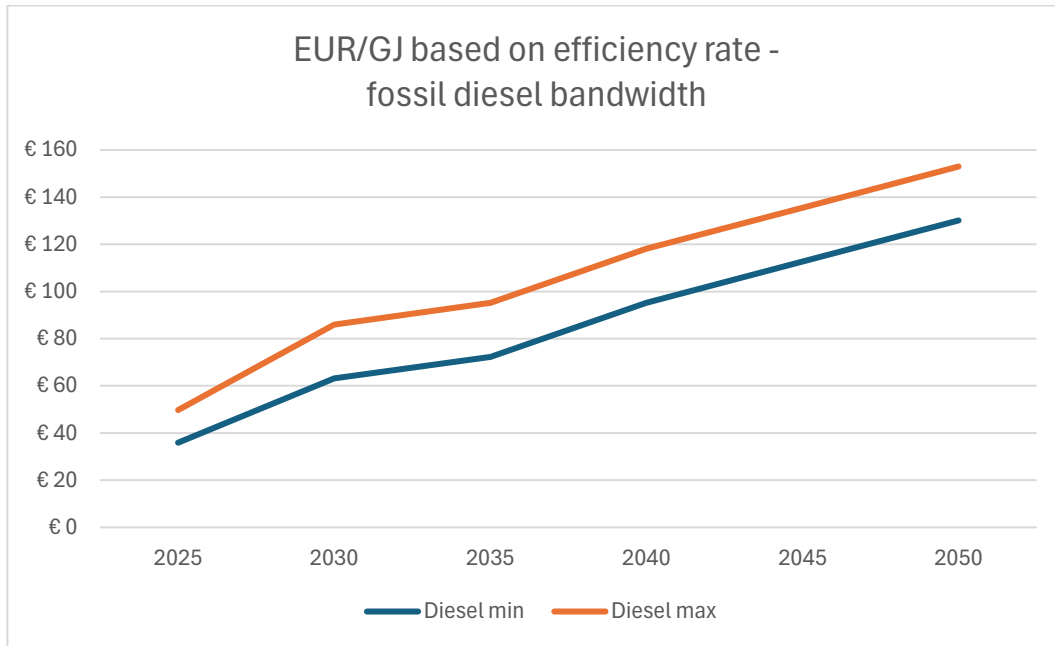
Minimum price level						
Scenario	2025	2030	2035	2040	2045	2050
<b>STEPS</b>	€ 546	€ 960	€ 1099	€ 1449	€ 1714	€ 1979
<b>APS</b>	€ 546	€ 879	€ 1356	€ 1834	€ 2311	€ 2788
<b>NZE</b>	€ 546	€ 1308	€ 1795	€ 2281	€ 2768	€ 3254

Maximum price level						
Scenario	2025	2030	2035	2040	2045	2050
<b>STEPS</b>	€ 756	€ 1308	€ 1447	€ 1796	€ 2061	€ 2326
<b>APS</b>	€ 756	€ 1226	€ 1704	€ 2181	€ 2659	€ 3136
<b>NZE</b>	€ 756	€ 1656	€ 2142	€ 2629	€ 3115	€ 3602

## STEPS

Under the STEPS, which reflects the continuation of currently announced and implemented policies, diesel prices are projected to increase substantially, reaching approximately EUR 150/GJe by 2050. This price evolution results from a combination of a modest increase in wholesale prices and the introduction of RED3 and ETS 2 (Emissions Trading System for transport and buildings), which adds additional carbon costs. Furthermore, from 2040, a gradually increasing price of CO<sub>2</sub> is assumed to simulate the phase-out of fossil fuels by 2045 as a result of ETS. Despite these cost drivers, the overall price bandwidth remains relatively narrow, indicating limited variation across market assumptions within this scenario.



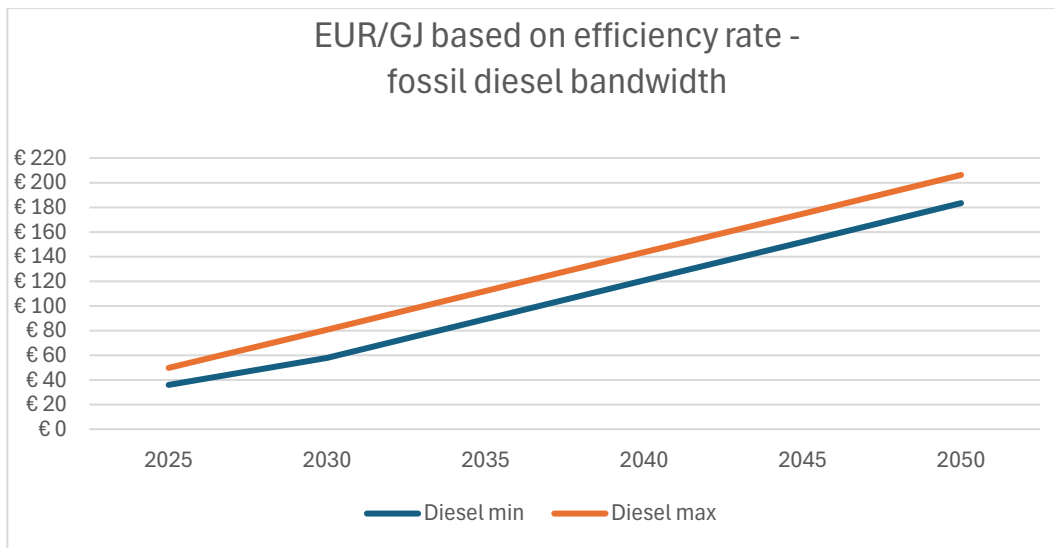


25 | STEPS, fossil diesel energy prices euro per GJe, taking into account efficiency of energy conversion

**APS**

In the APS, reflecting more ambitious climate commitments, diesel prices rise more sharply. By 2050, total prices are expected to exceed EUR 200/GJe.

While wholesale diesel prices may decline due to reduced demand in a decarbonizing market, this effect is outweighed by the impact of a higher ETS 2 price and more strict targets for fuel suppliers to reduce the CO<sub>2</sub>e intensity of the energy (grams CO<sub>2</sub>e per MJ) as result of successors of Renewable Energy Directive 3. Together, these policy measures substantially increase the total cost of fossil diesel.



26 | APS, fossil diesel energy prices euro per GJe, taking into account efficiency of energy conversion

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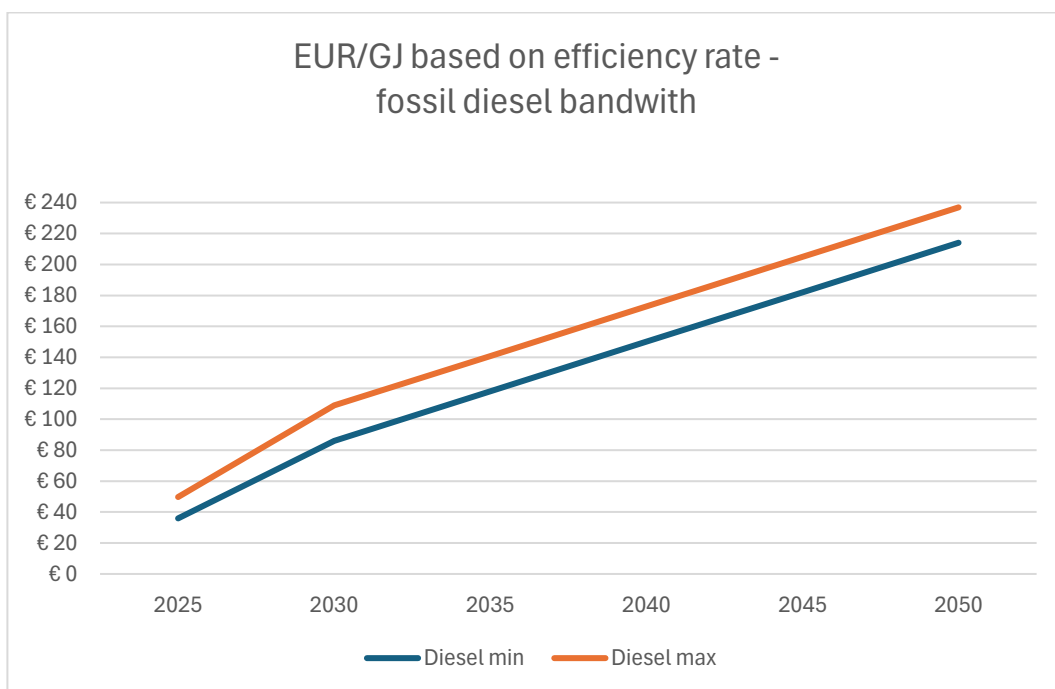
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## NZE

In the NZE, the price bandwidth for diesel remains narrow, but overall price levels increase significantly. Diesel prices are projected to reach between EUR 214/GJe and EUR 237/GJe in 2050, making it one of the most expensive fossil-based energy carriers by 2050, comparable only to grey methanol, which is projected in a range of EUR 212–242/GJe.

The strong price increase in this scenario is primarily driven by more aggressive targets for ETS and Renewable Energy Directive and higher taxation levels (e.g. by means of revision Energy Taxation Directive) aimed at achieving the stringent emission reduction targets of the NZE pathway. These measures reflect a deliberate policy effort to accelerate the transition away from fossil fuels and to promote the adoption of low-carbon alternatives within the inland and coastal shipping sector within a shorter time horizon compared to APS and STEPS.



27 | NZE fossil diesel, energy prices euro per GJe, taking into account efficiency of energy conversion

## HVO

HVO is also called “Renewable diesel” and can directly replace fossil diesel in existing engines and vessels. Therefore, not only the price projections are presented of HVO but also the comparison with the price levels of fossil diesel to show in what time period HVO can become most cost efficient and thus will be used by vessel owners to replace the fossil diesel.

It is clear that today, the fossil diesel prices are lower compared to the price of HVO. However, due to the binding targets from Renewable Energy Directive and the increasing value of CO<sub>2</sub>e emission reductions (expressed by ETS) the prices of both fuels will gradually move closer towards each other. It can be seen that in STEPS, the fossil diesel will be more expensive from 2045 on all scenarios. This reflects the effectiveness of ETS-2 which indeed phases out fossil diesel by 2045.

This will occur even sooner in the APS and NZE scenarios, where approximately between 2035 and 2040 the diesel price will surpass the HVO price. The HVO price will not be affected by carbon pricing, keeping the prices steady at around EUR 100 – EUR 150 per GJ. Although the prices for HVO are expected to

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Grant agreement no. **| 101096809**

Page **87** of **122**



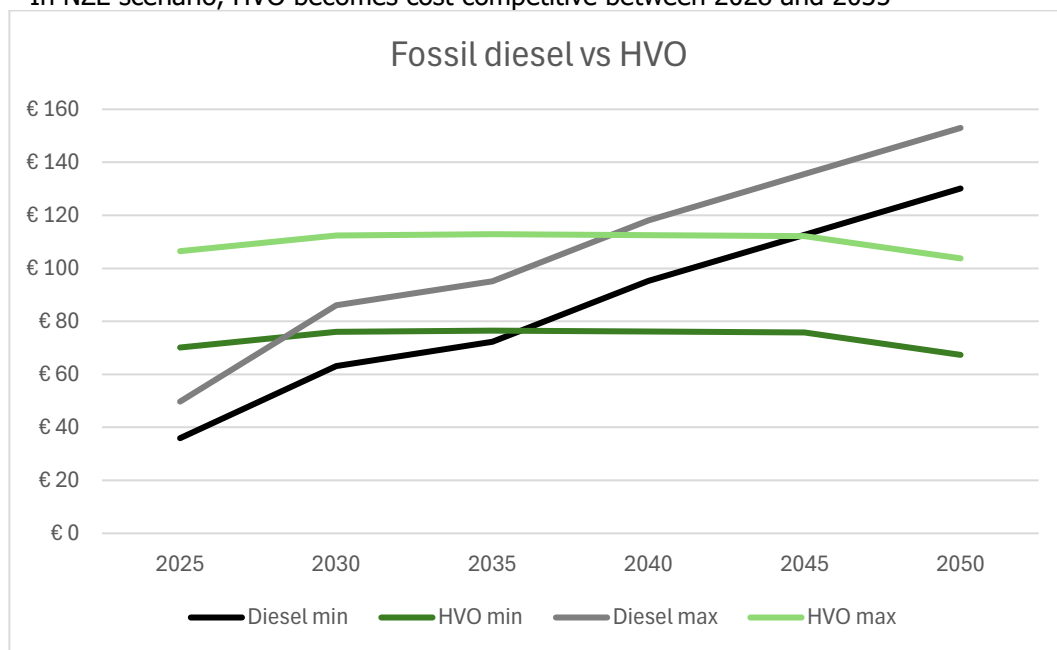
become more attractive for ship owners, there are concerns and questions about the scalability of HVO. There are doubts if there is sufficient feedstock on medium / long term to produce the required volumes of HVO to replace fossil diesel fuel.

Therefore, in this report, **the maximum price range for HVO is based on the price expected to produce E-diesel from green hydrogen and sustainable CO<sub>2</sub>**. E-diesel is a suitable alternative for fossil diesel and HVO, and will be scalable.<sup>33</sup> E-diesel is expected to fall within the HVO ranges around 2040.<sup>34</sup>

Also, for HVO some CO<sub>2</sub> costs have been included in the prices, since the well-to-wake performance of HVO is not zero. A reduction rate of CO<sub>2</sub>e emissions of 86% is assumed when comparing the CO<sub>2</sub> emission of one kg diesel versus one kg HVO.

In the figures, both the prices are presented of HVO and fossil diesel, both the minimum and maximum prices for the three scenarios. In a 'best case' situation for HVO, the prices of diesel are developing according to the maximum range while HVO is developing according to the minimum range. In a 'worst case' situation, the price of fossil diesel develops according to the minimum range and the price if HVO develops according to the maximum price range of HVO. It can be concluded that:

- In STEPS scenario, HVO becomes cost competitive between 2028 and 2045
- In APS scenario, HVO becomes cost competitive between 2028 and 2040
- In NZE scenario, HVO becomes cost competitive between 2028 and 2035



28 | STEPS, fossil diesel vs HVO, price comparison in euro per GJ, taking into account efficiency of energy conversion

<sup>33</sup> Viewpoint: European HVO demand to rise in 2025 | Latest Market News; Overzicht Fieten Olie Adviesprijzen - Fieten Olie

Fuel prices - FullTank by Hans de Baat; Diesel & HVO monthly averages - ovr.de (EN)

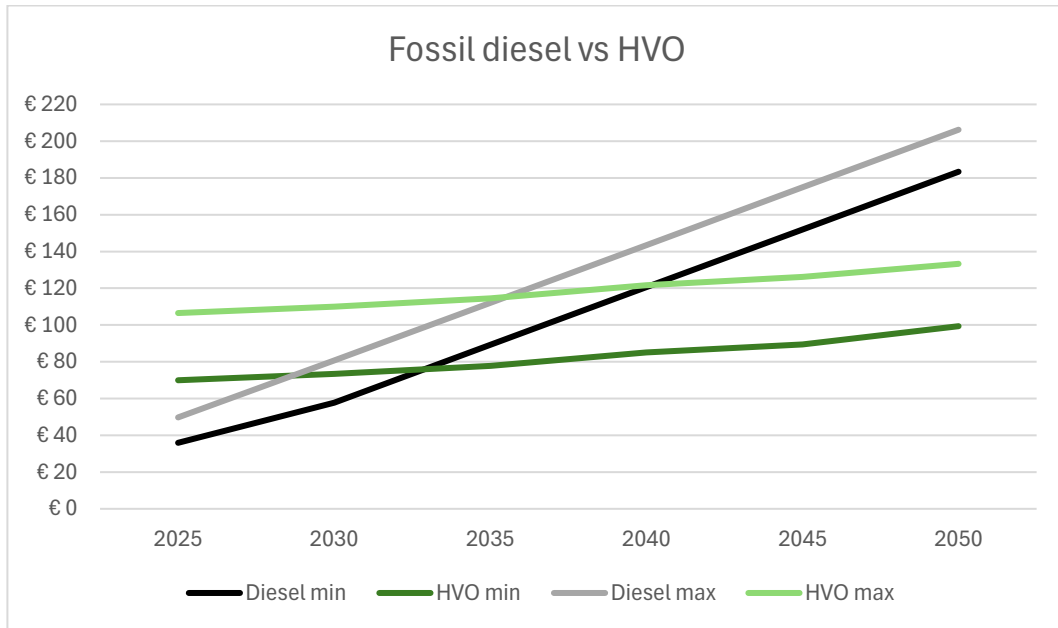
<sup>34</sup> The Royal Society – Sustainable synthetic carbon-based fuels for transport (2019)

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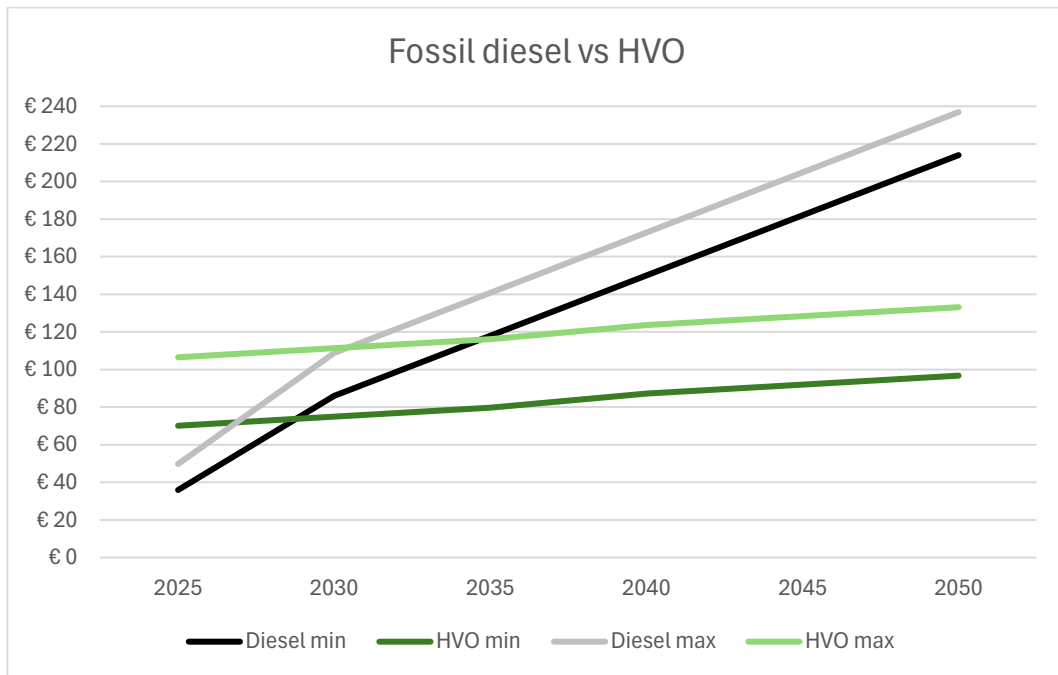
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Page **88** of **122**





29 | APS, fossil diesel vs HVO, price comparison in euro per GJe, taking into account efficiency of energy conversion



30 | NZE, fossil diesel vs HVO, price comparison in euro per GJe, taking into account efficiency of energy conversion

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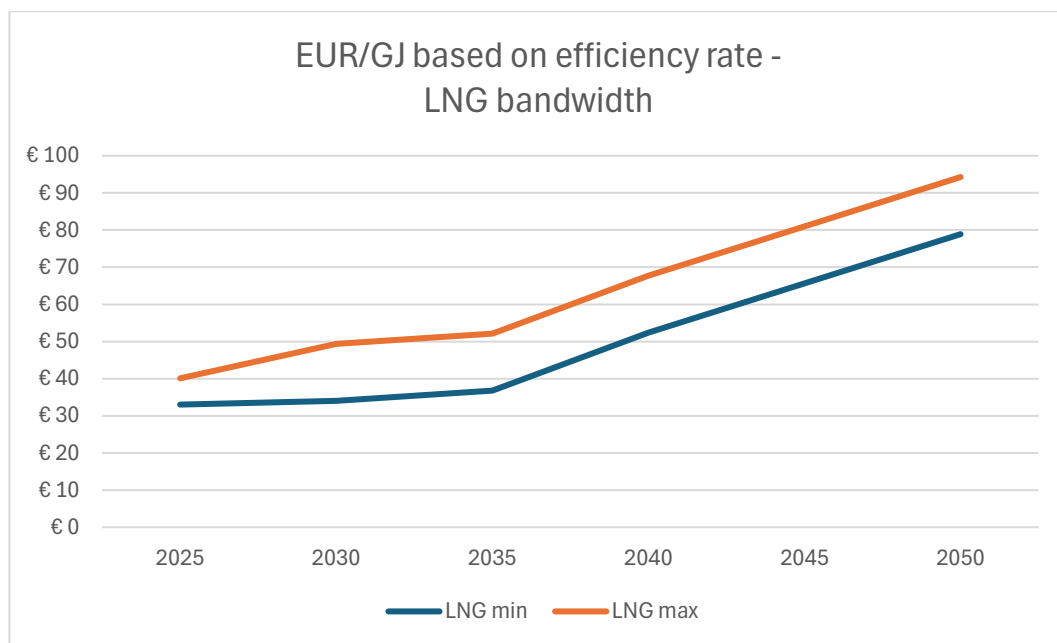


## LNG

Liquefied natural gas (LNG) has established itself as an alternative fuel in the maritime sector, particularly as operators seek compliance with tightening environmental regulations for air quality. However, LNG prices have shown notable volatility in recent years, directly influencing fuel competitiveness and investment decisions.

Looking ahead, LNG is expected to remain an important part of the maritime fuel mix, though not without challenges. Prices are likely to stay volatile due to global gas market dynamics, while regulatory tightening will continue to shape the relative attractiveness of different fuel types. For many operators, LNG will function less as a single solution and more as part of a diversified fuel portfolio, complementing other low-emission alternatives.

The 2025 bandwidth for the LNG price is between 700-1321 euro per MT. Taking into account the caloric value and the efficiency the LNG prices is in a range of EUR 33/GJe – EUR 40/GJe, after the significant prices increases due to the Russian impact on the gas prices in Europe. The wholesale price is expected to drop significantly, but on the other side the policy measures such RED3 and ETS will have a price increasing impact for the final consumer of the LNG. The World Energy Outlook 2040 foresees relatively stable wholesale prices between 2030 – 2050.<sup>35</sup> For the NZE scenario, there is a larger impact of ETS already assumed for 2030 which already results in much higher prices in 2030 compared to 2025 and the price increase is more steep compare to APS and STEPS.

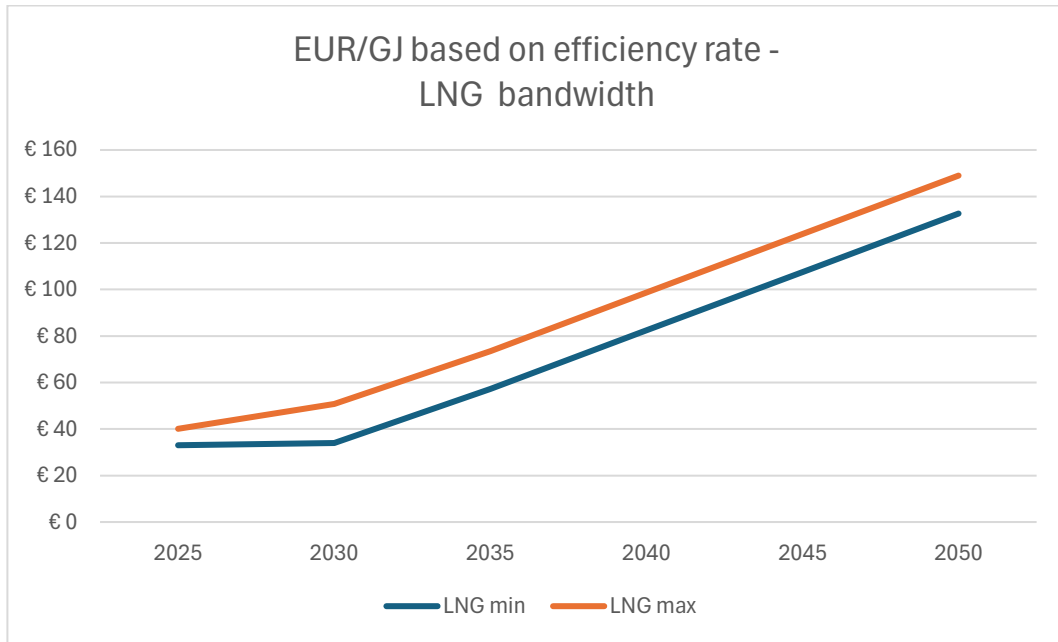


31 | STEPS, fossil LNG price in euro per GJe, taking into account efficiency of energy conversion

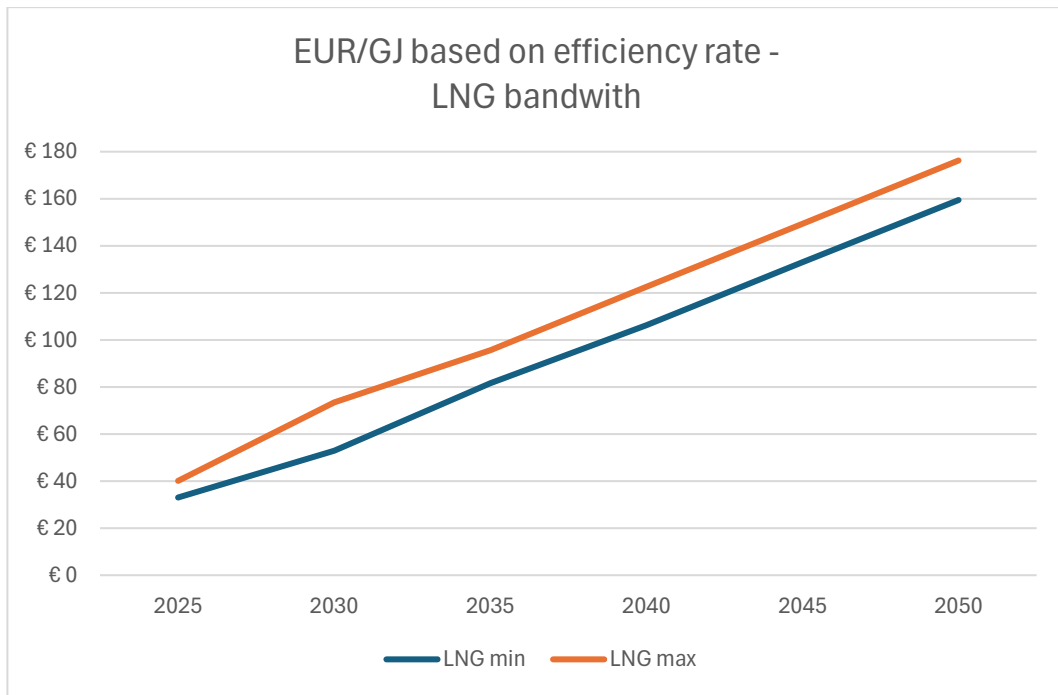
<sup>35</sup>LNG Pricing - Titan Clean Fuels

Lower LNG supply and higher prices expected to weaken China's demand while Europe stays the premium market in 2025 | Kpler - Mar 13, 2025





32 | APS, Fossil LNG price in euro per GJ<sub>e</sub>, taking into account efficiency of energy conversion



33 | NZE, fossil LNG price in euro per GJ<sub>e</sub>, taking into account efficiency of energy conversion



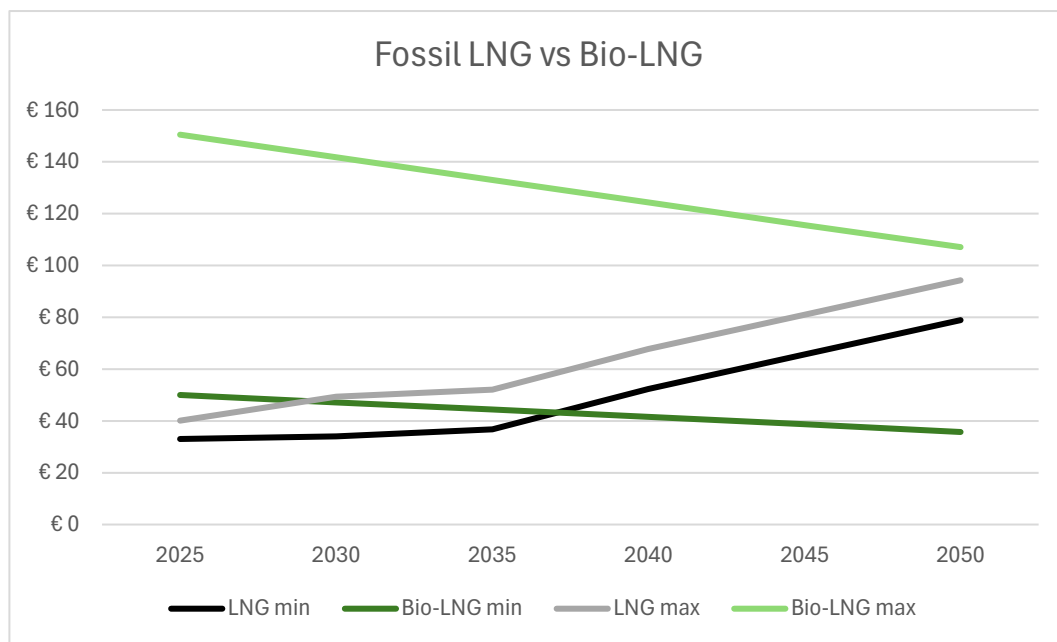
## Bio-LNG

Bio-LNG is liquefied biomethane derived from biogas (e.g. from organic waste, manure, or other sustainable feedstocks). It is chemically similar to fossil LNG, meaning it can be used in existing monofuel or dual-fuel gas-engines, storage tanks, and LNG bunkering infrastructure without major modifications.

It offers substantial greenhouse gas (GHG) savings compared to fossil LNG, depending on feedstock and production pathway. This makes it attractive for maritime operations seeking compliance with recent and upcoming emissions regulations (e.g. EU's FuelEU Maritime, EU ETS, RED-III) and for operators pursuing more sustainable operations.

Bio-LNG is significantly more expensive than fossil LNG in terms of the production and whole sale costs. The costs are approximately double or more compared to fossil LNG equivalent prices under normal conditions. However, it has become clear that with the upcoming legislations in place, the price variety for bio-LNG will become less extreme creating more room for people who would consider switching.

Because of its compatibility with existing infrastructure, bio-LNG is often viewed as a transitional fuel toward more ambitious zero-emission fuels. It allows gradual gains without wholesale retrofit. For many operators, paying the higher fuel cost of bio-LNG currently may not be economically justifiable compared to paying regulatory penalties (or carbon allowances) for using cheaper fossil LNG or other fossil fuels. As regulatory costs rise, that calculus may shift.

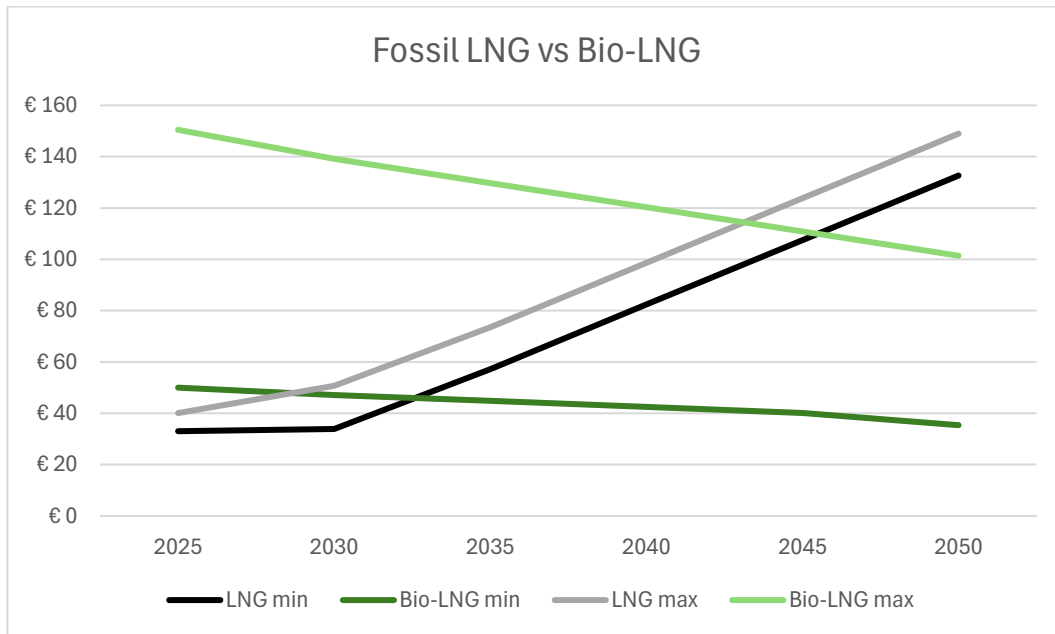


34 | STEPS, fossil LNG vs Bio-LNG, price comparison in euro per GJe, taking into account efficiency of energy conversion



Forecasts<sup>36</sup> suggest that with scale, more production plants, and improved feedstock sourcing, the cost of delivered bio-LNG may fall. But as can be seen in the figures, the price uncertainty for Bio-LNG is relatively large. There is a big spread between the minimum and maximum price for Bio-LNG.

For the APS scenario there is the expectation that LNG will be replaced by Bio-LNG based on the price advantage, worst case by 2045 and best case already before 2030.



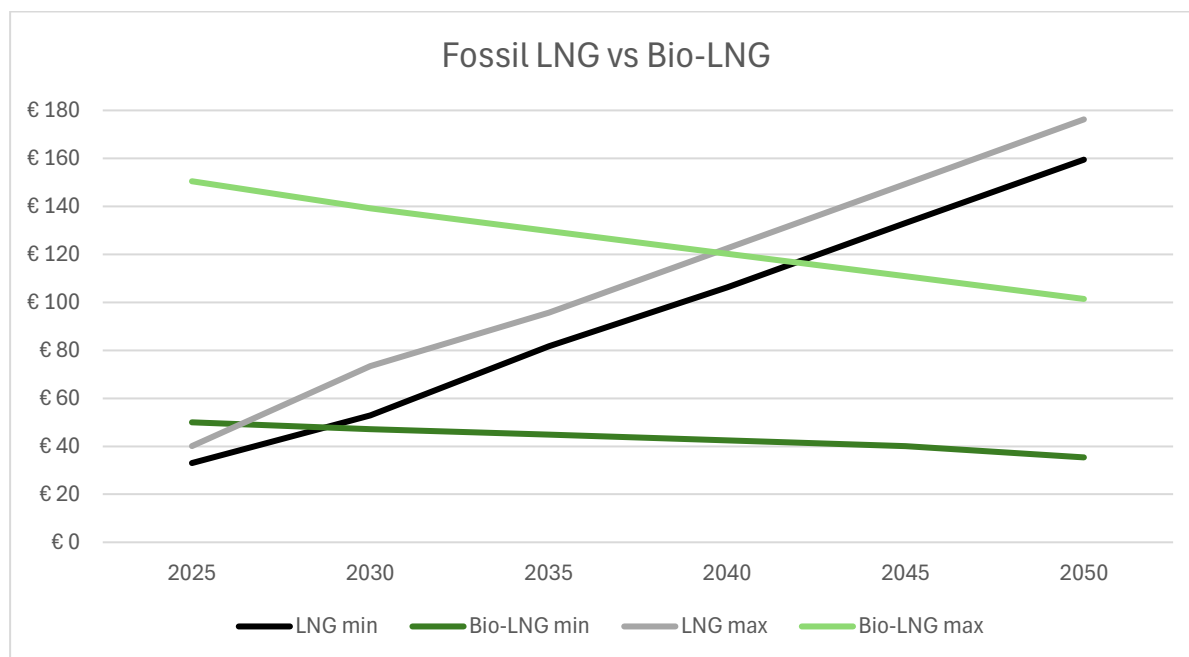
35 | APS, fossil LNG vs Bio-LNG, price comparison in euro per GJe, taking into account efficiency of energy conversion

It is estimated that by 2050 average delivered costs could decline to around EUR 35/GJe in the NZE scenario at minimum prices. Phasing out LNG will then occur earlier in time compared to the APS scenario.

<sup>36</sup> FEATURE: Bio-LNG to follow LNG path to Europe's net-zero future | S&P Global

Report: Bio-LNG can meet a significant proportion of future shipping demand - SAFETY4SEA





36 | NZE, fossil LNG vs Bio-LNG, price comparison in euro per GJ, taking into account efficiency of energy conversion

### Electricity

Electricity offers significant potential to completely eliminate local emissions such as NO<sub>x</sub>, SO<sub>x</sub>, and particulate matter, and when generated from renewable sources, to substantially reduce greenhouse gas emissions. Electric propulsion is therefore emerging as a central component of the energy transition in inland shipping.

Currently, two primary applications dominate this development: on-shore power supply (OPS), which replaces auxiliary engine use while vessels are berthed, and battery-electric propulsion, which enables fully zero-emission operation during navigation. Both technologies are supported by EU climate policy frameworks, national subsidy schemes, and increasing investment in port infrastructure. Nonetheless, widespread adoption remains constrained by high capital costs, limited charging infrastructure, and operational challenges such as range limitations. Battery-electric propulsion of inland freight vessels is still in the early stages of deployment while already more fully electric vessels are seen at short distance ferries and passenger vessels. Pilot projects in the Netherlands and Germany demonstrate that operational feasibility continues to improve, although costs remain significantly higher compared to conventional diesel systems.

Looking ahead, electricity is expected to play an increasingly prominent role in the inland shipping energy mix, though its application will vary depending on route characteristics and vessel profiles.

The total electricity cost for inland shipping, particularly in the context of shore power (OPS) is determined by three main components: wholesale price, policy impacts (taxes), and distribution costs.



The wholesale electricity price reflects the market value of power generation. Prices may fluctuate depending on the time of day, regional supply conditions, and grid constraints.<sup>37</sup>

Much more significant are the network and distribution costs for the delivery of electricity from production via the grid to the vessel through onshore infrastructure. These costs include investment, maintenance, and operational expenses related to the installation and use of shore power systems. A review of various European shore power installations shows that distribution costs (excluding taxes) typically average around €0.22 per kWh. The exact value depends on factors such as installation size, grid connection type, and local network tariffs.<sup>38</sup>

For the year 2025 the wholesale/production costs of electricity are estimated in a range between 3-10 cents per kWh. Taxes on energy depend per EU country. In the Netherlands for example, the energy tax on electricity used for shore power for inland vessels is relatively small, approximately EUR 0.008 per kWh. This rate has little impact on the overall electricity cost for vessel operators.<sup>39</sup>

The total costs for electricity from shore for the user in 2025 are estimated between 25 cents and 32 cents per kWh. When taking into account the conversion from kWh to GJ and the efficiency rate 90%, the price range expressed in euro per GJe is between 77 and 99 euro per GJe. Today this is still roughly 2 times higher compared to the costs of fossil diesel (at 36-50 euro per GJe).

In all three modelled scenarios, electricity prices remain more or less at current levels. While fossil fuels are becoming more expensive, electricity may become over time, a cost-effective energy source from the operational cost perspective of the energy itself. In the STEPS scenario, the direct energy costs of electricity will be lower by 2040 compared to direct energy costs when using fossil diesel.

However, these scenarios do not account for the high upfront investment costs associated with vessel electrification, which remain substantially higher than for most alternative fuels. Furthermore, the volume and weight required for sufficient electric energy storage on board is a limiting factor, as the energy density of batteries is much lower compared to other solutions.

Taken together, these components indicate that while electricity may be a cost-effective energy type in terms of operating costs, while the overall financial feasibility of electrification will depend heavily on infrastructure availability, vessel design, energy storage on board and capital financing options.

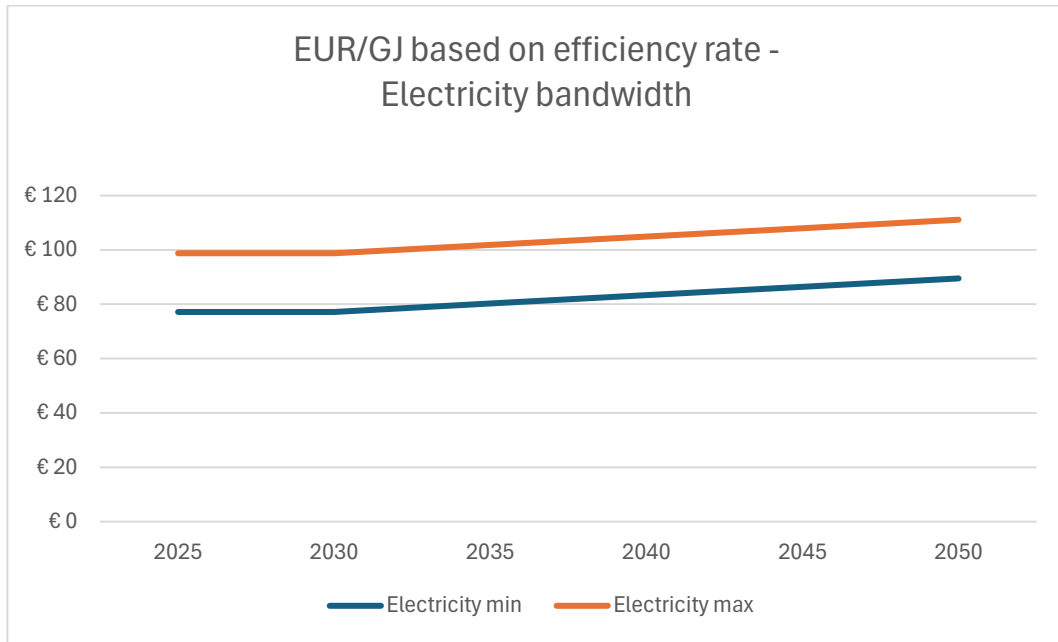
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<sup>37</sup> ⚡ Electricity prices Europe [https://ec.europa.eu/eurostat/databrowser/view/nrg\\_pc\\_205\\_custom\\_17724094/default/table?lang=en](https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_205_custom_17724094/default/table?lang=en)

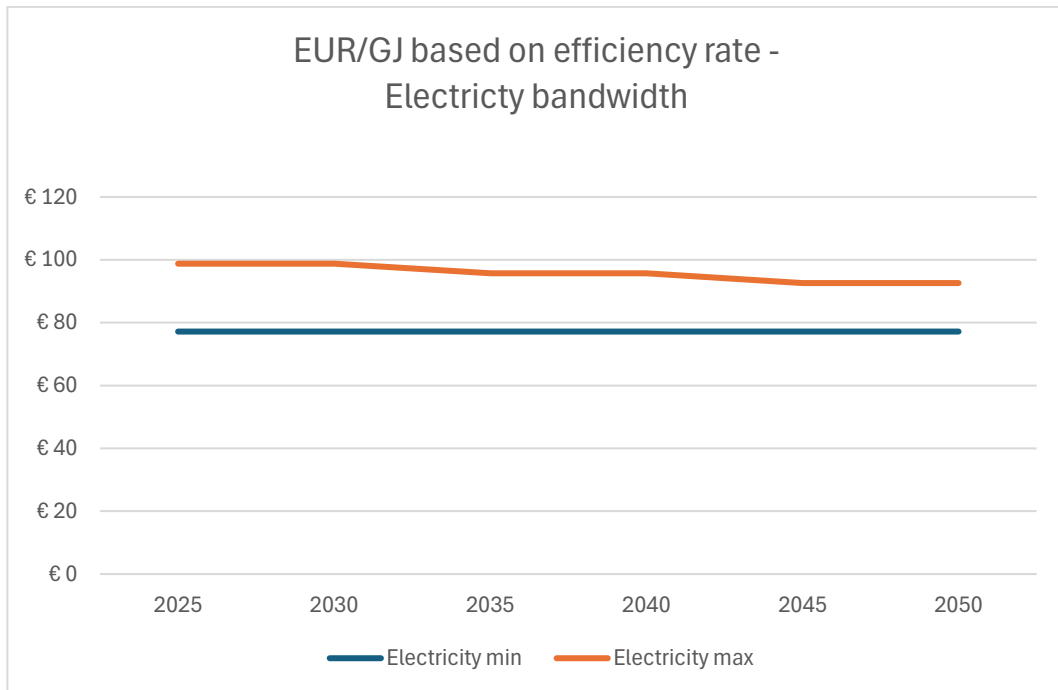
<sup>38</sup> Tarieven - Wat kost het gebruik van Connect4Shore?

Comparison EV Charging stations

<sup>39</sup> Netbeheerkosten | ACM

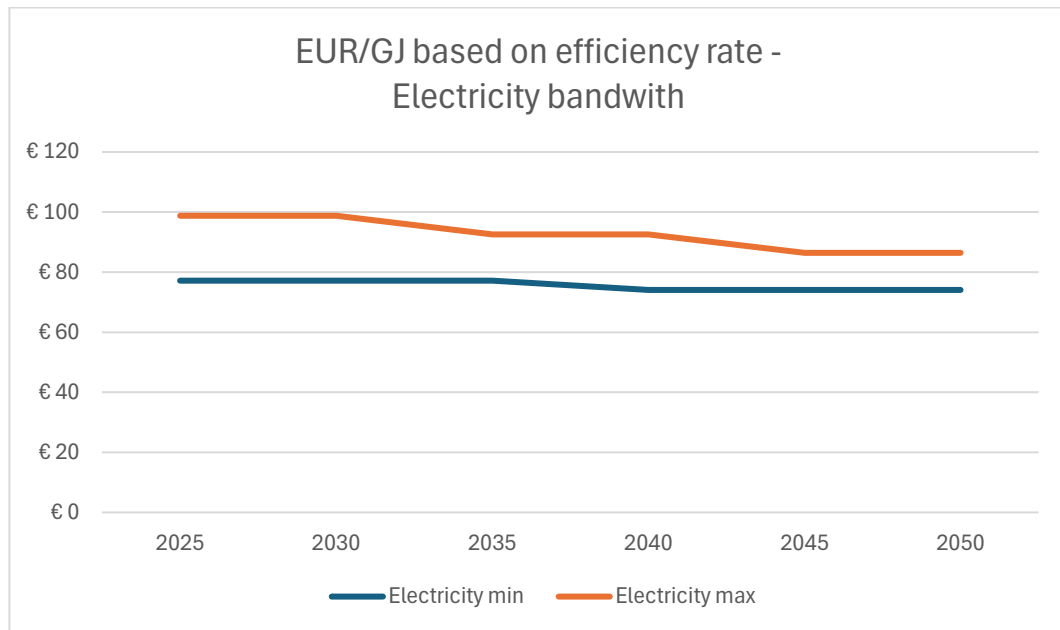


37 | STEPS, Electricity price in euro per GJe, taking into account efficiency of energy conversion



38 | APS, Electricity price in euro per GJe, taking into account efficiency of energy conversion





39 | NZE Electricity price in euro per GJe, taking into account efficiency of energy conversion



## Electricity Pay-per-Use

Zero Emission Services (ZES) has developed an innovative Pay-per-Use (PPU) system to accelerate the transition toward sustainable inland shipping in the Netherlands. Instead of purchasing batteries or investing in fixed energy infrastructure, shipping operators can use ZES's modular ZESpacks standardized, swappable battery containers on a service basis. Through this model, vessel owners pay only for the energy consumed and the availability of ZESpacks, much like a leasing system. The ZESpacks can be exchanged at dedicated swapping stations along major waterways, allowing vessels to continue operations without long bunkering times. This Pay-per-Use approach shifts a part of the capital expenditure (CAPEX) to operational expenditure (OPEX). In essence, the ZES Pay-per-Use model enables shipowners to adopt clean, electric propulsion without owning the batteries themselves paying only for what they use, when they use it. However, the shipowner still has to invest in an electric propulsion system for their ship to enable battery-powered operation.

Each ZESpack currently provides 2.6 MWh of usable energy. Consequently, depending on the number of ZESpacks exchanged daily, the vessel's total daily energy demand ranges from 2.6 MWh in the most conservative case to 10.4 MWh in the most intensive operational case. Over an entire year, this translates into an annual energy requirement of approximately 949 MWh, 1,898 MWh, 2,847 MWh, and 3,796 MWh, respectively.

For each of these scenarios, the vessel is assumed to have a dedicated allocation of one to four ZESpacks, which remain on board and available for 95% of the time throughout the year. This allocation ensures energy security and consistent operational performance.

However, in practice, it may be possible to operate more efficiently by dynamically allocating ZESpacks depending on route energy demand. On certain segments, fewer packs may be required, while other legs of the journey may need more. Such operational optimization would likely reduce total costs and result in actual values that fall somewhere within the estimated cost range.

The financial results presented here distinguish between two cost components:

- ZES Pay-per-Use (PPU) – covering the service and availability of ZESpacks.
- Electricity costs – representing the cost to ZES for recharging the battery containers.

The assumed electricity tariff is €0.184 per kWh, including approximately €0.04 per kWh in energy taxes.

It should be noted that ZES is already developing new battery containers with higher capacity, expected to reach around 4 MWh of usable energy per ZESpack. Once these become standard, they will directly reduce the number of units required on board and thereby influence the overall cost structure of vessel operations.

Under the baseline conditions described, each additional ZESpack increases the vessel's available energy capacity and operational range proportionally. In the first scenario, with one ZESpack permanently allocated, the vessel would require around 949 MWh of energy annually. The corresponding annual ZES Pay-per-Use fee would be approximately €322,000, translating to about €0.34 per kWh excluding electricity costs. The additional cost of electricity procurement would amount to around €175,000 per year.

In the second scenario, with two ZESpacks dedicated to the vessel, the total annual energy demand doubles to 1,898 MWh. The associated ZES Pay-per-Use cost rises to roughly €643,000, with electricity costs of around €350,000.

Similarly, for three and four ZESpacks, the annual energy demands would reach 2,847 MWh and 3,796 MWh, respectively. The ZES Pay-per-Use expenses would be about €965,000 and €1,286,000, while the annual electricity costs would increase proportionally to €524,000 and €699,000.

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **98** of **122**



Across all scenarios, the relationship between energy consumption and Pay-per-Use cost remains consistent, resulting in a nearly constant rate of €0.34 per kWh for the ZES service component, excluding the electricity purchase itself.

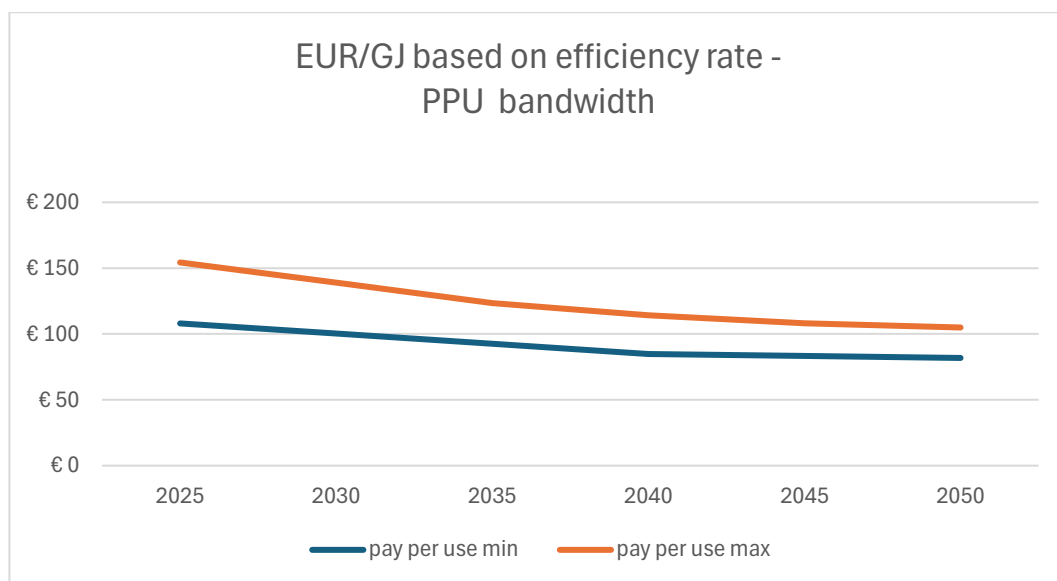
When the electricity cost is added, the total Energy-as-a-Service (EaaS) cost for the vessel is estimated at approximately €0.53 per kWh. This combined rate represents the all-in cost of operating the vessel using ZESpacks under the current assumptions.

It is important to recognize that these results are derived from simplified, steady-state scenarios where the same number of ZESpacks remains on board for most of the year. In real-world operations, ZESpack usage is likely to fluctuate depending on route distance, cargo load, and energy demand patterns. This flexibility could reduce the effective cost per kilowatt-hour.

In summary, the analysis demonstrates that the ZES Pay-per-Use model results in a consistent rate of roughly €0.34 per kWh, regardless of the total number of ZESpacks utilized. Including electricity procurement, the indicative total Energy-as-a-Service cost for full-electric vessel operations is approximately €0.53 per kWh.

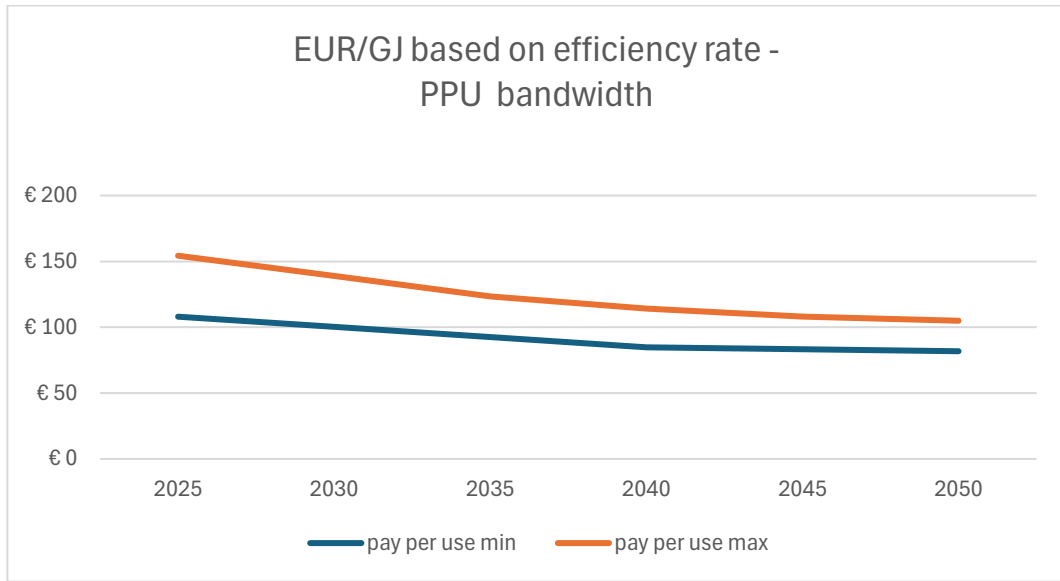
For benchmarking and further analysis, it is recommended to adopt €0.34 per kWh for the Pay-per-Use component and €0.18 per kWh for electricity costs as a reasonable reference point.

Future optimizations, including improved operational planning, higher-capacity ZESpacks, and dynamic allocation, additional services (network stability) are expected to reduce both the absolute and unit costs of ZESpacks.

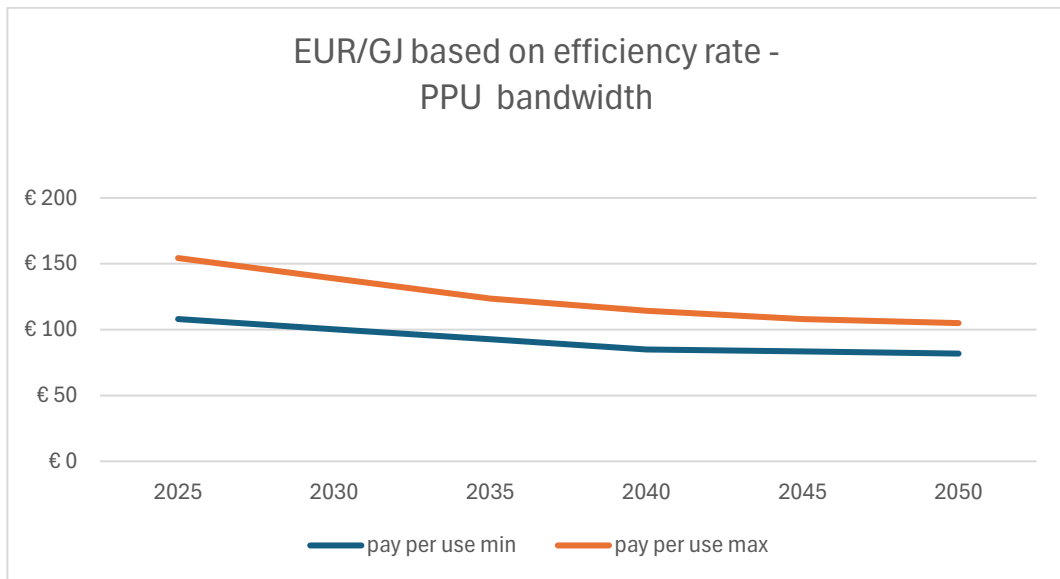


40 | STEPS, PPU price in euro per GJe, taking into account efficiency of energy conversion





41 | APS, PPU price in euro per GJe, taking into account efficiency of energy conversion



42 | NZE, PPU price in euro per GJe, taking into account efficiency of energy conversion



## Fossil and green Methanol

Green methanol is increasingly viewed as a promising alternative fuel for the decarbonisation of maritime transport. The developments for seagoing vessels could possibly bring a spin-off to inland vessels. In contrast to gaseous alternatives such as hydrogen or LNG, methanol is liquid at ambient temperature, which simplifies storage, handling, and integration within existing bunkering systems provided that appropriate safety measures are implemented. This ease of use has attracted attention from shipowners, policymakers, and technology suppliers, as methanol may be introduced with relatively limited retrofitting compared to other low-carbon fuels. However, the first pilots showed that also for a methanol retrofit substantial capital costs are involved to make a vessel 'methanol ready'. Furthermore, there is no supply of methanol engines for inland vessels because of bottlenecks in the legislation, the "Non-Road Mobile Machinery Regulation". For the short term, fossil methanol might be used, which is usually made from natural gas<sup>40</sup>.

For 2025 the price of methanol is estimated within a range of 650 to 850 euro per MT for grey methanol and 850 and 2150 euro per MT for green methanol.<sup>41</sup> When assuming the efficiency of 38% and 20 MJ/kg of energy density, the range per GJ is 86-112 euro per GJe for grey methanol and 112-283 euro per GJe for green methanol.

Under current policy settings, green methanol becomes a more cost-effective option over the next decade. Green methanol prices are expected to decline between 2025 and 2035, after which they stabilise. However, there is a relatively large bandwidth in the cost estimates for green methanol, which indicates a relatively high uncertainty regarding the price levels. Furthermore, because of the lack of engines and the involved CAPEX to retrofit existing vessels, a large-scale adoption in inland shipping is unlikely in the short term, except in niche applications supported by subsidies or pilot funding.

In the Announced Pledges Scenario, carbon pricing and stricter emission regulations exert upward pressure on the cost of grey methanol. Meanwhile, continued technological improvements and growing renewable production capacity drive a steady decline in green methanol costs. In this context, early adopters may benefit from reduced long-term exposure to carbon costs and enhanced access to green financing mechanisms.

The Net Zero Emissions scenario presents the most pronounced shift. Intensified internalisation of CO<sub>2</sub> costs and fossil phase-out measures significantly raise the cost of grey methanol, while large-scale deployment of renewable production technologies, particularly e-methanol derived from captured CO<sub>2</sub> and green hydrogen, leads to a substantial reduction in green methanol prices.

By 2050, green methanol becomes nearly cost-competitive with, and in some projections cheaper than, grey methanol. This transition indicates a potential turning point where renewable methanol could become a mainstream solution, particularly for operators targeting full decarbonisation of their fleets.

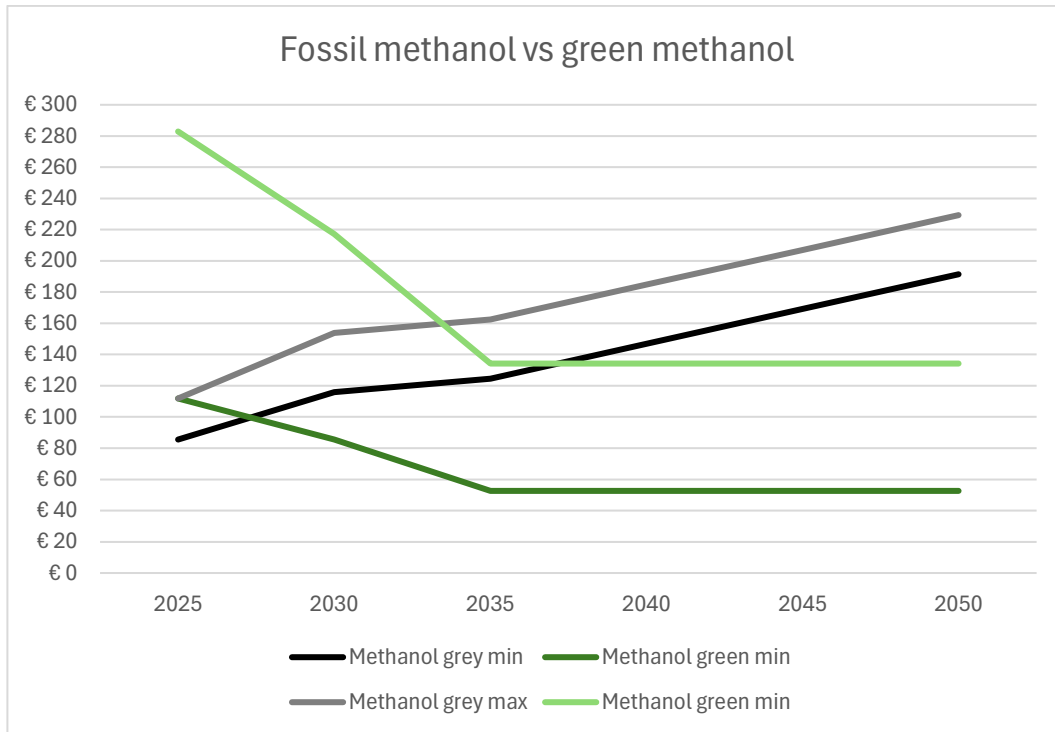
As carbon prices rise and renewable methanol production scales up, the relative attractiveness of green methanol improves. Early movers can leverage policy incentives, subsidy schemes, and reputational benefits in increasingly sustainability-driven logistics chains. In the long term, methanol is expected to play a complementary role within a diversified energy mix. It is unlikely to emerge as the single dominant

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<sup>40</sup> 2022\_sGU-for-MI\_Methanol-carbon-footprint-DEF-1.pdf

<sup>41</sup> Pricing - Methanex | Methanex

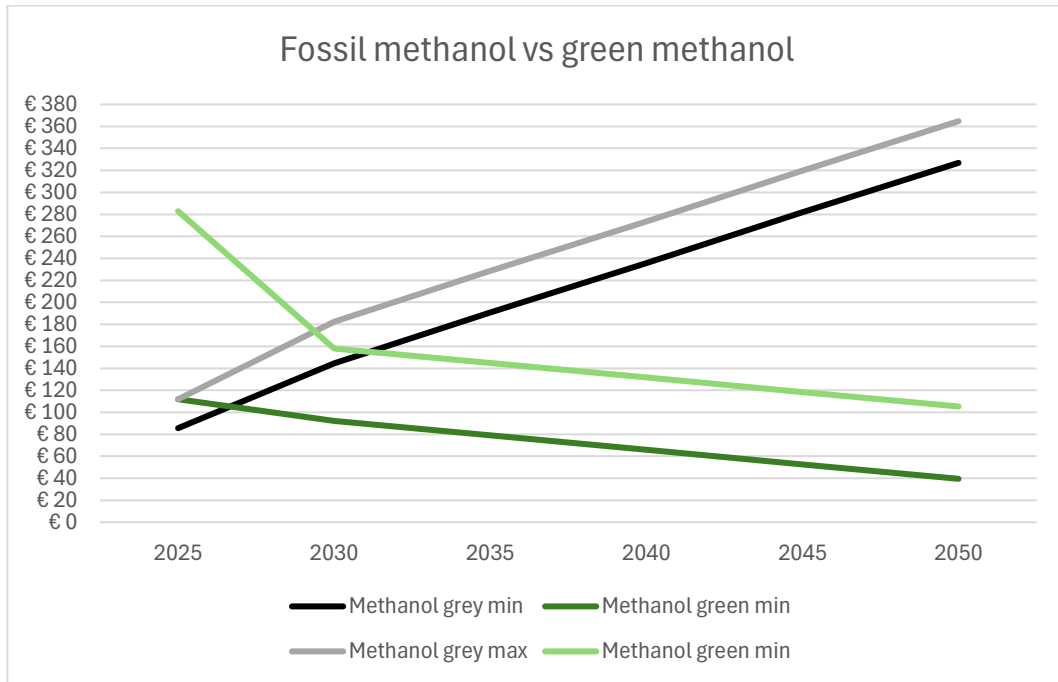
fuel for inland shipping, but rather as part of a portfolio of solutions in which operators balance cost, availability, and emission performance.<sup>42</sup>



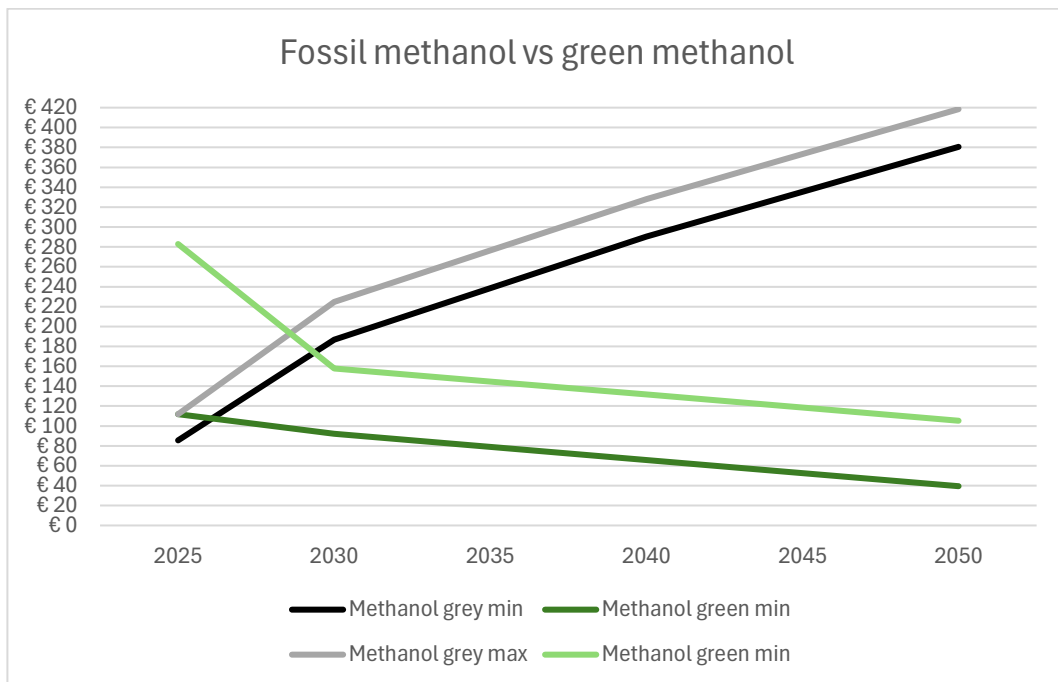
43 | STEPS, fossil methanol vs green methanol, price comparison in euro per GJe, taking into account efficiency of energy conversion

<sup>42</sup> Innovation Outlook: Renewable Methanol





44 | APS, fossil methanol vs green methanol, price comparison in euro per GJe, taking into account efficiency of energy conversion



45 | NZE, fossil methanol vs green methanol, price comparison in euro per GJe, taking into account efficiency of energy conversion

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**



## Fossil and green hydrogen (H<sub>2</sub>)

Hydrogen does not have any carbon in the fuel and burning H<sub>2</sub> therefore does not result in direct emissions of CO<sub>2</sub>. However, H<sub>2</sub> can be made from Natural Gas (CH<sub>4</sub>) and the production of such grey H<sub>2</sub> can therefore still result in high levels of CO<sub>2</sub>. However, when using electrolyses of water, splitting the H<sub>2</sub>O into H<sub>2</sub> (hydrogen) and O<sub>2</sub> (oxygen), can result in zero GHG emissions from the well-to-wake viewpoint if for the electrolyses green electricity is used (e.g. solar power, wind, water power).

The cost of H<sub>2</sub> can vary today between 3.5 – 12 euro per kg for grey hydrogen and between 5.5 – 21 euro per kg for green hydrogen. For the future it is expected that the grey hydrogen will become more expensive because of the climate policy (e.g. ETS costs in the production of grey H<sub>2</sub>), while green hydrogen will become available at lower price levels. Bandwidths for 2050 are between 4-10 euro per kg for green H<sub>2</sub>, depending on the scenario, the variety between minimum and maximum levels in the STEPS, APS and NZE scenarios. A price of 4 euro per kg corresponds to price of 67 euro per GJe, which is equivalent to a diesel price of 1020 euro per m<sup>3</sup>. The diesel price today of 550 euro per m<sup>3</sup> therefore corresponds to a hydrogen price of 2,15 euro per kg. This shows the big gap between the hydrogen price and the price today of fossil diesel. Since CAPEX is also much higher of a hydrogen propulsion system compared to a diesel propulsion, there is a big gap to be closed in order to make hydrogen an economically competitive option compared to using diesel.

The figures on the next pages illustrate the projected evolution of grey and green hydrogen costs under the three scenarios.

In the STEPS scenario, both the minimum and maximum costs of grey hydrogen increase steadily from 2025 to 2050. This reflects rising natural gas prices and moderate carbon pricing under current policy settings. Green hydrogen, by contrast, shows a marked cost decline between 2025 and 2035, after which prices stabilize. Despite the downward trend, green hydrogen remains more expensive than grey hydrogen across the entire period in this baseline scenario.

In the APS scenario, where countries implement their announced climate pledges, grey hydrogen costs rise more sharply compared to STEPS, mainly due to higher carbon costs. Green hydrogen costs drop rapidly until 2035 and then level off. By around 2045–2050, the upper range of green hydrogen overlaps with the lower range of grey hydrogen, indicating emerging cost competitiveness.

The NZE scenario shows the most pronounced divergence between fossil-based and renewable hydrogen pathways. Grey hydrogen costs rise significantly due to stringent emission reduction policies and high carbon pricing, while green hydrogen experiences substantial cost reductions, driven by rapid technological progress and low renewable electricity prices. By 2040–2050, green hydrogen becomes nearly cost-competitive with, and in some cases cheaper than, grey hydrogen.<sup>43</sup>

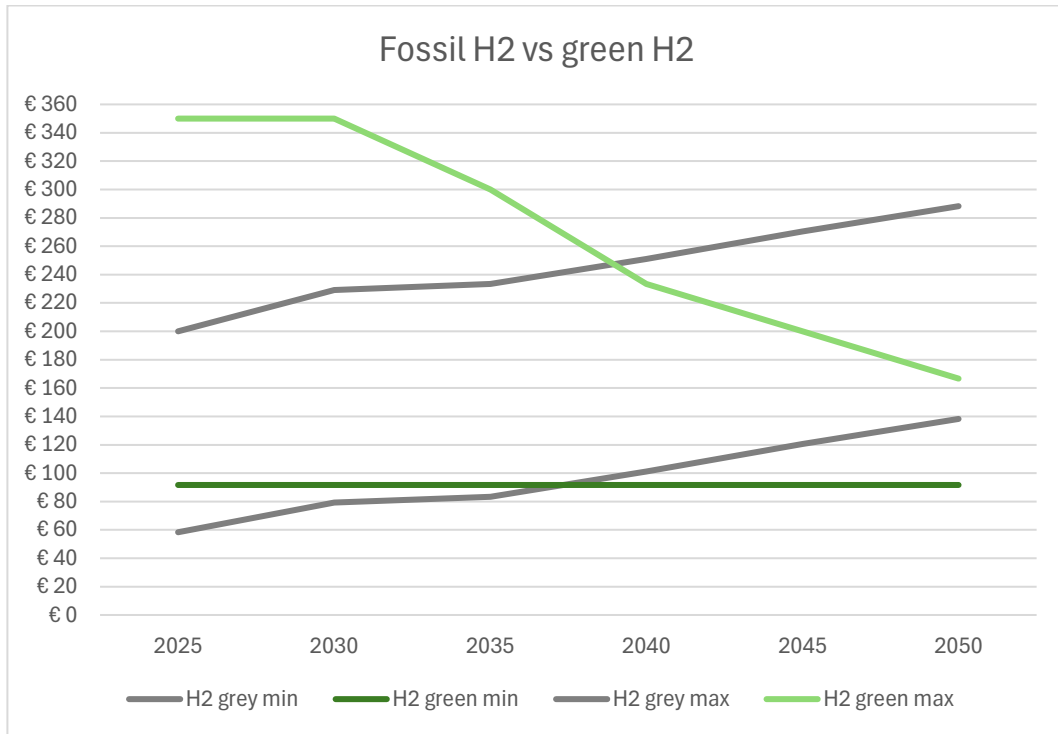
Overall, the figures highlight a consistent pattern: the cost gap between grey and green hydrogen narrows considerably across all scenarios, with full convergence likely only under ambitious climate policy conditions (APS and NZE). These results underscore the crucial role of policy ambition and technological innovation in accelerating the cost parity and large-scale adoption of green hydrogen<sup>44</sup>.

<sup>43</sup> Evaluation of the levelised cost of hydrogen based on proposed electrolyser projects in the Netherlands

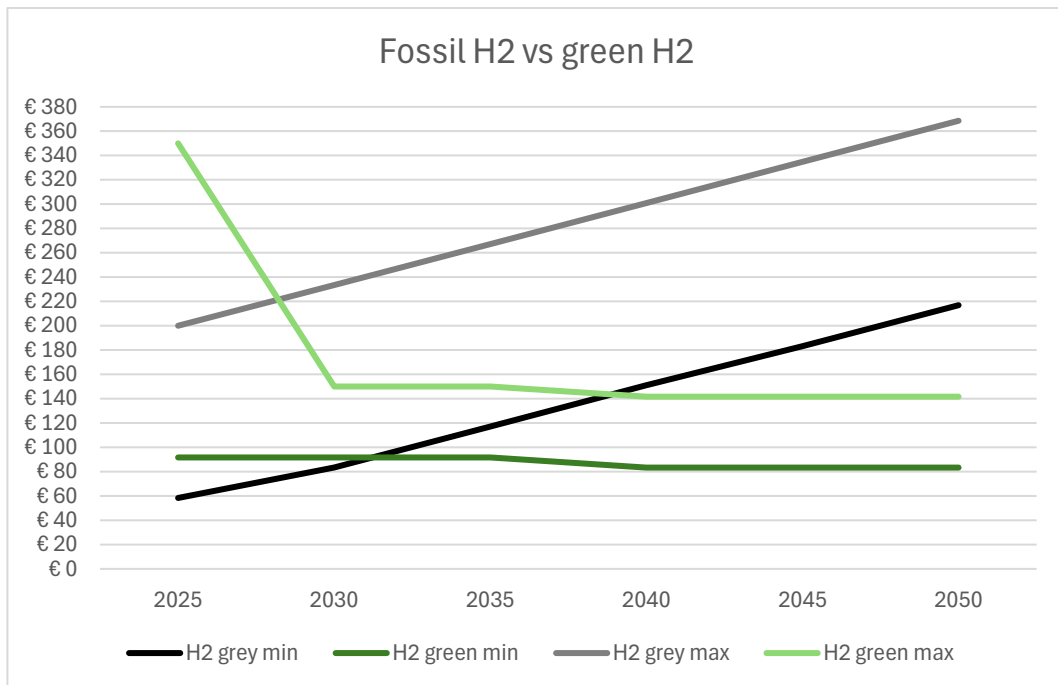
Grey hydrogen price index - businessanalytiq

[https://e-bridge.com/competencies/energy-markets/hydex/?utm\\_source=chatgpt.com](https://e-bridge.com/competencies/energy-markets/hydex/?utm_source=chatgpt.com)

<sup>44</sup> Global Hydrogen Review 2024



46 | STEPS, fossil hydrogen vs green hydrogen, price comparison in euro per GJe, taking into account efficiency of energy conversion

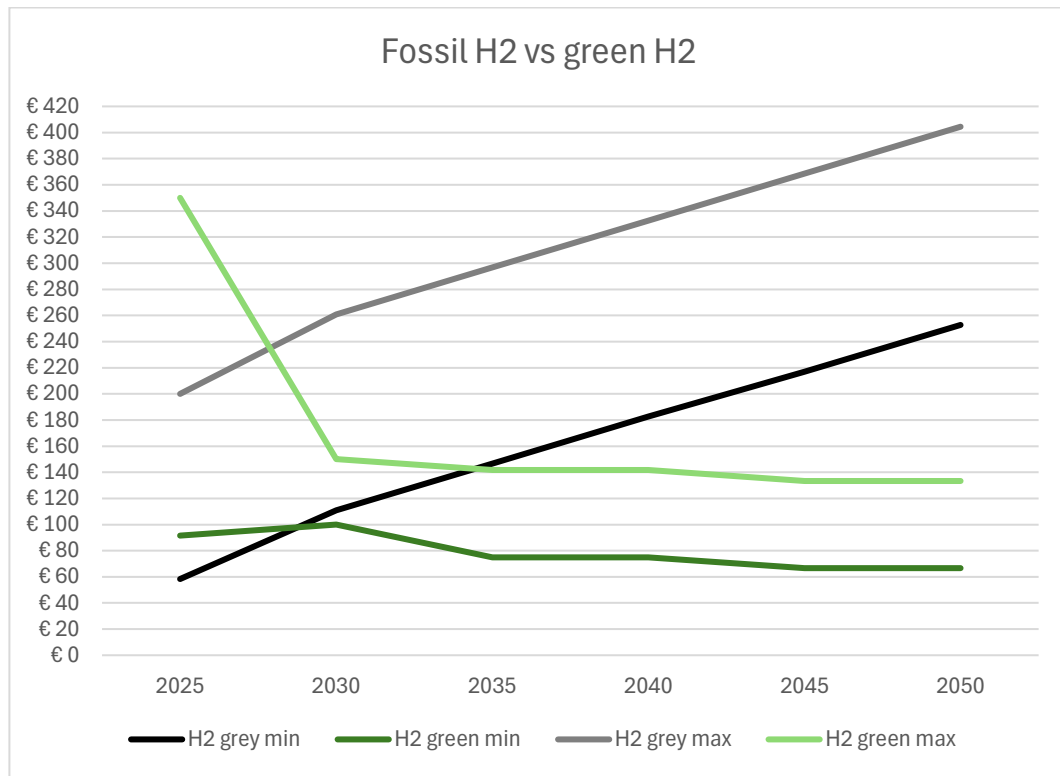


47 | APS, fossil hydrogen vs green hydrogen, price comparison in euro per GJe, taking into account efficiency of energy conversion

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**





48 | NZE, fossil hydrogen vs green hydrogen, price comparison in euro per GJe, taking into account efficiency of energy conversion



## Emission, heating values and efficiency rates

Emission factors applied in SYNERGETICS

- Fossil diesel: 4097 grams CO2e per kg fuel
- Fossil methanol: 2200 grams CO2e per kg fuel
- Fossil hydrogen: 12516 grams CO2e per kg fuel
- Fossil LNG: 3651 grams CO2e per kg fuel
- HVO: 567 grams CO2e per kg fuel

41 | LHV and efficiency rate applied in SYNERGETICS

Fuel Type	LHV [MJ/kg]	Technology	Efficiency
Methanol grey	20	MeOH ICE Single Fuel	0,38
Methanol green	20	MeOH ICE Dual Fuel	0,38
H2 grey	120	Battery system	0,9
H2 green	120	H2 ICE	0,38
Diesel	43,1	H2 FC	0,5
HVO	44	New Diesel Engine (diesel)	0,42
LNG	53	New Diesel Engine (HVO)	0,42
Diesel Unregulated	43,1	Gas Engine	0,4
Diesel CCNR1	43,1	Old diesel engine (unregulated)	0,33
Diesel CCNR2	43,1	Old diesel engine (CCNR1)	0,34
		Old diesel engine (CCNR2)	0,36

## Price details per energy type

This section presents the structure of prices, broken down by the following components:

- wholesale price
- internalised CO2 costs
- distribution costs

The tables present for each fuel/energy type the minimum and maximum price levels for each scenario (STEPS, APS, NZE) for the time period 2025-2050.

### Methodology

Total cost fuel prices EUR/kg = *sum (estimated wholesale price, taxes and subsidies, CO2 costs, distribution costs)*

Total cost fuel prices EUR/gj =  $\frac{\text{Total cost fuel prices EUR/kg}}{\text{Lower heating value mj/kg}} * 1000$

Total cost fuel prices EUR/gj based on efficiency rate =  $\frac{\text{Total cost fuel prices EUR/gj}}{\text{efficiency rate fuel type}}$

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **107** of **122**



#### 42 | Fossil diesel. Prices in euro per kg fuel

	Minimum						Maximum					
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
<b>STEPS</b>												
Wholesale price	0,60	0,70	0,80	0,90	0,90	0,90	0,75	0,85	0,95	1,05	1,05	1,05
Internalised CO2e costs EU	0,00	0,39	0,46	0,77	1,09	1,41	0,00	0,56	0,62	0,94	1,25	1,57
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>0,65</b>	<b>1,14</b>	<b>1,31</b>	<b>1,72</b>	<b>2,04</b>	<b>2,36</b>	<b>0,90</b>	<b>1,56</b>	<b>1,72</b>	<b>2,14</b>	<b>2,45</b>	<b>2,77</b>
<b>APS</b>												
Wholesale price	0,60	0,57	0,54	0,51	0,48	0,45	0,75	0,72	0,69	0,66	0,63	0,60
Internalised CO2e costs EU	0,00	0,43	1,02	1,62	2,22	2,82	0,00	0,59	1,19	1,79	2,38	2,98
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>0,65</b>	<b>1,05</b>	<b>1,61</b>	<b>2,18</b>	<b>2,75</b>	<b>3,32</b>	<b>0,90</b>	<b>1,46</b>	<b>2,03</b>	<b>2,60</b>	<b>3,16</b>	<b>3,73</b>
<b>NZE</b>												
Wholesale price	0,60	0,54	0,48	0,42	0,36	0,30	0,75	0,69	0,63	0,57	0,51	0,45
Internalised CO2e costs EU	0,00	0,97	1,61	2,25	2,88	3,52	0,00	1,13	1,77	2,41	3,05	3,69
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>0,65</b>	<b>1,56</b>	<b>2,14</b>	<b>2,72</b>	<b>3,29</b>	<b>3,87</b>	<b>0,90</b>	<b>1,97</b>	<b>2,55</b>	<b>3,13</b>	<b>3,71</b>	<b>4,29</b>

#### 43 | Fossil LNG. Prices in euro per kg fuel

	Minimum						Maximum					
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
<b>STEPS</b>												
Wholesale price	0,65	0,32	0,32	0,37	0,37	0,37	0,70	0,40	0,40	0,45	0,45	0,45
Internalised CO2e costs EU	0,00	0,38	0,91	1,45	1,98	2,51	0,00	0,53	1,06	1,59	2,13	2,66
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>0,70</b>	<b>0,75</b>	<b>1,28</b>	<b>1,87</b>	<b>2,40</b>	<b>2,93</b>	<b>0,85</b>	<b>1,08</b>	<b>1,61</b>	<b>2,19</b>	<b>2,73</b>	<b>3,26</b>
<b>APS</b>												
Wholesale price	0,65	0,29	0,25	0,25	0,25	0,25	0,70	0,40	0,35	0,35	0,35	0,35
Internalised CO2e costs EU	0,00	0,38	0,91	1,45	1,98	2,51	0,00	0,53	1,06	1,59	2,13	2,66
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>0,70</b>	<b>0,72</b>	<b>1,21</b>	<b>1,75</b>	<b>2,28</b>	<b>2,81</b>	<b>0,85</b>	<b>1,08</b>	<b>1,56</b>	<b>2,09</b>	<b>2,63</b>	<b>3,16</b>
<b>NZE</b>												
Wholesale price	0,65	0,21	0,25	0,20	0,20	0,19	0,70	0,40	0,30	0,30	0,30	0,30
Internalised CO2e costs EU	0,00	0,86	1,43	2,00	2,57	3,14	0,00	1,01	1,58	2,15	2,72	3,29
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>0,70</b>	<b>1,12</b>	<b>1,73</b>	<b>2,25</b>	<b>2,82</b>	<b>3,38</b>	<b>0,85</b>	<b>1,56</b>	<b>2,03</b>	<b>2,60</b>	<b>3,17</b>	<b>3,74</b>

#### 44 | Bio-LNG. Prices in euro per kg fuel

	Minimum						Maximum					
	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
<b>STEPS</b>												
Wholesale price	1,01	0,95	0,89	0,83	0,77	0,71	3,04	2,86	2,67	2,49	2,30	2,12
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>1,06</b>	<b>1,00</b>	<b>0,94</b>	<b>0,88</b>	<b>0,82</b>	<b>0,76</b>	<b>3,19</b>	<b>3,01</b>	<b>2,82</b>	<b>2,64</b>	<b>2,45</b>	<b>2,27</b>
<b>APS</b>												
Wholesale price	1,01	0,95	0,90	0,85	0,80	0,70	3,04	2,80	2,60	2,40	2,20	2,00
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>1,06</b>	<b>1,00</b>	<b>0,95</b>	<b>0,90</b>	<b>0,85</b>	<b>0,75</b>	<b>3,19</b>	<b>2,95</b>	<b>2,75</b>	<b>2,55</b>	<b>2,35</b>	<b>2,15</b>
<b>NZE</b>												
Wholesale price	1,01	0,95	0,90	0,85	0,80	0,70	3,04	2,80	2,60	2,40	2,20	2,00
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
<b>Total</b>	<b>1,06</b>	<b>1,00</b>	<b>0,95</b>	<b>0,90</b>	<b>0,85</b>	<b>0,75</b>	<b>3,19</b>	<b>2,95</b>	<b>2,75</b>	<b>2,55</b>	<b>2,35</b>	<b>2,15</b>

#### 45 | HVO. Prices in euro per kg fuel

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**



	Minimum						Maximum					
STEPS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	1,20	1,30	1,30	1,25	1,20	1,00	1,75	1,85	1,85	1,80	1,75	1,55
Internalised CO2e costs EU	0,00	0,05	0,06	0,11	0,15	0,19	0,00	0,08	0,09	0,13	0,17	0,22
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	1,25	1,40	1,41	1,41	1,40	1,24	1,90	2,08	2,09	2,08	2,07	1,92
APS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	1,20	1,25	1,25	1,30	1,30	1,40	1,75	1,80	1,80	1,85	1,85	1,90
Internalised CO2e costs EU	0,00	0,06	0,14	0,22	0,31	0,39	0,00	0,08	0,16	0,25	0,33	0,41
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	1,25	1,36	1,44	1,57	1,66	1,84	1,90	2,03	2,11	2,25	2,33	2,46
NZE	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	1,20	1,20	1,20	1,25	1,25	1,25	1,75	1,75	1,75	1,80	1,80	1,80
Internalised CO2e costs EU	0,00	0,13	0,22	0,31	0,40	0,49	0,00	0,16	0,24	0,33	0,42	0,51
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	1,25	1,38	1,47	1,61	1,70	1,79	1,90	2,06	2,14	2,28	2,37	2,46

#### 46 | Fossil Methanol. Prices in euro per kg

	Minimum						Maximum					
STEPS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,60	0,62	0,65	0,65	0,65	0,65	0,70	0,72	0,75	0,75	0,75	0,75
Internalised CO2e costs EU	0,00	0,21	0,25	0,42	0,59	0,75	0,00	0,30	0,33	0,50	0,67	0,84
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	0,65	0,88	0,95	1,12	1,29	1,45	0,85	1,17	1,23	1,40	1,57	1,74
APS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,60	0,82	0,85	0,87	0,90	0,92	0,70	0,92	0,95	0,97	1,00	1,02
Internalised CO2e costs EU	0,00	0,23	0,55	0,87	1,19	1,51	0,00	0,32	0,64	0,96	1,28	1,60
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	0,65	1,10	1,45	1,79	2,14	2,48	0,85	1,39	1,74	2,08	2,43	2,77
NZE	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,60	0,85	0,90	0,95	0,95	0,95	0,70	0,95	1,00	1,05	1,05	1,05
Internalised CO2e costs EU	0,00	0,52	0,86	1,21	1,55	1,89	0,00	0,61	0,95	1,29	1,64	1,98
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	0,65	1,42	1,81	2,21	2,55	2,89	0,85	1,71	2,10	2,49	2,84	3,18

#### 47 | Green Methanol. Prices in euro per kg

	Minimum						Maximum					
STEPS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,80	0,60	0,35	0,35	0,35	0,35	2,00	1,50	0,87	0,87	0,87	0,87
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	0,85	0,65	0,40	0,40	0,40	0,40	2,15	1,65	1,02	1,02	1,02	1,02
APS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,80	0,65	0,55	0,45	0,35	0,25	2,00	1,05	0,95	0,85	0,75	0,65
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	0,85	0,70	0,60	0,50	0,40	0,30	2,15	1,20	1,10	1,00	0,90	0,80
NZE	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,80	0,65	0,55	0,45	0,35	0,25	2,00	1,05	0,95	0,85	0,75	0,65
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,05	0,05	0,05	0,05	0,05	0,05	0,15	0,15	0,15	0,15	0,15	0,15
Total	0,85	0,70	0,60	0,50	0,40	0,30	2,15	1,20	1,10	1,00	0,90	0,80

#### 48 | Fossil hydrogen. Prices in euro per kg

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **109** of **122**



	Minimum						Maximum					
STEPS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	1,50	1,55	1,60	1,70	1,90	2,00	8,00	8,05	8,10	8,20	8,40	8,50
Internalised CO2e costs EU	0,00	1,30	3,13	4,96	6,79	8,61	0,00	1,80	3,63	5,46	7,29	9,11
Distribution costs	2,00	2,00	2,00	2,00	2,00	2,00	4,00	4,00	4,00	4,00	4,00	4,00
<b>Total</b>	<b>3,50</b>	<b>5,00</b>	<b>7,03</b>	<b>9,06</b>	<b>10,99</b>	<b>13,01</b>	<b>12,00</b>	<b>14,00</b>	<b>16,03</b>	<b>18,06</b>	<b>20,09</b>	<b>22,11</b>
APS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	1,50	1,70	1,90	2,10	2,20	2,40	8,00	8,20	8,40	8,60	8,80	9,00
Internalised CO2e costs EU	0,00	2,95	4,91	6,86	8,81	10,77	0,00	3,45	5,41	7,36	9,31	11,27
Distribution costs	2,00	2,00	2,00	2,00	2,00	2,00	4,00	4,00	4,00	4,00	4,00	4,00
<b>Total</b>	<b>3,50</b>	<b>6,65</b>	<b>8,81</b>	<b>10,96</b>	<b>13,01</b>	<b>15,17</b>	<b>12,00</b>	<b>15,65</b>	<b>17,81</b>	<b>19,96</b>	<b>22,11</b>	<b>24,27</b>
NZE	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	1,50	1,70	1,90	2,10	2,20	2,40	8,00	8,20	8,40	8,60	8,80	9,00
Internalised CO2e costs EU	0,00	2,95	4,91	6,86	8,81	10,77	0,00	3,45	5,41	7,36	9,31	11,27
Distribution costs	2,00	2,00	2,00	2,00	2,00	2,00	4,00	4,00	4,00	4,00	4,00	4,00
<b>Total</b>	<b>3,50</b>	<b>6,65</b>	<b>8,81</b>	<b>10,96</b>	<b>13,01</b>	<b>15,17</b>	<b>12,00</b>	<b>15,65</b>	<b>17,81</b>	<b>19,96</b>	<b>22,11</b>	<b>24,27</b>

#### 49 | Green hydrogen. Prices in euro per kg

	Minimum						Maximum					
STEPS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	3,50	3,50	3,50	3,50	3,50	3,50	17,00	17,00	14,00	10,00	8,00	6,00
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	2,00	2,00	2,00	2,00	2,00	2,00	4,00	4,00	4,00	4,00	4,00	4,00
<b>Total</b>	<b>5,50</b>	<b>5,50</b>	<b>5,50</b>	<b>5,50</b>	<b>5,50</b>	<b>5,50</b>	<b>21,00</b>	<b>21,00</b>	<b>18,00</b>	<b>14,00</b>	<b>12,00</b>	<b>10,00</b>
APS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	3,50	3,50	3,50	3,00	3,00	3,00	17,00	5,00	5,00	4,50	4,50	4,50
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	2,00	2,00	2,00	2,00	2,00	2,00	4,00	4,00	4,00	4,00	4,00	4,00
<b>Total</b>	<b>5,50</b>	<b>5,50</b>	<b>5,50</b>	<b>5,00</b>	<b>5,00</b>	<b>5,00</b>	<b>21,00</b>	<b>9,00</b>	<b>9,00</b>	<b>8,50</b>	<b>8,50</b>	<b>8,50</b>
NZE	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	3,50	4,00	2,50	2,50	2,00	2,00	17,00	5,00	4,50	4,50	4,00	4,00
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	2,00	2,00	2,00	2,00	2,00	2,00	4,00	4,00	4,00	4,00	4,00	4,00
<b>Total</b>	<b>5,50</b>	<b>6,00</b>	<b>4,50</b>	<b>4,50</b>	<b>4,00</b>	<b>4,00</b>	<b>21,00</b>	<b>9,00</b>	<b>8,50</b>	<b>8,50</b>	<b>8,00</b>	<b>8,00</b>

#### 50 | Electricity. Prices in euro per kWh

	Minimum						Maximum					
STEPS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,03	0,03	0,04	0,05	0,06	0,07	0,10	0,10	0,11	0,12	0,13	0,14
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22
<b>Total</b>	<b>0,25</b>	<b>0,25</b>	<b>0,26</b>	<b>0,27</b>	<b>0,28</b>	<b>0,29</b>	<b>0,32</b>	<b>0,32</b>	<b>0,33</b>	<b>0,34</b>	<b>0,35</b>	<b>0,36</b>
APS	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,03	0,03	0,03	0,03	0,03	0,03	0,10	0,10	0,09	0,09	0,08	0,08
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22
<b>Total</b>	<b>0,25</b>	<b>0,25</b>	<b>0,25</b>	<b>0,25</b>	<b>0,25</b>	<b>0,25</b>	<b>0,32</b>	<b>0,32</b>	<b>0,31</b>	<b>0,31</b>	<b>0,30</b>	<b>0,30</b>
NZE	2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Wholesale price	0,03	0,03	0,03	0,02	0,02	0,02	0,10	0,10	0,08	0,08	0,06	0,06
Internalised CO2e costs EU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Distribution costs	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22	0,22
<b>Total</b>	<b>0,25</b>	<b>0,25</b>	<b>0,25</b>	<b>0,24</b>	<b>0,24</b>	<b>0,24</b>	<b>0,32</b>	<b>0,32</b>	<b>0,30</b>	<b>0,30</b>	<b>0,28</b>	<b>0,28</b>

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **110** of **122**



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<b>Methanol:</b>	<a href="https://www.methanex.com/about-methanol/pricing/">https://www.methanex.com/about-methanol/pricing/</a> <a href="https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf">https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Jan/IRENA_Innovation_Renewable_Methanol_2021.pdf</a>
<b>Hydrogen</b>	<a href="https://publications.tno.nl/publication/34642511/mzKClN/TNO-2024-R10766.pdf">https://publications.tno.nl/publication/34642511/mzKClN/TNO-2024-R10766.pdf</a> <a href="https://businessanalytiq.com/procurementanalytics/index/grey-hydrogen-price-index/">https://businessanalytiq.com/procurementanalytics/index/grey-hydrogen-price-index/</a> <a href="https://e-bridge.com/competencies/energy-markets/hydex/">https://e-bridge.com/competencies/energy-markets/hydex/</a> <a href="https://iea.blob.core.windows.net/assets/89c1e382-dc59-46ca-aa47-9f7d41531ab5/GlobalHydrogenReview2024.pdf">https://iea.blob.core.windows.net/assets/89c1e382-dc59-46ca-aa47-9f7d41531ab5/GlobalHydrogenReview2024.pdf</a> <a href="https://iea.blob.core.windows.net/assets/89c1e382-dc59-46ca-aa47-9f7d41531ab5/GlobalHydrogenReview2024.pdf">https://iea.blob.core.windows.net/assets/89c1e382-dc59-46ca-aa47-9f7d41531ab5/GlobalHydrogenReview2024.pdf</a>

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Grant agreement no. | **101096809**

Page **111** of **122**



## Annex II NEEDS IWT Model

### Fuel properties and emission factors

51 | NEEDS model fuel properties and emission factor overview

Fuel name	Fuel Transfer	Contained energy density	Bunker speed	WTT	TTW	Storage	Energy verter	Con-	Energy distribution	Retrofit time
		MJ/kg	kWh/h	kg/GJ	kg/GJ					days
<b>Diesel</b>	Bunkering	29.65	326421.3	22.57009	75.25701	Tank	4 stroke – medium speed		Direct propulsion	20
<b>Bio-Diesel</b>	Bunkering	31.9	310566.7	1.159091	28.56818	Tank	4 stroke – medium speed		Direct propulsion	20
<b>LNG</b>	Bunkering	28.37	204583.3	25.76375	74.27699	Tank	4 stroke – medium speed		Direct propulsion	28
<b>Bio-LNG</b>	Bunkering	28.37	204583.3	0.94	28.86	Tank	4 stroke – medium speed		Direct propulsion	28
<b>Current Electricity mix</b>	Charging	0.36	1000	73	0	Lithium-Ion Battery	None		Battery electric propulsion	60
<b>Renewable Electricity</b>	Charging	0.36	1000	73	0	Lithium-Ion Battery	None		Battery electric propulsion	60
<b>Renewable Electricity</b>	Swapping	0.36	6000	73	0	Lithium-Ion Battery	None		Battery electric propulsion	60
<b>Grey Hydrogen</b>	Bunkering	1.4	2666.667	101.3	0	H2Tank 700bar	LT PEMFC		FC electric propulsion	60
<b>Grey Hydrogen</b>	Swapping	1.4	720	101.3	0	H2Tank 700bar	LT PEMFC		FC electric propulsion	60
<b>Green Hydrogen</b>	Bunkering	1.4	2666.667	14.6	0	H2Tank 700bar	LT PEMFC		FC electric propulsion	60
<b>Green Hydrogen</b>	Swapping	1.4	720	14.6	0	H2Tank 700bar	LT PEMFC		FC electric propulsion	60

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Grant agreement no. | **101096809**

Page **112** of **122**

Fuel name	Fuel Transfer	Contained energy density	Bunker speed	WTT	TTW	Storage	Energy Converter	Energy distribution	Retrofit time
		MJ/kg	kWh/h	kg/GJ	kg/GJ				days
<b>Grey Hydrogen, Diesel 4%</b>	Bunkering	2.53	13748.05	14.9188	3.01028	H2Tank 700bar	4 stroke – medium speed	Direct propulsion	40
<b>Green Hydrogen, Diesel 4%</b>	Bunkering	2.53	13748.05	98.1508	3.01028	H2Tank 700bar	4 stroke – medium speed	Direct propulsion	40
<b>Methanol</b>	Bunkering	14.5	144291.6	27.35	72.01005	Tank	4 stroke – medium speed	Direct propulsion	60
<b>Bio-Methanol</b>	Bunkering	14.5	144291.6	72.01005	0	Tank	4 stroke – medium speed	Direct propulsion	60
<b>Methanol, Diesel 5%</b>	Bunkering	15.2575	153398.1	69.53805	3.76285	Tank	4 stroke – medium speed	Direct propulsion	40
<b>Methanol, Diesel 35%</b>	Bunkering	19.8025	208037	54.70607	26.33995	Tank	4 stroke – medium speed	Direct propulsion	40
<b>Methanol, Bio Diesel 5%</b>	Bunkering	15.37	152605.3	68.4675	1.428409	Tank	4 stroke – medium speed	Direct propulsion	40

Authors | **D.J. Ho-Sam-Sooi, M. Quispel, F. Dahlke-Wallat**

Grant agreement no. | **101096809**

Page **113** of **122**

## Minimum and maximum for energy carrier, equipment and integration costs

52 | Equipment cost in €/kW

Equipment	min	max
<b>DPF&amp;SCR</b>	82	115
<b>Battery</b>	300	650
<b>Electric Engine</b>	150	250
<b>MEOH ICE SF</b>	500	600
<b>MEOH ICE DF</b>	500	600
<b>H2 ICE SF</b>	600	900
<b>H2 ICE DF</b>	600	900
<b>Stage V+ Euro VI ICEs</b>	350	590
<b>MEOH FC</b>	2000	3000
<b>H2 Fuel Cell</b>	1500	2500
<b>H2-Tank</b>	500	800
<b>Unregulated CCNR1 and CCNR2 ICEs</b>	150	200
<b>Methane ICE</b>	450	450

53 | Integration cost in €/kW

Installation	min	max
<b>ICE high-speed</b>	160	240
<b>Methanol system</b>	600	800
<b>Hydrogen System</b>	900	1100
<b>Electric system for FC</b>	370	450
<b>Battery electric system</b>	800	1200
<b>DPF&amp;SCR</b>	70	90
<b>cryogenic fuel storage system</b>	700	900

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Grant agreement no. | **101096809**

Page **114** of **122**



## Temporal development of equipment and integration costs and Readiness and availability levels

54 | Development over time for equipment and integration of systems

	2030	2035	2040	2045	2050
<b>Installation and Integration Retrofit System</b>	1	0.95	0.8	0.75	0.7
<b>MEOH ICE SF</b>	1	0.95	0.8	0.75	0.7
<b>MEOH ICE DF</b>	1	0.95	0.8	0.75	0.7
<b>Electric Engine</b>	1	0.95	0.8	0.75	0.7
<b>H2-Tank</b>	1	0.95	0.8	0.75	0.7
<b>H2 ICE SF</b>	1	0.95	0.8	0.75	0.7
<b>H2 ICE DF</b>	1	0.95	0.8	0.75	0.7
<b>H2 Fuel Cell</b>	1	0.95	0.8	0.75	0.7
<b>MeOH FC</b>	1	0.95	0.8	0.75	0.7
<b>Stage V+ Euro VI</b>	1	0.95	0.8	0.75	0.7
<b>Medium Speed IMO Tier II ICE</b>	1	0.95	0.8	0.75	0.7
<b>Medium Speed IMO Tier III ICE</b>	1	0.95	0.8	0.75	0.7
<b>DPF&amp;SCR</b>	1	0.95	0.8	0.75	0.7
<b>cryogenic fuel storage system</b>	1	0.95	0.8	0.75	0.7
<b>Hydrodynamic measures equipment cost</b>	1	0.95	0.8	0.75	0.7
<b>Methane ICE</b>	1	0.95	0.8	0.75	0.7
<b>ICE high-speed</b>	1	0.95	0.8	0.75	0.7

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Grant agreement no. | **101096809**

Page **115** of **122**



55 | NZE and STEPS scenario development of port availability, social readiness level and technology readiness level

	Port availability						Social readiness level						Technology readiness level						
	nze		steps		nze		steps		nze		steps		nze		steps				
	2023	2035	2050	2023	2035	2050	2023	2035	2050	2023	2035	2050	2023	2035	2050	2023	2035	2050	
<b>Fuel</b>																			
Bio-LNG	4	3	2	4	4	5	6	6	5	6	7	8	9	9	9	9	9	9	9
Bio-Diesel	7	8	7	7	9	9	9	8	7	9	9	9	9	9	9	9	9	9	9
Bio-Methanol	1	6	7	1	4	6	5	6	7	5	6	7	7	9	9	9	7	9	9
Bio-Methanol/ Bio-Diesel.5%	1	6	7	1	4	6	4	6	7	4	5	6	5	9	9	9	5	9	9
Bio-Methanol/ Diesel 35 %	1	6	7	1	4	6	4	6	7	4	5	6	5	9	9	9	5	9	9
Bio-Methanol/ Bio-Diesel.5%	1	6	7	1	4	6	4	6	7	4	5	6	5	9	9	9	5	9	9
Grey Hydrogen Diesel 5%	1	7	8	1	5	7	5	7	8	5	6	7	5	9	9	9	5	9	9
LNG	4	3	2	4	4	4	3	2	1	3	2	1	9	9	9	9	9	9	9
Bio-Diesel	9	8	7	9	9	9	9	7	6	9	8	7	9	9	9	9	9	9	9
Grey Hydrogen Bunker	1	7	8	1	5	7	6	7	8	6	7	8	7	9	9	9	7	9	9
Grey Hydrogen Swap	1	7	8	1	5	7	6	7	8	6	7	8	7	9	9	9	7	9	9
Methanol	1	6	7	1	4	6	5	6	7	5	6	7	7	9	9	9	7	9	9
Current Electricity mix Charging	2	8	9	2	6	8	7	8	9	7	8	9	8	9	9	9	8	9	9
Current Electricity mix Swapping	2	8	9	2	6	8	7	8	9	7	8	9	8	9	9	9	8	9	9
Green Hydrogen Bunker	1	7	8	1	5	7	6	7	8	6	7	8	7	9	9	9	7	9	9
Green Hydrogen Diesel.5%	1	7	8	1	5	7	5	7	8	5	6	7	5	9	9	9	5	9	9
Green Hydrogen Swap	1	7	8	1	5	7	6	7	8	6	7	8	7	9	9	9	7	9	9
Renewable Electricity Charging	2	8	9	2	6	8	7	8	9	7	8	9	8	9	9	9	8	9	9
Renewable Electricity Swapping	2	8	9	2	6	8	7	8	9	7	8	9	8	9	9	9	8	9	9

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Grant agreement no. | **101096809**

Page **116** of **122**



## Fuel cost table STEPS scenario

56 | Minimum and maximum fuel cost for STEPS

Fuel	unit	STEPS											
		min						max					
		2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Bio-LNG	€/kWh	0.23	0.22	0.20	0.19	0.18	0.16	0.08	0.07	0.07	0.06	0.06	0.05
Bio-Diesel	€/kWh	0.16	0.17	0.17	0.17	0.17	0.16	0.10	0.11	0.12	0.12	0.11	0.10
Bio-Methanol	€/kWh	0.39	0.30	0.18	0.18	0.18	0.18	0.15	0.12	0.07	0.07	0.07	0.07
Bio-Methanol / Bio-Diesel 5%	€/kWh	0.36	0.29	0.18	0.18	0.18	0.18	0.15	0.12	0.08	0.08	0.08	0.08
Bio-Methanol / Diesel 35 %	€/kWh	0.22	0.21	0.16	0.18	0.20	0.21	0.10	0.11	0.09	0.11	0.13	0.14
Bio-Methanol / Bio-Diesel 5%	€/kWh	0.36	0.28	0.18	0.18	0.19	0.19	0.14	0.12	0.08	0.08	0.08	0.09
Grey Hydrogen Diesel 5%	€/kWh	0.36	0.42	0.48	0.54	0.60	0.66	0.10	0.15	0.21	0.27	0.33	0.39
LNG	€/kWh	0.06	0.08	0.12	0.16	0.20	0.24	0.05	0.05	0.09	0.14	0.18	0.21
Bio-Diesel	€/kWh	0.08	0.13	0.14	0.18	0.21	0.23	0.05	0.10	0.11	0.14	0.17	0.20
Grey Hydrogen Bunker	€/kWh	0.36	0.42	0.48	0.54	0.60	0.66	0.11	0.15	0.21	0.27	0.33	0.39
Grey Hydrogen Swap	€/kWh	0.36	0.42	0.48	0.54	0.60	0.66	0.11	0.15	0.21	0.27	0.33	0.39
Methanol	€/kWh	0.15	0.21	0.22	0.25	0.28	0.31	0.12	0.16	0.17	0.20	0.23	0.26
Current Electricity mix Charging	€/kWh	0.32	0.32	0.33	0.34	0.35	0.36	0.25	0.25	0.26	0.27	0.28	0.29
Current Electricity mix Swapping	€/kWh	0.50	0.45	0.40	0.37	0.35	0.34	0.35	0.33	0.30	0.28	0.27	0.27
Green Hydrogen Bunker	€/kWh	0.63	0.63	0.54	0.42	0.36	0.30	0.17	0.17	0.17	0.17	0.17	0.17
Green Hydrogen Diesel 5%	€/kWh	0.62	0.62	0.53	0.42	0.36	0.30	0.16	0.16	0.16	0.16	0.17	0.17
Green Hydrogen Swap	€/kWh	0.63	0.63	0.54	0.42	0.36	0.30	0.17	0.17	0.17	0.17	0.17	0.17
Renewable Elec- tricity Charging	€/kWh	0.32	0.32	0.33	0.34	0.35	0.36	0.25	0.25	0.26	0.27	0.28	0.29
Renewable Elec- tricity Swapping	€/kWh	0.50	0.45	0.40	0.37	0.35	0.34	0.35	0.33	0.30	0.28	0.27	0.27

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 Grant agreement no. | **101096809**

 Page **117** of **122**


## Fuel cost table NZE scenario

57 | Minimum and maximum fuel costs for NZE

Fuel	unit	NZE											
		min						max					
		2025	2030	2035	2040	2045	2050	2025	2030	2035	2040	2045	2050
Bio-LNG	€/kWh	0.23	0.21	0.20	0.18	0.17	0.15	0.08	0.07	0.07	0.06	0.06	0.05
Bio-Diesel	€/kWh	0.16	0.17	0.18	0.19	0.19	0.20	0.10	0.11	0.12	0.13	0.14	0.15
Bio-Methanol	€/kWh	0.39	0.22	0.20	0.18	0.16	0.14	0.15	0.13	0.11	0.09	0.07	0.05
Bio-Methanol / Bio-Diesel 5%	€/kWh	0.36	0.21	0.20	0.18	0.17	0.15	0.15	0.13	0.11	0.09	0.08	0.06
Bio-Methanol / Diesel 35 %	€/kWh	0.22	0.19	0.21	0.23	0.24	0.26	0.10	0.13	0.15	0.16	0.18	0.20
Bio-Methanol / Bio-Diesel 5%	€/kWh	0.36	0.21	0.20	0.19	0.18	0.17	0.14	0.13	0.12	0.10	0.09	0.08
Grey Hydrogen Diesel 5%	€/kWh	0.36	0.47	0.53	0.59	0.66	0.72	0.10	0.20	0.26	0.33	0.39	0.45
LNG	€/kWh	0.09	0.11	0.15	0.19	0.23	0.27	0.05	0.08	0.13	0.17	0.21	0.25
Bio-Diesel	€/kWh	0.08	0.17	0.21	0.26	0.31	0.36	0.05	0.13	0.18	0.23	0.28	0.33
Grey Hydrogen Bunker	€/kWh	0.36	0.47	0.53	0.60	0.66	0.73	0.11	0.20	0.26	0.33	0.39	0.46
Grey Hydrogen Swap	€/kWh	0.36	0.47	0.53	0.60	0.66	0.73	0.11	0.20	0.26	0.33	0.39	0.46
Methanol	€/kWh	0.15	0.31	0.38	0.45	0.51	0.58	0.12	0.26	0.33	0.40	0.46	0.52
Current Electricity mix Charging	€/kWh	0.32	0.32	0.30	0.30	0.28	0.28	0.25	0.25	0.25	0.24	0.24	0.24
Current Electricity mix Swapping	€/kWh	0.50	0.45	0.40	0.37	0.35	0.34	0.35	0.33	0.30	0.28	0.27	0.27
Green Hydrogen Bunker	€/kWh	0.63	0.27	0.26	0.26	0.24	0.24	0.17	0.18	0.14	0.14	0.12	0.12
Green Hydrogen Diesel 5%	€/kWh	0.62	0.27	0.25	0.26	0.24	0.24	0.16	0.18	0.14	0.14	0.12	0.12
Green Hydrogen Swap	€/kWh	0.63	0.27	0.26	0.26	0.24	0.24	0.17	0.18	0.14	0.14	0.12	0.12
Renewable Electricity Charging	€/kWh	0.32	0.32	0.30	0.30	0.28	0.28	0.25	0.25	0.25	0.24	0.24	0.24
Renewable Electricity Swapping	€/kWh	0.50	0.45	0.40	0.37	0.35	0.34	0.35	0.33	0.30	0.28	0.27	0.27

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 Grant agreement no. | **101096809**

 Page **118** of **122**


## Energy carrier storage cost table

58 | Minimum and maximum energy carrier costs over time

€/kWh	min					max				
	2030	2035	2040	2045	2050	2030	2035	2040	2045	2050
<b>Fuel</b>										
Bio-LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-Diesel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-Methanol- Fuel Cell	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-Methanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-Methanol / Bio-Diesel 5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-Methanol / Diesel 35 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-Methanol / Bio-Diesel 5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grey Hydrogen Diesel 5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LNG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bio-Diesel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grey Hydrogen Bunker	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grey Hydrogen Swap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Current Electricity mix Charging	210.00	147.00	102.00	72.00	51.00	520.00	416.00	331.50	266.50	214.50
Current Electricity mix Swapping	210.00	147.00	102.00	72.00	51.00	520.00	416.00	331.50	266.50	214.50
Green Hydrogen Bunker	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green Hydrogen Diesel 5%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green Hydrogen Swap	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Renewable Electricity Charging	210.00	147.00	102.00	72.00	51.00	520.00	416.00	331.50	266.50	214.50
Renewable Electricity Swapping	210.00	147.00	102.00	72.00	51.00	520.00	416.00	331.50	266.50	214.50

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Grant agreement no. | **101096809**

Page **119** of **122**



## Energy system converter cost table

59 | Minimum and maximum energy converter cost over time

€/kW Fuel	min					max				
	2030	2035	2040	2045	2050	2030	2035	2040	2045	2050
Bio-LNG	450	427.5	360	337.5	315	450	427.5	360	337.5	315
Bio-Diesel	350	350	350	350	350	590	590	590	590	590
Bio-Methanol- Fuel Cell	2450	2442.5	2420	2412.5	2405	3900	3887.5	3850	3837.5	3825
Bio-Methanol	980	977	968	965	962	1560	1555	1540	1535	1530
Bio-Methanol / Bio-Diesel 5%	582	552.9	465.6	436.5	407.4	715	679.25	572	536.25	500.5
Bio-Methanol / Diesel 35 %	582	552.9	465.6	436.5	407.4	715	679.25	572	536.25	500.5
Bio-Methanol / Bio-Diesel 5%	582	552.9	465.6	436.5	407.4	715	679.25	572	536.25	500.5
Grey Hydrogen Diesel 5%	272.8	259.16	218.24	204.6	190.96	406	385.7	324.8	304.5	284.2
LNG	450	427.5	360	337.5	315	450	427.5	360	337.5	315
Bio-Diesel	350	350	350	350	350	590	590	590	590	590
Grey Hydrogen Bunker	780	747	648	615	582	1360	1305	1140	1085	1030
Grey Hydrogen Swap	780	747	648	615	582	1360	1305	1140	1085	1030
Methanol	980	977	968	965	962	1560	1555	1540	1535	1530
Current Electric- ity mix Charging	150	142.5	120	112.5	105	250	237.5	200	187.5	175
Current Electric- ity mix Swap- ping	150	142.5	120	112.5	105	250	237.5	200	187.5	175
Green Hydrogen Bunker	780	747	648	615	582	1360	1305	1140	1085	1030
Green Hydrogen Diesel 5%	272.8	259.16	218.24	204.6	190.96	406	385.7	324.8	304.5	284.2
Green Hydrogen Swap	780	747	648	615	582	1360	1305	1140	1085	1030
Renewable Elec- tricity Charging	150	142.5	120	112.5	105	250	237.5	200	187.5	175
Renewable Elec- tricity Swapping	150	142.5	120	112.5	105	250	237.5	200	187.5	175

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Grant agreement no. | **101096809**

Page **120** of **122**



## Energy system integration cost table

60 | Minimum and maximum system integration cost over time

€/kW	min					max				
	2030	2035	2040	2045	2050	2030	2035	2040	2045	2050
<b>Fuel</b>										
Bio-LNG	860	817	688	645	602	1140	1083	912	855	798
Bio-Diesel	230	218.5	184	172.5	161	330	313.5	264	247.5	231
Bio-Methanol-Fuel Cell	970	970	970	970	970	1250	1250	1250	1250	1250
Bio-Methanol	388	388	388	388	388	500	500	500	500	500
Bio-Methanol / Bio-Diesel 5%	760	752	728	720	712	1040	1028	992	980	968
Bio-Methanol / Diesel 35 %	760	752	728	720	712	1040	1028	992	980	968
Bio-Methanol / Bio-Diesel 5%	760	752	728	720	712	1040	1028	992	980	968
Grey Hydrogen Diesel 5%	424	420.8	411.2	408	404.8	536	531.2	516.8	512	507.2
LNG	860	817	688	645	602	1140	1083	912	855	798
Bio-Diesel	230	218.5	184	172.5	161	330	313.5	264	247.5	231
Grey Hydrogen Bunker	508	508	508	508	508	620	620	620	620	620
Grey Hydrogen Swap	508	508	508	508	508	620	620	620	620	620
Methanol	388	388	388	388	388	500	500	500	500	500
Current Electricity mix Charging	800	800	800	800	800	1200	1200	1200	1200	1200
Current Electricity mix Swapping	800	800	800	800	800	1200	1200	1200	1200	1200
Green Hydrogen Bunker	508	508	508	508	508	620	620	620	620	620
Green Hydrogen Diesel 5%	424	420.8	411.2	408	404.8	536	531.2	516.8	512	507.2
Green Hydrogen Swap	508	508	508	508	508	620	620	620	620	620
Renewable Electricity Charging	800	800	800	800	800	1200	1200	1200	1200	1200
Renewable Electricity Swapping	800	800	800	800	800	1200	1200	1200	1200	1200

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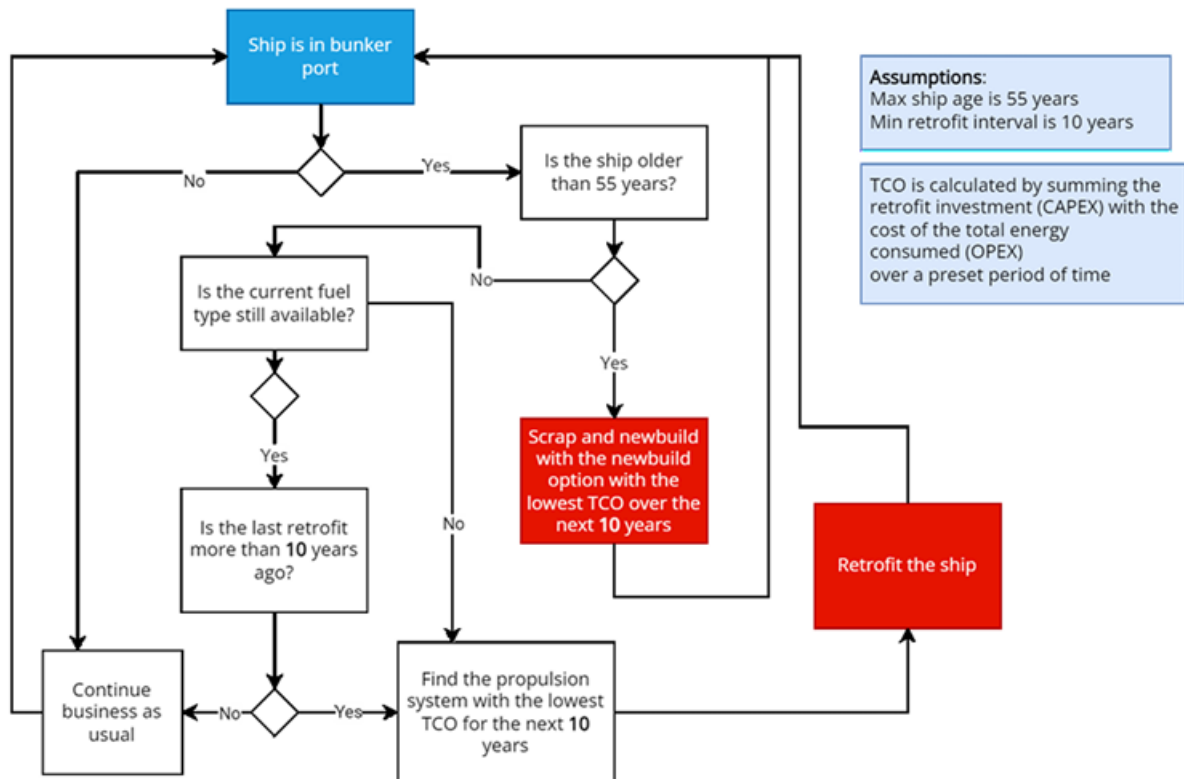
Page **121** of **122**



## Energy system selection logic

If the ship reaches a port with a shipyard and the last check was 10 years ago, the captain uses a system selection logic:

61| Ship owner system selection logic for scrapping and retrofit decision making



The TCO calculation includes fuel price, income loss and fuel efficiency into OPEX and system retrofit CAPEX. Together with the technology readiness level (TRL), social readiness level (SRL) and port availability (PA) these are combined into a rating which is used by the captain decision mimic to select one of the top retrofit options.

