The NEEDS project has received funding from
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Needs

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

D3.2 Analysis of the potential of the inland region

Document information	
Short description	Focusing on the inland shipping network, this deliverable describes the applicability of different energy carriers and solutions, potential upscale of renewable energy production, harbour infrastructure and likely impact of energy transition in the wider Rhine region.
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Task	Task 3.2: Analysis of regional potential
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Executive summary

There is no panacea that can help the entire IWT fleet towards zero-emission. A broad set of possible alternatives to fossil diesel are currently being considered. The most promising and likely feasible solutions in time towards the year 2050 have been identified. These include:

- HVO and LBM to be used in Stage V certified ICE's.
- Green H_2 in combination with fuel cells and ICE's.
- Green methanol in combination with fuel cells and ICE's.
- Green electricity in combination with Batteries

Given these solutions, two transition pathways have been developed for the IWT fleet. A distribution was made for the technologies and forms of energy by fleet family for two pathway scenarios, i.e. the conservative and innovative pathways. The former pathway is based on technologies that are already mature, cost efficient in the short-term but with uncertainties on the availability on certain fuels, and a more innovative one, relying on technologies still in their infancy stage but providing more promising emission reduction potential on the long run.

The current energy mix in the Rhine region still mainly consists of fossil sources. Policies such as the proposed Fit For 55 package and REPowerEU will accelerate the transition to a zero-emission economy by substituting fossil fuels with renewable alternatives such as green fuels and electricity and will for sure have an effect on the energy mix of the EU and the Rhine countries. There are currently a large number of sizeable renewable energy projects on the drawing board and under implementation, especially also in the wider Rhine region.

The question is being raised whether there will be sufficient renewable energy available for the IWT sector. Eventually, renewable energy will also find its way to IWT, just as is happening today with fossil fuels. However, competition from other sectors and a limited supply of renewable energy, will cause relatively high prices especially in the run-up phase towards 2050. In such situation, it stands to reason that the IWT sector may experience difficulties in obtaining renewable energy in a dynamic market. It is expected though that further towards 2050 this problem will be remedied, provided the demand side to renewable energy from the fleet also develops sufficiently.

The energy infrastructure for IWT will play a pivotal role in this respect. The required infrastructure will need to develop so that the actual bunkering, charging and swapping of energy containers can be facilitated. The realization of the clean energy infrastructure faces gaps and challenges. A total of 52 gaps and challenges were identified. The main challenge is the lack of demand for renewable energy from the fleet. Framework conditions should be created to encourage investment by ship owners in clean propulsion technologies and energy.

Whether the infrastructure side in the Rhine region will be able to timely adapt to the foreseen transition towards a zero-emission IWT fleet by 2050, will depend on the ability to timely overcome the identified gaps and challenges and on the coordination between countries on implementation of regulations and incentives. Here there is a role for both public and private stakeholders to take action in a timely manner.

An adoption of the Fit For 55 proposals, revision of the TEN-T as well as the relatively recent REPowerEU action plan contain actions that can address some of the identified gaps and challenges. Furthermore, there are developments in the market in terms of (pilot) demonstrations with ships on renewable energy and further development by OEM's of technologies. Such initiatives and a further deployment of clean vessels will need to be accelerated in order to create a sizeable demand for clean energy to justify investments in the clean energy infrastructure.

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List of abbreviations

CCNR	Central Commission for the Navigation of the Rhine
DPF	Diesel Particulate Filter
FC	Fuel Cell
GHG	Greenhouse Gas
H2	Hydrogen
H2 ICE	Hydrogen Internal Combustion Engine
H2 FC	Hydrogen Fuel Cell
HVO	Hydrotreated Vegetable Oil
ICE	Internal Combustion Engine
IWT	Inland Waterway Transport
LBM	Liquid Bio Methane (Bio-LNG)
LMG	Liquefied Methane Gas
LNG	Liquefied Natural Gas
MeOH	Methanol
MeOH FC	Methanol Fuel Cell
MeOH ICE	Methanol Internal Combustion Engine
PEM FC	Proton Exchange Membrane Fuel Cell
PM	Particulate Matter
RED	Renewable Energy Directive

1. Introduction

This deliverable provides an assessment about the potential of the wider Rhine region for supporting renewable and clean energy use in the Inland Waterway Transport (IWT) sector. Analyses have been performed on:

- current capacity of sustainable energy production
- ongoing and planned investments and
- promising opportunities not yet exploited

Throughout the analyses, existing literature was identified and reviewed and also in-depth interviews with experts in the field have been carried out.

This deliverable is made up of five main chapters presenting the technical content. First, the IWT fleet characteristics as identified in previous analyses[1] are taken as starting point and a number of clean technologies and different types of energy carriers are identified which are seen as likely for the transition of the IWT fleet towards near zero-emission performance by the year 2050.

These clean alternatives for the current conventional propulsion systems (which mostly run on fossil diesel) clearly will need to be supplied with renewable energy for propulsion power and auxiliary power of the vessels. Hence, secondly, the deliverable dives into the potential upscale of renewable energy production and import in the wider Rhine region.

Thirdly, the relevant energy infrastructure in ports and along waterways is analysed to see whether the current state of the energy infrastructure will be able to facilitate the production, processing and supply of renewable energy to the IWT sector.

Fourthly, it is analysed what the impact of the energy transition will be on the infrastructure. Here it will be reviewed whether the Rhine region will be able to adapt (on time) to changing energy demand and energy carrier types and how it needs to adapt.

The fifth part of the deliverable presents the conclusions about the potential of the Rhine region to produce, import, process and facilitate renewable energy to IWT.

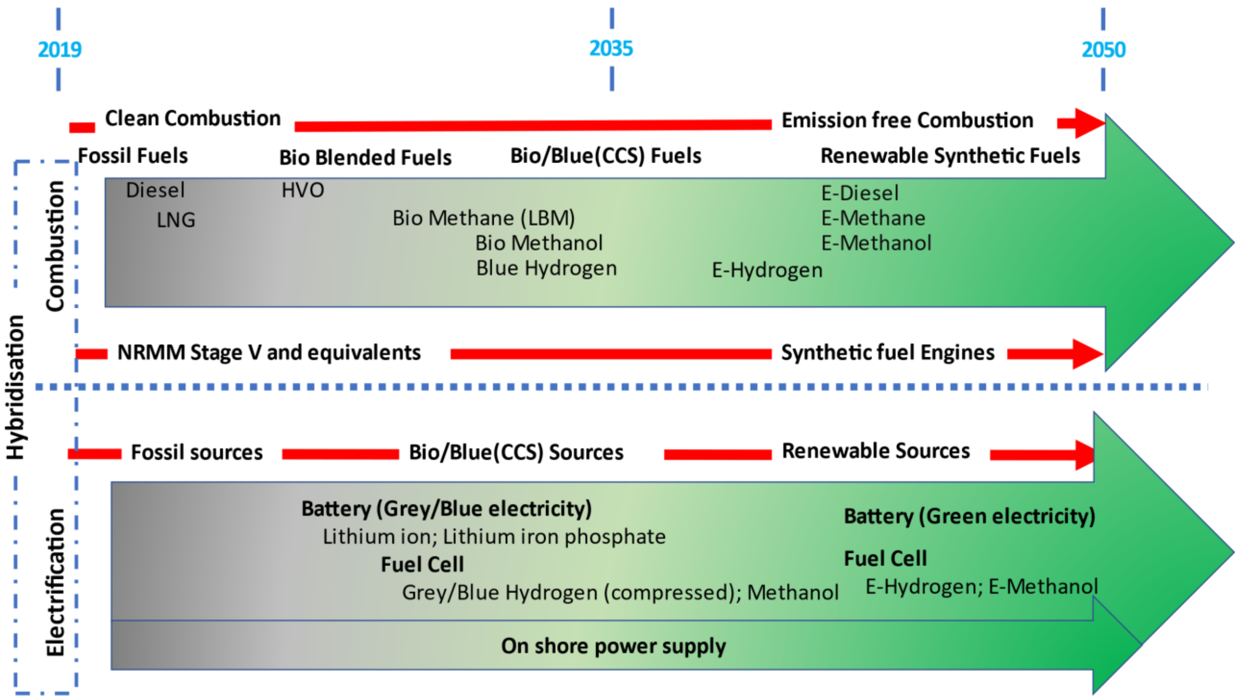
[1] The NEEDS deliverable 3.1 "Categorisation of inland vessel types and operational profiles for inland waterway transport" identified the relevant IWT fleet vessel types and characteristics.

2. Applicability of different energy carriers and solutions

Inland navigation in the Rhine region and far beyond currently uses mainly one type of fuel which is fossil diesel[2]. The energy transition and the goal of largely eliminating air quality and climate change emissions by the year 2050 is a very challenging one for the IWT sector. The Central Commission for the Navigation of the Rhine (CCNR) developed a roadmap for reducing at least 90% of the greenhouse gases (GHG) and air pollutant emissions by the year 2050 compared with the year 2015. This is in line with the European Commission's Green deal for Europe, of December 2019 and its "Smart and Sustainable Mobility Strategy" of December 2020.[3] Since the maturity of most of technologies is not there yet and further developments need to take place, there is a broad set of possible alternatives to fossil diesel currently being considered.

Given the task and the various types of vessels and boating profiles, there is no so-called "silver bullet" (e.g. multiple solutions are needed). Various researchers, policy makers and ship owners are therefore focusing on a rather broad list of possible alternatives to fossil diesel. Given current developments and the state-of-art, Figure 1 below shows some of the most promising and likely feasible solutions in time towards the year 2050.

Figure 1: Alternative technologies and forms of energy towards 2050



Source: TNO&EICB, 2021, study for Provincie Zuid-Holland on the sustainability outlook for inland navigation

Starting with fossil diesel today, there are various intermediate and final solutions possible towards the year 2050. This includes creating hybrid solutions which combine different type of energy carriers and energy convertors on board of a vessel. Depending on technological developments, for

[2] Specifically Diesel under the EN590 specifications, which is a Low Sulfur Diesel.
[3] https://www.ccr-zkr.org/files/documents/Roadmap/Roadmap_en.pdf

example in the field of hydrogen energy carriers and battery technology, this overview may of course change over time with the addition of new energy carriers and technologies and the omission of existing ones, or ones which may not be implemented (e.g. due to too high costs or lack of maturity).

Given the many variations in the inland navigation fleet in terms of types of vessels and sailing profiles, the big challenge is to link all these various technologies and associated energy carrier types to the various types of vessels and sailing profiles. The applicability of a particular power storage and conversions technology (fuel tank or battery, ICE or fuel cells) and the type of primary energy (fuel or electricity) on board a ship depends on many factors. Elements to consider are the physical space available on board, the required energy storage on board for a vessel and the sailing profile, the dynamics of the sailing profile, the price of the hardware and energy, etc.

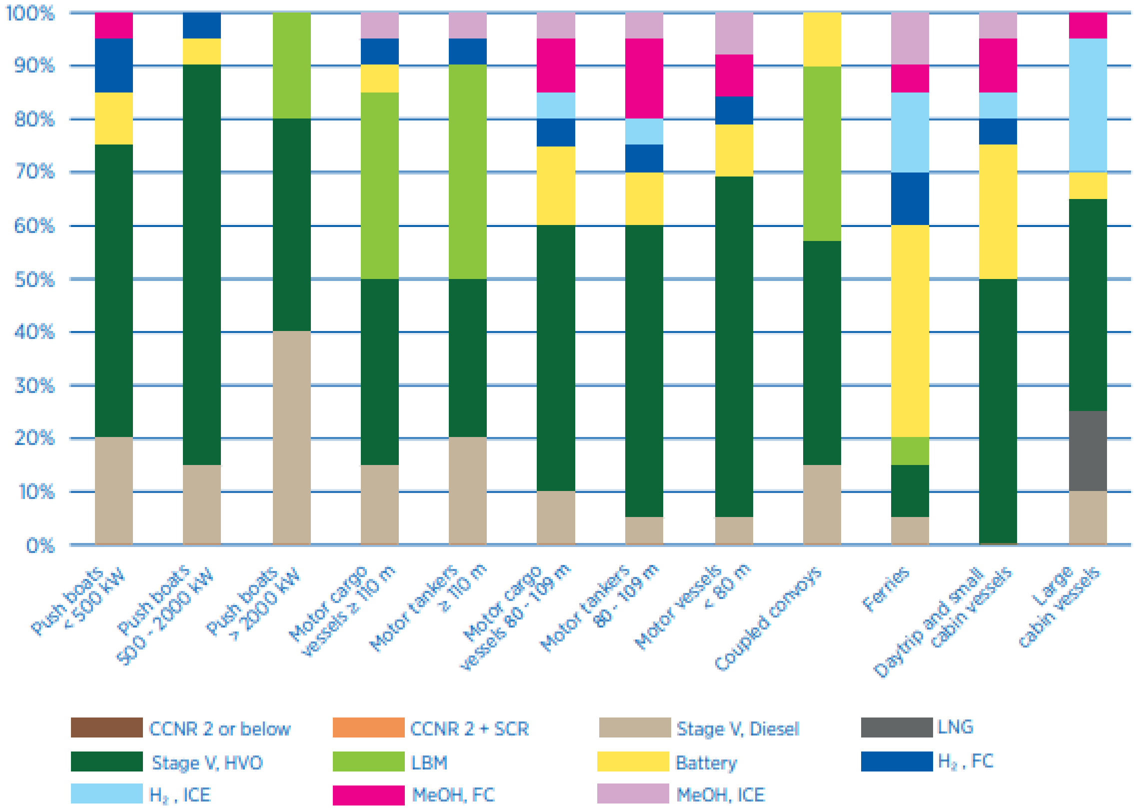
Moreover, given all uncertainties regarding developments in prices and availability, techniques and energy carriers are best allocated to subsegments in the IWT fleet by means of scenario analysis. This analysis was carried out[4] and included by the CCNR for their roadmap for reducing inland navigation emissions.[5] Achieving the 2035 intermediate emission objective and the 2050 target of achieving at least 90% reduction with the identified greening technologies and forms of energy was analysed. Two transition scenarios were developed and applied to make the estimations on the type of technology and energy carrier and the related costs. These two scenarios were called the conservative and innovative scenario. Here the conservative scenario is more aimed on the usage of existing technologies using internal combustion engines and drop-in fuels such as HVO and synthetic diesel (e-diesel). The innovative scenario however does have a stronger focus on the electrification of vessels and the usage of fuel cell technologies (using hydrogen or methanol as energy carrier) and the usage of batteries and electric power from shore.

The distribution of technologies and forms of energy by fleet family for both scenarios is shown in the following two figures:

[4] DST and EICB carried out an assessment of technologies in view of zero-emission IWT in 2021. The results can be found via the following link https://www.ccr-zkr.org/files/documents/EtudesTransEner/Deliverable_RQ_C_Edition2.pdf

[5] https://www.ccr-zkr.org/files/documents/Roadmap/Roadmap_en.pdf

Figure 2: Conservative transition pathway: technology share for each fleet family in 2050



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

In 2050, the conservative transition pathway will enable the following emissions reduction potential to be achieved compared with 2015:

- GHG: -91%
- NOx : -90%
- Particulate matters: -96%

The drop-in fuels HVO for usage in diesel engines and LBM for usage in gas engines, account for a relatively large share of the total, especially in the fleet families with a relatively high installed power. Vessels in those fleet families will be relatively less suitable for alternatives such as batteries.

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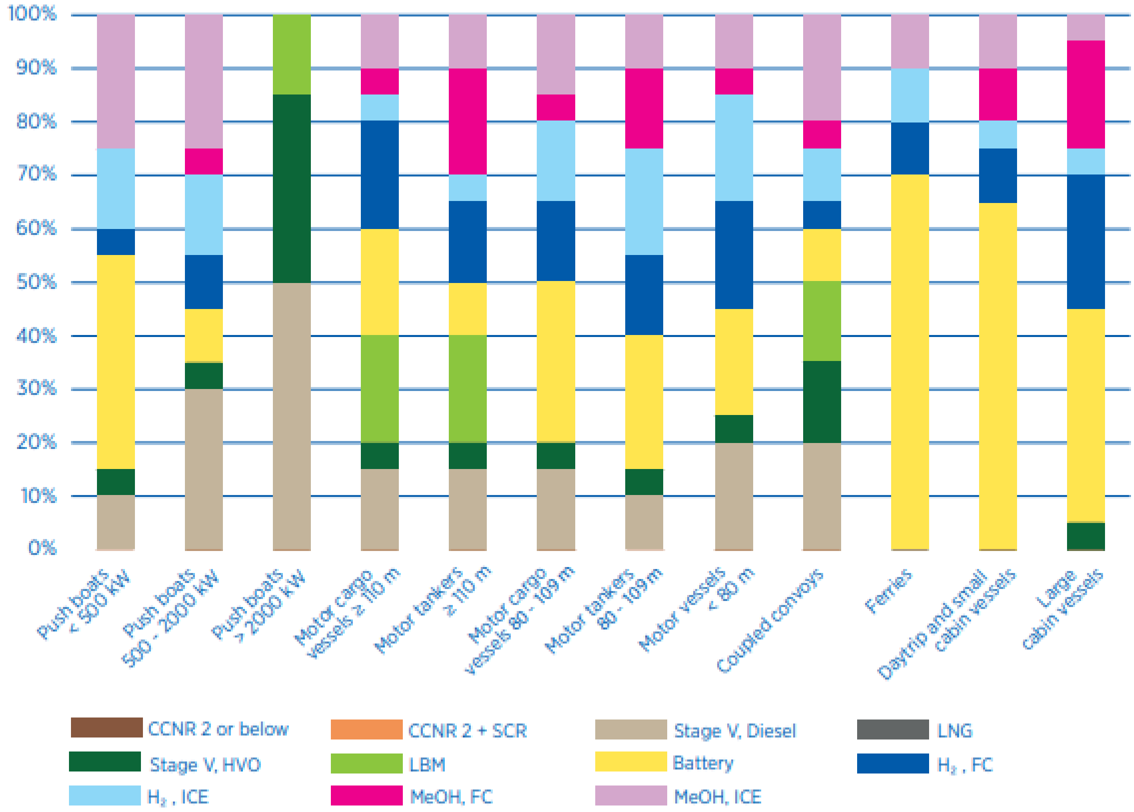
Figure 3: Innovative transition pathway: technology share for each fleet family in 2050



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

In 2050, the innovative transition pathway will enable the following emissions reduction potential compared with the year 2015 to be achieved:

- GHG: -91%
- NOx : -94%
- Particulate matters: -98%

It can be seen from the figure that the share of technologies has shifted both towards battery-electric propulsion and hydrogen (H_2) and methanol (MeOH). All these technologies exhibit a relatively lower TRL level than HVO and LBM. An exception is the fleet family for the largest pusher boats (>2,000 kW). These vessels are characterised by high installed power, their high fuel consumption (highest in the sector on average), and their potentially limited suitability for alternative technologies/fuels. For example, owing to their volume and weight, batteries might be less suitable because of their potentially severe impact on the vessel.

A latest update on this analysis that can be given as a result of expert consultations[6] relates to the application of methanol. The application of green methanol seemed to be a rather pragmatic solution in both the maritime sector as well as IWT. It was also initially deemed that the application

[6] Consultations were held with experts in the field during the final Platina Stage Event in Brussels and with experts involved in the EU Horizon Europe project "SYNERGETICS".

of methanol in IWT could be relatively straightforward compared to, for example, batteries and hydrogen, especially in existing vessels. The required retrofit works were expected to be minimal to retrofit an existing vessel from conventional diesel propulsion to methanol propulsion. However, it now appears that even a methanol drive requires quite a lot of interventions on board an existing vessel (e.g. insulation work on fuel tank, a separate chamber for fuel handling before it goes from the tank to the engine room, etc). In addition, a bottleneck for internal combustion engines using methanol and hydrogen is the Stage V NRMM regulation[7]. At this moment, hydrogen and methanol are not eligible as reference fuels for certification of engines to put them on the market for sales by engine manufacturers. This would first require a full revision of the current NRMM regulation, which is not expected to take effect before 2027/2028. This situation could have a negative impact on the market share of this particular solution to reduce emissions.

However, the effect of this latest information on the global distribution in Figures 2 and 3 cannot yet be estimated. Especially as there is a long time period until the year 2050 and there are also still many other uncertainties attached to the other options, for example, the applicability and economic feasibility of hydrogen and fuel cells. Further RD&I works are needed for many of the solutions, some of them being currently planned in projects such as RH2IWER[8] and SYNERGETICS[9] funded by the Horizon Europe Programme.

Given the current state of knowledge, it can be concluded that the techniques and energy carrier types shown in Figure 1 and in more detail in Figures 2 and 3 can currently be seen as the most feasible applications to meet the 2050 targets on the reduction of climate change and air quality emissions for inland navigation in the Rhine region.

[7] Source: PLATINA 6th Stage Event, presentation Euromot on 23 March 2023. See https://platina3.eu/event/final_stage_event/
[8] More information on RH2IWER: https://cordis.europa.eu/project/id/101101358
[9] More information on SYNERGETICS: https://cordis.europa.eu/project/id/101096809

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3. Potential upscale of renewable energy production

Having identified in the previous chapter the forecasts on the fleet side in terms of possible transition pathways and the technologies and energy carriers that go with them, it is important to identify what the potential is on the production, processing and supply side to meet the expected increase in demand for renewable energy for the energy carriers expected to be applied in IWT towards the year 2050.

In this chapter the focus will be on the potential to upscale the production of renewable energy, assuming that current volumes will not be sufficient for the expected increase in demand by all sectors (transport, industry, etc.). Based on this overview, an attempt will be made to deduce what this might imply for IWT. Indeed, IWT is of relatively small size compared to other transport modes and sectors. The question, therefore, is whether and how the IWT sector can keep up and be provided with renewable energy supplied in the type of energy carrier which could fit the IWT sector.

Renewable energy can either come from advanced biofuels or from green electricity which can be used to develop green hydrogen. Another trend is the possible import of green ammonia[10] from other continents (e.g. produced in countries with an abundance of solar power) which can be turned into green H2 as a base product for production of materials and can be applied as hydrogen as fuel. Examples of advanced biofuels are HVO from sustainable feedstocks such as used cooking oil and algae's, and liquid bio-methane made from residual products and wet manure. Green hydrogen combined with carbon capture from air can be a source to produce e-fuels like e-diesel, e-methane or e-methanol.

Relevant is therefore to see how much green electricity can be produced in Europe and in particular in the Rhine area. In addition it is relevant to see what the plans are for massive imports of energy carriers like green ammonia (NH3) of liquified hydrogen (LH2) from other continents in the world.

First, it is relevant to develop the picture of the current energy mix in the Rhine region. Figure 4 shows the gross available energy in the EU countries in the wider Rhine region.

[10] Importing renewable hydrogen in the form of ammonia is more practical/efficient. Ammonia has a higher volumetric energy density than liquid hydrogen, and so more energy can be transported via ammonia for the same volume than in the form of liquid hydrogen. The latter is also more difficult to store for transport.

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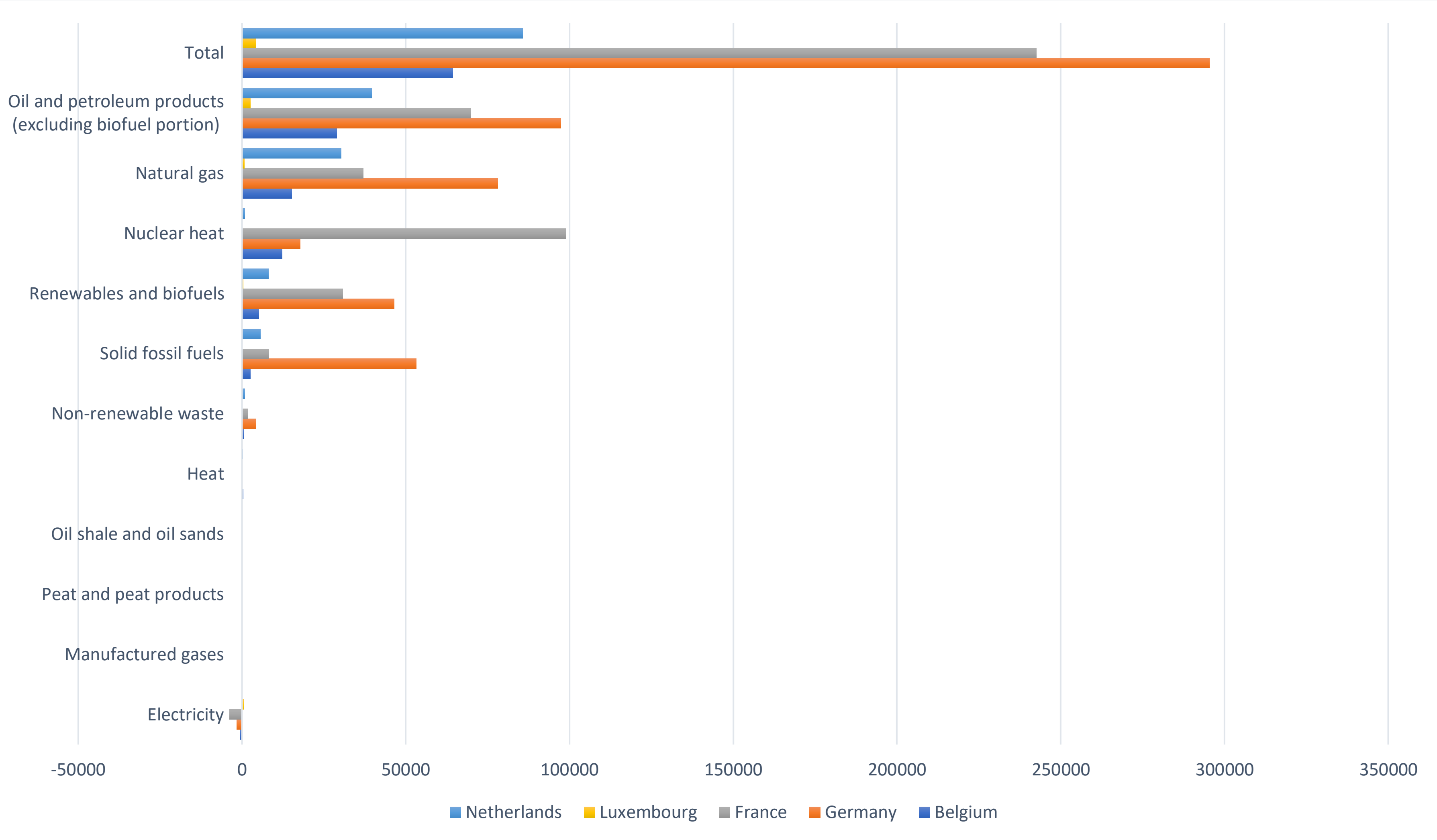
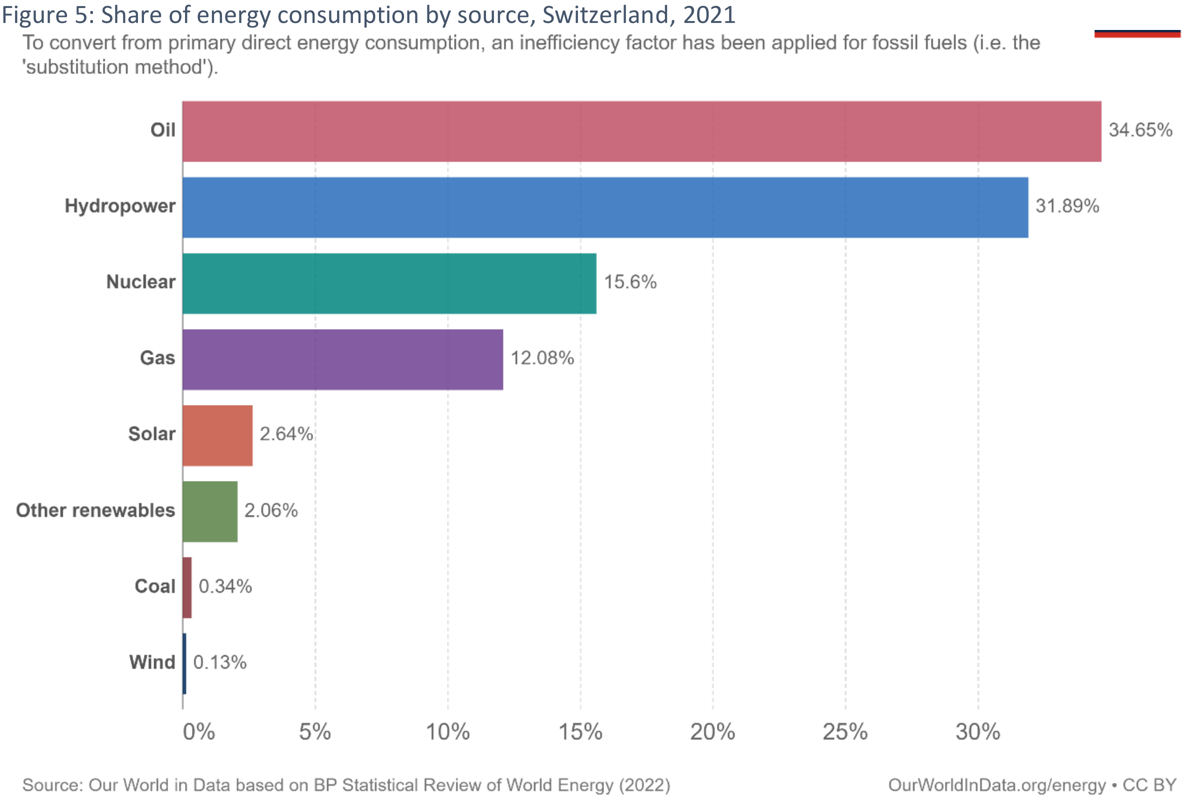
Figure 4: Gross available energy in thousand tonnes of oil equivalent for EU countries in Rhine region in 2021



Source: based on Eurostat data[11]

Gross available energy means the overall supply of energy for all activities on the territory of the country. It includes energy needs for energy transformation, support operations of the energy sector itself, transmission and distribution losses, final energy consumption and the use of fossil fuel products for non-energy purposes. It also includes fuel purchased within the country that is used elsewhere (e.g. international maritime bunkers). For secondary products, which are produced as transformation output in the middle block of energy balances, the Gross available energy can be negative as it reflects only on the trade and stock changes.[12] For Switzerland, the only non-EU country in the Rhine region, figure 5 below provides a concise overview of the energy consumption by source. Approximately 70% of the consumed energy consists of imports, whereas the remaining 30% comes from domestic production.[13]

Figure 5: Share of energy consumption by source, Switzerland, 2021



Source: https://ourworldindata.org/energy/country/switzerland#what-sources-does-the-country-get-its-energy-from

However, it should be mentioned that the energy mix of countries in the Rhine region and beyond has changed significantly in the past year because of the war in Ukraine. Unfortunately, no data is yet available to reflect this as accurately as possible.

Both figures 4 and 5 show that oil and petroleum products, natural gas and solid fossil fuels play an important role in the energy mix of the Rhine countries. Fossil energy plays an important role in the

[12] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Gross_available_energy#:~:text=Gross%20available%20energy%20means%20the,the%20territory%20of%20the%20country.
[13] https://www.eda.admin.ch/aboutswitzerland/en/home/wirtschaft/energie/energie---fakten-und-zahlen.html

gross available energy of the EU. Most of this energy is also imported, and as a matter of fact, the dependence on energy imports in the EU has reached as high as 60% in recent years.[14]

When looking at renewable energy and the potential scale-up of production, we should actually look at both regional production and imports, assuming that not all renewable energy will be produced regionally in the Rhine area. Recent developments in this area also point that there is a commitment to both regional renewable energy production, imports from other EU countries and imports from other continents in the world.

The war in Ukraine and the developments to make the EU independent from Russian (fossil) energy has prompted the EU to work on a new energy plan. Consequently, the EC published the **'REPowerEU'** plan on 18 May 2022.[15]

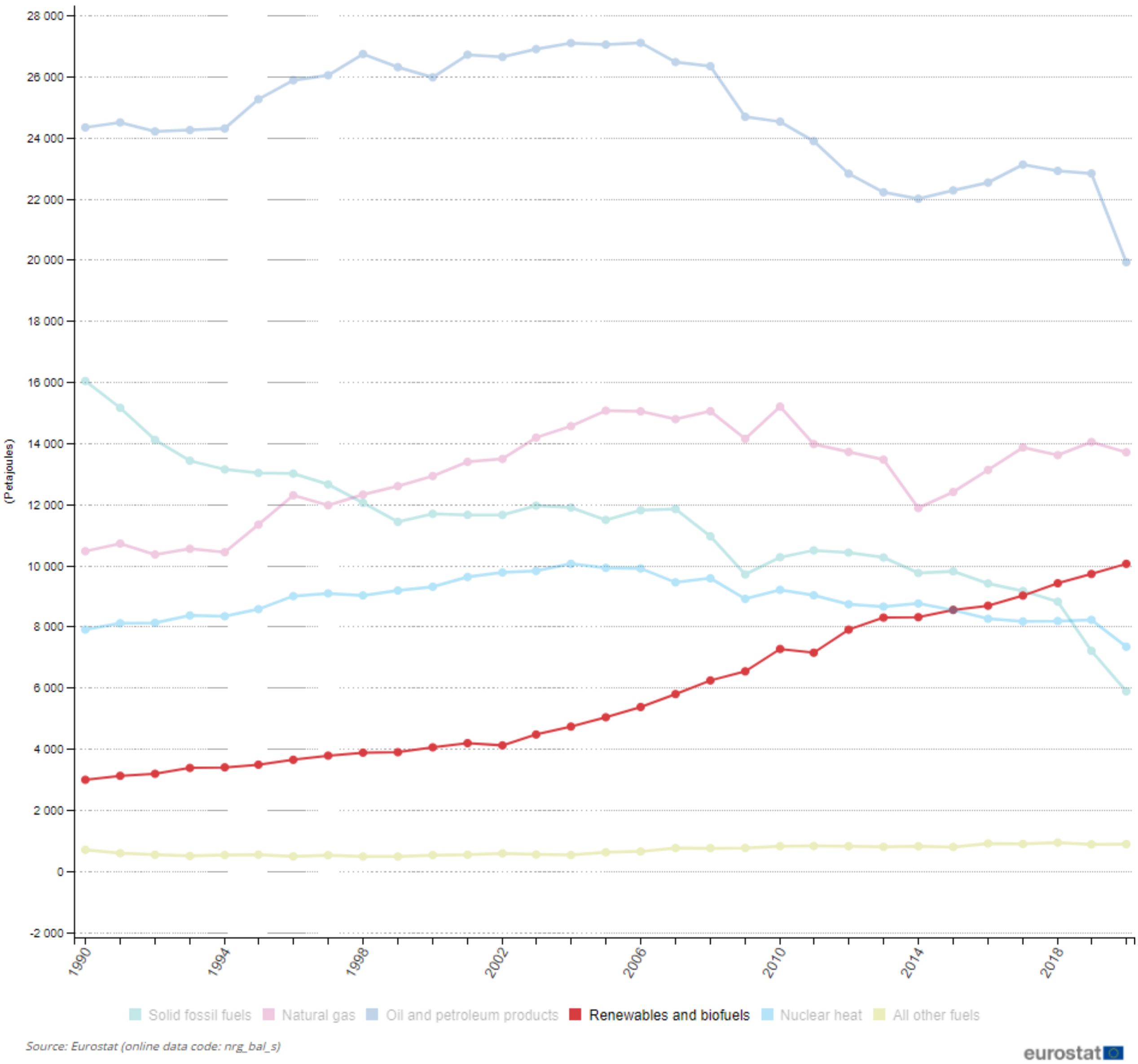
The plan builds on the Fit For 55 package and puts forward an additional set of activities to save energy, diversify supplies, smartly combine investment and reforms and, most importantly for the scope of this study, accelerating the energy transition by substituting fossil fuels.[16] The plan aims a "massive speed-up and scale-up in renewable energy in power generation, industry, buildings and transport". The targets include among others:

- Increase the target in the Renewable Energy Directive (RED) to 45% by 2030, bringing the total renewable energy generation capacities to 1236 GW by 2030.
- 600 GW of **Solar** photovoltaics (PV) by 2030.
- Strengthening supply chains and accelerating permitting to further stimulate the **wind energy** sector.
- 10 million tonnes of domestic **renewable hydrogen** production and 10 million tonnes of renewable hydrogen imports by 2030. The North Sea area, where the Rhine corridor ends in seaport such as Amsterdam, Rotterdam and Antwerp, will be one of the three major hydrogen import corridors for Europe.
- Boosting sustainable **biomethane** production to 35 billion cubic meters (bcm) by 2030.

In anticipation of the implementation of the REPowerEU plan, investments in renewable energy projects have been made for years. Figure 6 provides an overview of the steady increase of renewables and biofuels in the total gross available energy. This share needs to rise much faster in the coming years to meet the intended targets.

[14] https://www.statista.com/topics/9165/energy-import-dependency-in-europe/#topicOverview
[15] https://fsr.eui.eu/first-look-at-repowereu-eu-commission-plan-for-energy-independence-from-russia/
[16] https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF

Figure 6: EU gross available energy 1990-2020



There are currently a large number of sizeable renewable energy projects on the drawing board and under implementation, especially also in the wider Rhine region and its countries. To paint a picture, the following is a brief overview with a sampling of key projects by energy area.

WIND

Europe installed 17 GW (11 GW in the EU-27) of new wind capacity in 2021 and had 236 GW of wind capacity. The countries with the most newly installed capacity were the UK, Sweden, Germany, Turkey and the Netherlands, in this order. The Rhine countries have a good potential for wind energy, as also appears from the large and numerous completed and planned projects in the Netherlands and Germany, either on land or in coastal waters. It is expected that 116 GW of new wind farms will be installed over the period from 2022-2026. A number of important wind projects in the Rhine countries are as follows:

Table 1: Wind projects Rhine countries

Project name	Location	Type	Size
Ijmuiden Ver[17]	Netherlands	Offshore wind	6GW
Hollandse Kust[18]	Netherlands	Offshore wind	~2,28GW
N-7.2 offshore wind[19]	Germany	Offshore wind	980 MW
Fécamp Offshore Wind Project[20]	France	Offshore wind	497 MW
Saint-Brieuc offshore wind farm[21]	France	Offshore wind	496 MW
Baltic Eagle [22]	Germany	Offshore wind	476 MW

Source: own elaboration

Although the rise in new wind power capacity is significant, it will fall short to meet the EU's renewable electricity objective for 2030.[23]

SOLAR

A likely scenario for solar power in the EU expects at least 85 GW of new solar power generation per year by 2026. This means the EU solar market is set to more than double within four years and reach 484 GW by 2026.[24] A number of important solar projects in the Rhine countries are as follows:

Table 2:Solar projects Rhine countries

Project name	Location	Type	Size
Leipzig Witznitz Energy Solar PV Park[25]	Germany	Solar	650 MW
Doellen Solar Power Plant[26]	Germany	Solar	154 MW
HORIZEO[27]	France	Solar	1GW
Gondosolar Solar PV Park[28]	Switzerland	Solar	18MW

[17] https://www.rvo.nl/onderwerpen/windenergie-op-zee/ijmuiden-ver
[18] https://www.rvo.nl/subsidies-financiering/sde/feiten-en-cijfers
[19] https://group.vattenfall.com/press-and-media/pressreleases/2022/vattenfall-awarded-major-wind-power-project-off-the-coast-of-germany
[20] https://www.enbridge.com/projects-and-infrastructure/projects/fecamp-offshore-wind-project
[21] https://www.iberdrola.com/about-us/what-we-do/offshore-wind-energy/saint-brieuc-offshore-wind-farm
[22] https://www.iberdrola.com/about-us/what-we-do/offshore-wind-energy/baltic-eagle-offshore-wind-farm
[23] https://www.iea.org/reports/is-the-european-union-on-track-to-meet-its-repowereu-goals
[24] https://www.solarpowereurope.org/press-releases/new-report-reveals-eu-solar-power-soars-by-almost-50-in-2022
[25] https://www.power-technology.com/marketdata/top-five-construction-projects-europe-solar-energy-q2-2022/
[26] https://www.power-technology.com/marketdata/top-five-construction-projects-europe-solar-energy-q2-2022/
[27] https://en.newsroom.engie.com/assets/pr-horizeo-a-new-stage-pdf-0328-314df.html?dl=1
[28] https://www.alpiq.com/fileadmin/user_upload/documents/publications/gondosolar_media_release_20220207_en.pdf

Zonnepark Musselkanaal[29]	Netherlands	Solar	176MW

Source: own elaboration

The EU wants to make solar power its single biggest source of energy by 2030. This implies that solar power generation should triple over the next seven years.[30] More than half of this energy should come from rooftops.[31]

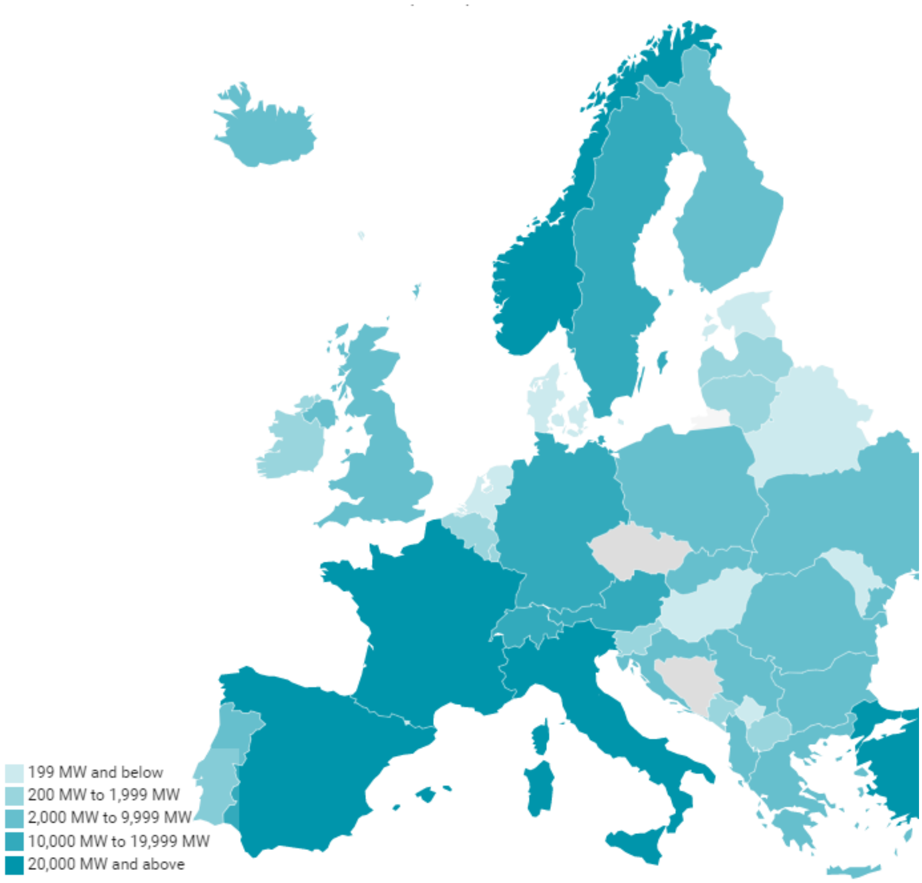
HYDROPOWER

Hydropower is an energy form with a long history in Europe. Nowadays, almost 650 TWh are generated in an average hydrological year, which equates to about 65% of the economically feasible hydropower potential within Europe. Lately, the yearly production of hydropower stabilizes near 650 TWh and the total installed capacity near 230 GW.

In the Rhine countries, France and Switzerland have the largest share of hydropower production. Especially France still has some untapped potential for hydropower.[32] Figure 7 provides an actual overview of the European installed hydro capacity in 2021.

[29] https://www.rvo.nl/subsidies-financiering/sde/feiten-en-cijfers
[30] https://www.ft.com/content/009d8434-9c12-48fd-8c93-d06d0b86779e
[31] https://www.solarpowereurope.org/press-releases/landmark-eu-solar-strategy-solar-power-europe-response
[32] https://hydropower-europe.eu/about-hydropower-europe/hydropower-energy/

Figure 7: Europe installed capacity 2021 (MW)



Source: https://www.hydropower.org/region-profiles/europe

New projects are being planned, the Swiss government has recently identified multiple new potential hydropower sites and opportunities for dam enlargements. This could result in up to 2 TWh additional hydroelectric production.

Norway is by far the largest hydropower in Europe and increased its capacity by 396 MW in 2021. Although Norway is far outside the Rhine region, it is a priority for the Norwegian region to establish electricity links with European countries, e.g. the NordLink to Germany which was commission in 2020.[33]

NUCLEAR

Although not recognised by everyone in the EU, nuclear is seen as relevant to the energy transition and the European Parliament decided to label investments in nuclear energy as green.[34]

Compared to previous forms of energy, the lead times for deciding, building and delivering nuclear capacity are very long and complex. Within the Rhine region, only France currently has new reactors under construction, worth 1650MWe. With again only France currently having new reactors

[33] https://www.hydropower.org/region-profiles/europe

[34] https://www.euractiv.com/section/energy/opinion/eu-decision-to-label-nuclear-green-is-key-to-energy-transition-and-autonomy/

proposed, worth 9900MWe. Furthermore, there are plans for new reactors in five other EU countries worth 7210MWe.[35] Switzerland has 4 reactors in operation with a total MWE of 2973, with no further reactors planned.

Figure 8: Nuclear energy in the EU

COUNTRY (Click name for Country Profile)	NUCLEAR ELECTRICITY GENERATION 2021		REACTORS OPERABLE September 2022		REACTORS UNDER CONSTRUCTION September 2022		REACTORS PLANNED September 2022		REACTORS PROPOSED September 2022		URANIUM REQUIRED 2021
	TWh	% e	No.	MWe net	No.	MWe gross	No.	MWe gross	No.	MWe gross	tonnes U
Belgium	48.0	50.8	5	3928	0	0	0	0	0	0	790
Bulgaria	15.8	34.6	2	2006	0	0	1	1000	3	3000	322
Czech Republic	29.0	36.6	6	4212	0	0	1	1200	3	3600	706
Finland	22.6	32.8	5	4394	0	0	1	1170	0	0	421
France	363.4	69.0	56	61,370	1	1650	0	0	6	9900	8233
Germany	65.4	11.9	3	4055	0	0	0	0	0	0	521
Hungary	15.1	46.8	4	1916	0	0	2	2400	0	0	320
Lithuania	0	0	0	0	0	0	0	0	2	2700	0
Netherlands	3.6	3.1	1	482	0	0	0	0	2	2000	69
Poland	0	0	0	0	0	0	0	0	6	6000	0
Romania	10.4	18.5	2	1300	0	0	2	1440	1	720	185
Slovakia	14.6	52.3	5	2308	1	471	0	0	1	1200	359
Slovenia	5.4	36.9	1	688	0	0	0	0	1	1000	127
Spain	54.2	20.8	7	7123	0	0	0	0	0	0	1221
Sweden	51.4	30.8	6	6885	0	0	0	0	0	0	914
EU Total	**698.9**	**c 29.7**	**103**	**100,667**	2	**2121**	**7**	**7210**	25	30,120	**14,188**

Source: https://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx

With the adoption of two Delegated Acts required under the RED, the EC proposed detailed rules to define what constitutes renewable hydrogen in the EU.[36] This includes rules under which hydrogen produced with nuclear energy is to be considered green in a wider sense. To be specific, hydrogen produced with electricity coming from nuclear energy is to be allowed, but naming it rather "low-carbon" instead of "green".[37] This creates possibilities for using "low-carbon" hydrogen fuel in the transport sector.

[35] https://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx
[36] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_594
[37] https://www.euronews.com/my-europe/2023/02/13/nuclear-energy-included-in-eus-new-rules-on-green-hydrogen

GEOTHERMAL

Geothermal energy is another source of clean energy Europe is betting on to realise the 2050 zero-emission ambition. It is a generally abundant, ubiquitous, versatile, low-carbon, and non-intermittent source of energy.

Geothermal energy has two main applications, i.e. power and heat production. In 2019, there were 130 geothermal electricity plants in operation in Europe. There were 36 projects under development and 124 projects in the planning phase for a total 3.3 GWe capacity. In terms of geothermal heating and cooling systems, in 2019 there were 5.5 GWth of installed capacity in 25 European countries with many new projects planned.[38]

The use of geothermal energy is expected to grow in the coming decades. For power production, geothermal power could grow to around 100–210 TWh/yr in 2050. For heat production there could be a rise to about 880–1050 TWh/yr in 2050. By 2050, geothermal energy plants could contribute approximately with 4% up to 7% to European electricity generation.[39]

In Europe, it is Iceland, Turkey and Italy, respectively, that use geothermal energy the most for power generation. Those three countries have substantial shares of geothermal power in the national electricity mix. As regards heat, shallow geothermal energy is used in virtually all European countries. Deep geothermal energy is concentrated, a.o. in the Rhine countries France and Germany. There are recent developments in Belgium and the Netherlands which are encouraging for increased use of geothermal energy.[40]

BIOENERGY

Biomass, biogas, liquid biofuels and renewable waste form together bioenergy and make up an important part of total renewable energy in the EU (around 60%[41]). The share of bioenergy in EU's gross final energy consumption increased in the period 2005-2017 from 5.9% to 10.3%. By 2017, biomass installed capacity in the EU almost tripled in comparison with 2005, reaching 32 GW. Figure 9 provides an overview of the progress.

[38] https://www.egec.org/the-geothermal-energy-market-grows-exponentially-but-needs-the-right-market-conditions-to-thrive/#:~:text=At%20the%20end%20of%202019,the%20next%205%2D8%20years.
[39] https://www.sciencedirect.com/science/article/pii/S0360544220311671
[40] http://europeangeothermalcongress.eu/wp-content/uploads/2019/07/CUR-00-Summary-Europe.pdf
[41] https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_EU28_final.pdf

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

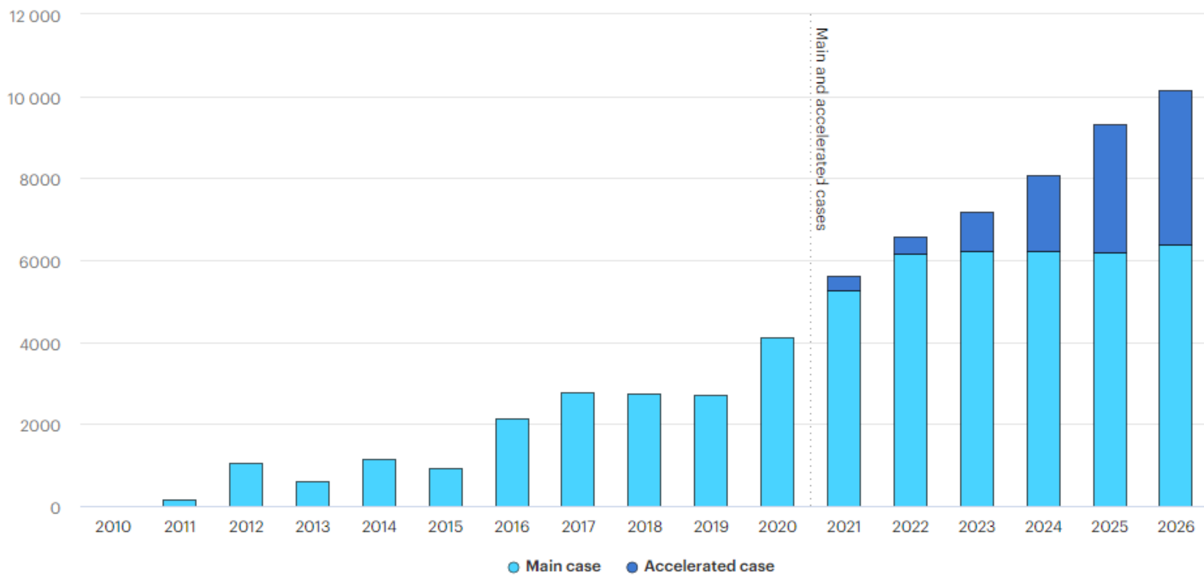
Figure 9: Progress of bioenergy in the EU (2005-2017) and the 2020 plans

	2005	2010	2011	2012	2013	2014	2015	2016	2017	2020
Bioelectricity	6 000	10 669	11 471	12 812	13 571	14 417	15 353	15 612	15 985	20 052
- Solid biomass-el	4 743	7 476	7 891	8 456	8 570	9 014	9 609	9 713	10 041	13 462
- Biogas-el	1 105	2 766	3 295	4 045	4 633	4 986	5 270	5 443	5 515	5 497
- Bioliquids-el	152	428	285	312	368	417	474	456	429	1 096
Bioheat	**62 612**	**80 805**	**75 604**	**82 450**	**85 418**	**80 668**	**84 181**	**86 594**	**88 585**	**90 411**
Solid biomass-th	61 700	78 595	73 281	80 133	82 712	77 602	80 810	82 784	84 431	80 887
Biogas-th	743	1578	2122	2097	2490	2821	3124	3580	3909	4 526
Bioliquids-th	168	631	200	218	213	238	240	223	237	4 998
Biofuels	**3 277**	**13 184**	**10 890**	**11 163**	**11 418**	**12 453**	**13 093**	**14 081**	**15 192**	**29 054**
Bioethanol	594	2 809	2 493	2 314	2 250	2 155	2 535	2 727	2 859	7 324
Biodiesel	2 683	10 347	8 319	8 743	9 043	10 168	10 425	11 216	12 174	20 983
Total Bioenergy	**71 889**	**104 658**	**97 966**	**106 425**	**110 407**	**107 538**	**112 628**	**116 287**	**119763**	**139 516**

Source: https://www.sciencedirect.com/science/article/pii/S0301421519302873

For IWT, especially the rise in biodiesel, and to a far lesser extent biogas (biomethane), is relevant. Liquid biofuels are on the rise, particularly as transport fuel. In the EU this is especially true for Sweden, where the use of liquid biofuels is already equivalent to more than 15% of fossil oil use (for transport and heat production).[42] The consumption of renewable diesel is expected to significantly increase in Europe as shown in figure 10. The consumption of biodiesel is expected to slightly increase or even stabilise as shown in figure 11.

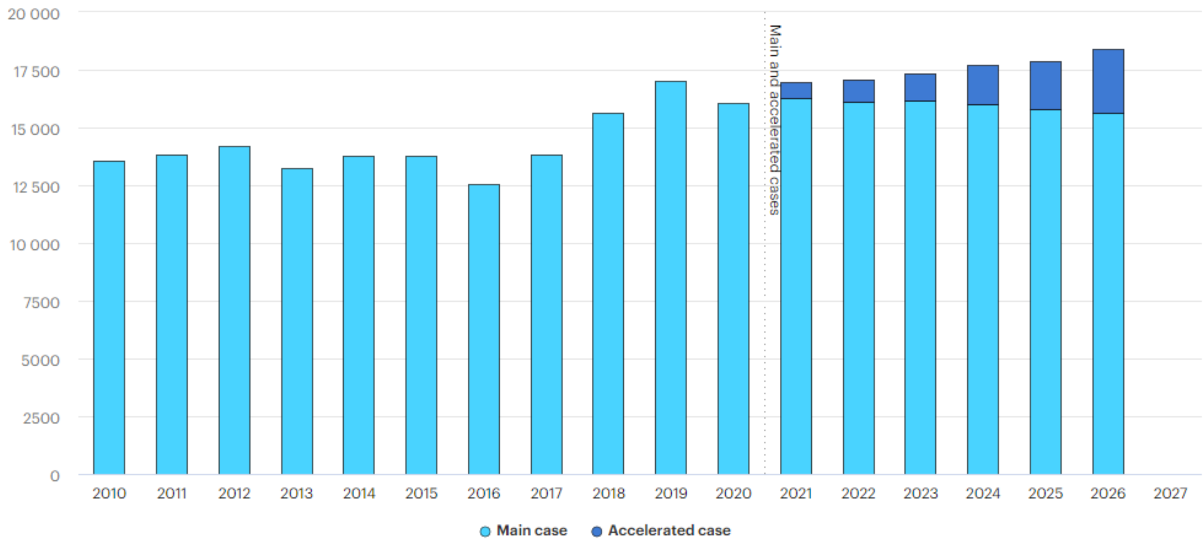
Figure 10: Renewable diesel consumption, Europe, 2010-2026 (M litres/year)



Source: https://www.iea.org/reports/renewables-2021/biofuels

[42] https://www.ieabioenergy.com/blog/publications/iea-bioenergy-countries-report-update-2021/

Figure 11: Biodiesel consumption, Europe, 2010-2026 (M litres/year)



Source: https://www.iea.org/reports/renewables-2021/biofuels

Major projects have been announced for additional renewable fuel production capacity in the main bunkering city for IWT, being Rotterdam. These include the projects by Neste and Shell to add 1.3 million tonnes annually to production capacity and to produce 820,000 tonnes annually, respectively.[43] But these facilities will mainly produce fuel for aviation.

In all likelihood, regional production of biodiesel and renewable diesel will not be able to keep up with the increase in demand and imports will have to be made.

OTHER FORMS OF SECONDARY ENERGY

In addition to renewable diesel, large projects have also been announced for the production of other forms of secondary energy, such as renewable hydrogen and methanol.

The Important Project of Common European Interest (IPCEI) Hydrogen includes the most important European H2 projects. The first set of clean hydrogen projects (IPCEI Hy2Tech) received approval in July 2022. These 41 projects across 15 EU countries will receive up to €5.4 billion in public funding, unlocking an additional €8.8 billion in private investments. The second group of clean hydrogen projects (IPCEI Hy2Use) received approval from the EC in September 2022. These 35 projects in 13 EU countries will receive up to €5.2 billion in public funding, and expected an additional €7 billion in private investments. Hy2Tech focuses on end-users in the mobility sector whereas Hy2use focuses on the hydrogen-related infrastructure and hydrogen applications in the industrial sector.

Examples of specific and major projects are Hydeal ambition, NorthH2 and Aquaventus.

[43] https://www.shell.com/media/news-and-media-releases/2021/shell-to-build-one-of-europes-biggest-biofuels-facilities.html & https://www.neste.com/releases-and-news/renewable-solutions/neste-invests-its-world-scale-renewable-products-refinery-rotterdam

HyDeal Ambition aims at producing 3.6 Mt of green hydrogen in 2030 with 95 GW of solar and 67 GW of electrolyzer capacity, in an integrated upstream, midstream and downstream system spanning from Spain to France and Germany. It has been ranked by the International Renewable Energy Agency (IRENA) in a January 2022 report as the world's largest green hydrogen project.[44]

NortH2 is investigating how a large-scale supply of hydrogen can be realised from wind energy and electrolysis. The aim is to be able to supply industry with 4 GW of green hydrogen by 2030, and grow to more than 10 GW by 2040, which is about 750,000 tonnes of green hydrogen a year.[45]

Aquaventus targets 10 gigawatts of green hydrogen generation capacity from offshore wind in the North Sea by 2035 plus transport ashore. This should translate into a production of 1 million tonnes of green hydrogen.[46]

For green methanol production, projects are also underway and announced to add additional capacity. In the Rhine region, Germany and the Netherlands are leading in terms of the number of renewable methanol projects with 8 and 5 projects, respectively. In Europe, most projects can be found in Denmark, being 11 in total.

In addition to the growing number of renewable methanol projects, there is a clear trend showing an increase in the (expected) sale of renewable methanol. Considering both advancements in the technology development and public support, the capacity of individual production plants for renewable methanol is expected to rise from 5,000-10,000 metric tons of methanol per year to 50,000-250,000 metric tons per year or more over the next five years.[47]

One particular example of a large project is the e-Methanol production facility, commissioned by European Energy, in Kassø/Denmark. It will be the world's largest e-Methanol production facility. The project is engineered to provide offtake to shipping company Maersk and others. It must be noted though, that the production of renewable methanol is being dwarfed by a growing demand that runs well into the gigawatts.[48]

NEED FOR IMPORT OF RENEWABLE ENERGY

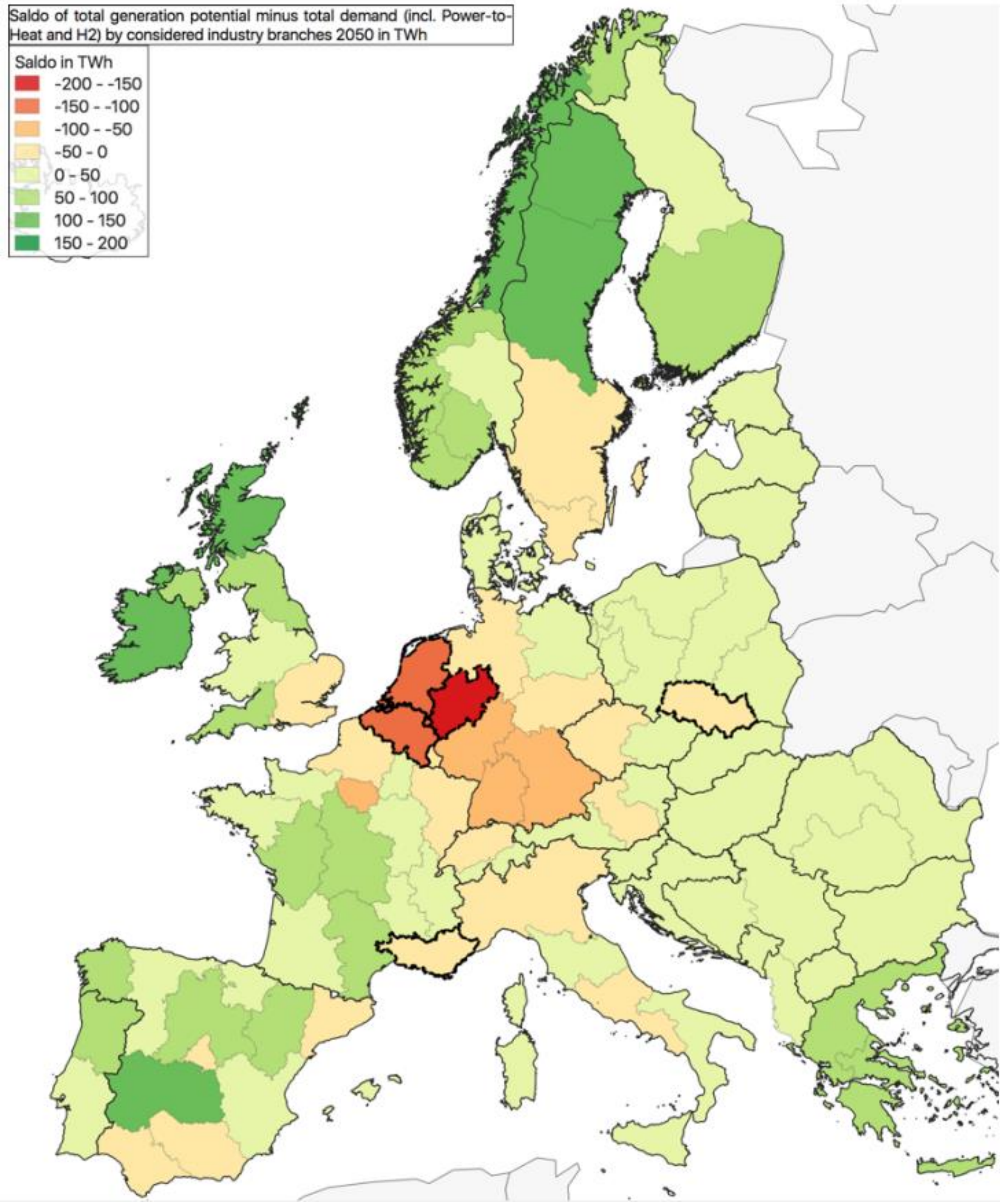
The previous paragraphs show that many projects are underway and announced for production capacity of primary and secondary renewable energy in the EU and especially the Rhine countries.

However, the (expected) demand for renewable energy will also have to increase exponentially, especially in view of the energy transition targets of the EC and national governments in the Rhine region. It is therefore expected that the EU cannot be self-sufficient, as is currently the case in fossil energy. Regionally, this is especially true for the Rhine region, given all the heavy logistic and

[44] https://www.hydeal.com/hydeal-ambition
[45] https://www.north2.eu/
[46] https://aquaventus.org/en/
[47] https://www.methanol.org/renewable/
[48] https://www.siemens-energy.com/global/en/news/magazine/2022/zero-emission-fuel-ramps-up-for-shipping.html

industrial activities there. To paint a picture, Figure 12 shows the regional distribution of the balance between maximum potential electricity generation and total electricity demand.

Figure 12: Regional distribution of the balance between maximum potential electricity generation and total electricity demand in TWh_{el} after -"NP" and (e-Highway 2050, 2014)-X7



Source: https://epub.wupperinst.org/frontdoor/deliver/index/docId/7594/file/7594_Merten.pdf

Although the total electricity mix is different from the total energy mix, it does give a good representation of the relative heavy imbalance between the generation potential and demand in the wider Rhine area as compared to other regions in Europe. Depending on the exact future demand for renewable energy, imports to the Rhine area from other regions and continents are already expected to be needed.

These imports need to be facilitated by existing and new infrastructure. There is a real "battle for hydrogen"[49] going on to supply Northwest Europe with green hydrogen. Several ports in the Hamburg-Le Havre range already have plans to become major hydrogen hubs.

The port of Rotterdam is the most important seaport for IWT in terms of cargo throughput and at the same time the main bunkering hub for inland vessels.[50,51] It is the fossil fuel leader of Northwest Europe, however, the port is also committed to greening and has a comprehensive plan to become a hydrogen hub. The ambition is to switch to a whole new hydrogen system to position the port industrial cluster of Rotterdam as hub for import, production and distribution of (green) hydrogen, and accelerate the development of the hydrogen economy in Rotterdam and Northwest Europe. This should be seen as a long-term transition that takes a programme-based approach and consists of many individual, yet related, projects and initiatives. This includes plans for the import of green hydrogen through new terminals.[52,53] It is estimated that the amount of green hydrogen coming in through Rotterdam in 2050 could rise to 18 million tons, and already 4.6 million annually by 2030.

In addition to Rotterdam, ports of Antwerp-Bruges, Hamburg and Amsterdam also have plans to become major hydrogen hubs, in which importing hydrogen is an important element. Port of Antwerp, for example, will import green hydrogen from countries such as Chile, Oman, Namibia, Egypt or Brazil, and expects the first imports in 2026.[54] Accordingly, other ports in the region also have plans for large-scale import of green hydrogen.

Green ammonia can be used as a carrier to import green hydrogen. For example, port of Antwerp-Bruges eyes an open-access (green) ammonia import terminal.[55] This also applies to the port of Rotterdam.[56] The ambition to import other forms of renewable energy also applies, although this seems to be in different levels of ambition compared to the hydrogen ambition. Interviews with representatives from both the port authority of Rotterdam and Antwerp-Bruges[57] show that both ports envisage a major role in import, storage, distribution and use (by the industry present in the port area) of renewable energy. This also includes green electricity from wind farms whose cables come ashore in the port area.

It should be mentioned that currently a lot of projects are ready to start. But they are still awaiting customers. When purchase contracts are concluded, then the projects will start.

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49 https://drift.eur.nl/app/uploads/2020/06/KSD_DRIFT_HavenbedrijfRotterdam_vDEF_lores.pdf
50 https://inland-navigation-market.org/chapitre/4-overslag-van-goederen-in-havens/?lang=nl#:~:text=In%202018%20werden%20in%20Rotterdam,van%20Rotterdam%2C%20jaarverslag%202018).
51 https://platina3.eu/clean-energy-infrastructure/
52 https://www.portofrotterdam.com/en/port-future/energy-transition/a-new-energy-system
53 https://www.portofrotterdam.com/en/port-future/energy-transition/ongoing-projects/hydrogen-rotterdam/import-of-hydrogen
54 https://www.portofantwerpbruges.com/en/our-port/climate-and-energy-transition/hydrogen
55 https://www.offshore-energy.biz/partners-eye-open-access-green-ammonia-import-terminal-at-port-of-antwerp-bruges/
56 https://www.portofrotterdam.com/en/news-and-press-releases/oci-expands-import-terminal-for-green-ammonia
57 Interviews were conducted with representatives from the Port authorities of Rotterdam and Antwerp-Bruges on 17th of April and 20th of April, respectively.

CLEAN ENERGY FOR IWT

Given the developments in the production and import of primary and secondary clean energy, the actual question with this is to what extent these forms of energy can be shaped into forms of energy that can be applied to power inland vessels and whether there can be sufficient supply for the IWT sector, or will other sectors such as heavy industry and aviation be prioritised by market dynamics. While energy demand from the IWT sector, as part of the overall transport and mobility sector[58] at an EU level, is marginal with a share of 2-3% in the total energy demand,[59] in the Rhine region this share will be slightly higher, since in the Netherlands this share is 7-8%, but overall it will still be a minor share in the total energy demand of the overall transport and mobility sector.

Eventually, renewable energy will also find its way to IWT, just as is happening today with fossil fuels. However, competition from other sectors and a limited supply of renewable energy, will cause relatively high prices especially in the run-up phase towards 2050, i.e. in the coming years. In such situation, it stands to reason that the IWT sector may experience difficulties in obtaining renewable energy in a dynamic market. Reasons for this are the lack of incentives, the relatively small size of the IWT sector as compared to other transport modes and non-transport energy demanding sectors, and its fragmented structure. Large sectors and the ones under ETS will need large volumes and might be more willing to pay.

But eventually there might also be synergies that can be of help. In large industrial complexes such as port areas, synergies can emerge between various sectors such as heavy industry, maritime shipping and IWT in terms of off-take of renewable energy.

Developments in local and regional production of renewable energy will be of less relevance for IWT. It is expected that this energy will be mainly designated for local and regional usage, by the local community, for example. Regional and local production of renewable energy will not be of the same order as the foreseen significant import volumes.

Asked what the biggest challenges are to channelling enough renewable energy to inland shipping, the interviewees from Port of Rotterdam and Port of Antwerp-Bruges see mainly two challenges:

- The missing demand for renewable energy is a problem. Whereas in maritime shipping, large orders are already being placed for ships to run on renewable energy, such as methanol-powered ships, the same development is not seen in the IWT sector.
- The current state of the energy infrastructure for IWT is also a challenge, since it does not enable bringing alternative energy on board of inland vessels. Here, an example can be taken from projects like Condor[60]. This is a project involving parties from the entire supply chain. The aim is also to create an open hydrogen market to enjoy standardisation and

[58] Consisting of aviation, deep sea shipping, short sea shipping, IWT, long haul trucks, distribution trucks, vans, passenger transport and other.

[59] Presentation: "TRANSITION PATHWAYS FOR ALTERNATIVE ENERGY FOR IWT" during PLATINA3 Stage 1 event, by Ruud Verbeek on 07-04-2021.

[60] https://www.schuttevaer.nl/nieuws/actueel/2023/03/31/project-condor-volgt-het-voorbeeld-van-zes-50-waterstofschepen-binnen-10-jaar/

economies of scale. In Condor, the concept is to build a pool of tank containers that can be exchanged between hydrogen suppliers.

The supply side is not being seen as a problem on the long term. Although there may be some challenges in the lead-up phase towards 2050 with making renewable energy available to the IWT sector, it is expected that further towards 2050 this problem will be remedied, provided the demand side to renewable energy from the fleet also develops sufficiently. Hence, the two abovementioned challenges should be addressed to overcome the hurdles towards zero-emission IWT by 2050. The infrastructure related challenges will be touched upon in more detail in the next chapter.

4. Energy infrastructure IWT

The previous chapter illustrated that major seaports already prepare and implement plans for large-scale import, production, storage and distribution of renewable energy. Good examples of this in the wider Rhine area include the ports of Rotterdam and Antwerp, currently also the largest bunkering ports for inland navigation in the wider Rhine area. Both ports have large plans for e.g. importing green hydrogen, producing renewable diesel, etc. To this end, the necessary infrastructure such as terminals and pipelines is also being worked on.

However, to bring this renewable energy on board of vessels, there will also be a need for new and/or adapted energy infrastructure for IWT. This includes bunkering stations and bunkering vessels for new types of liquid energy, battery (fast) charging points and locations for swapping energy containers containing H2 or batteries. And it cannot be excluded that in the further future, facilities to bunker gaseous fuels such as gaseous hydrogen might also have a market demand.

The current energy infrastructure used by IWT for the propulsion of vessels consists largely of the bunkering infrastructure for fossil diesel/gasoil and in much smaller quantities of bio- or renewable diesel (FAME or HVO), Gas-to-liquids (GTL) and LNG. To note here is that LNG is not supplied by the conventional bunkering infrastructure, i.e. the existing bunkering stations and bunkering boats. Bunkering of LNG is mainly done by truck-to-ship service by dedicated LNG suppliers on designated quays, while there is currently only one permanent land based bunkering station for LNG in operation in Cologne, Germany.

The Netherlands, and in particular the Rotterdam region, is the main bunkering hub for IWT in Europe.[61] The reason for this is the high transport intensity of inland vessels in the Rotterdam area and also the low price of oil and related diesel fuel in the Rotterdam area because the large oil refinery plants are based in Rotterdam as well (resulting in low logistic costs). The bunkering volumes are significantly smaller in other regions across Europe. The bunkered fuel predominantly consists of fossil diesel. In the Netherlands approximately 65% of the fuel is delivered by bunkering boat (ship-to-ship) where the remaining 35% is bunkered at a bunker station (station-to-ship). There are approximately 100 bunker boats and 25 bunker stations on pontoons with a shop. Diesel deliveries by truck (truck-to-ship) are practically not happening. In Belgium and Germany bunkering boats have by far the largest share in the delivered amount of fuel.[62]

Bunkering stations and bunkering boats, i.e. station-to-ship and ship-to-ship are the two dominant bunkering methods for IWT. Bunkering stations are usually pontoons on the water including a shop similar to the ones at a road service station. A bunker station often also operates bunker boats and provides ship-to-ship bunkering services. A bunker station such as the Heijmen bunker station in Millingen[63] has a storage capacity of 2000m³. Depending on the stored amount, the fuel can be

[61] CDNI provides official data concerning bunkering quantities in CCNR Member States. This information can be obtained through the following website https://www.cdni-iwt.org/dashboard/?lang=en
[62] Based on expert consultation
[63] https://heijmen.nl/bunkerstation-millingen-aan-de-rijn/

divided in several tanks. For example, the Reinplus Fiwado bunker station in Zwijndrecht[64] provides 10 ppm and 1000 ppm[65] diesel/gasoil and GTL of which the storage is divided into several tanks. However, the existing installation of a bunker station does not generally lend itself to supplying multiple and very different types of fuel.[66]
Bunker boats are usually 38m long and carry diesel, lubrication oil and water. E.g. a typical IWT bunker boat such as “Zwaantje 2”[67] carries 180m³ diesel.

LNG is not being provided by the traditional bunkering infrastructure that provides (bio)diesel and GTL. LNG deliveries are mainly done through truck-to-ship operations. There are bunkering vessels providing LNG, like the ones from the company Titan[68], but these usually don’t deliver to inland vessels due to the limited demand from inland vessels as compared to seagoing vessels. Furthermore, there is a fixed LNG bunker station in Cologne delivering to inland vessels.

Thus, the current infrastructure relies mainly on liquid fossil diesel which alternatives such as GTL and biodiesel can also use, albeit in much smaller quantities. As for other alternative forms of energy and propulsion technologies such as batteries, hydrogen and methanol, there has been a piecemeal movement in the market and on the infrastructure side in hardware and regulation.

A pilot demonstration has been performed with a compact bunkering station for methanol in the EU-funded Horizon2020 Fastwater project. Although fossil methanol may be available at over 100 ports across the globe[69], there are no dedicated operational bunkering facilities for IWT in the Rhine region. The same situation applies to Hydrogen fuel. Experiences have been gathered with bunkering hydrogen in the Netherlands, such as with the canal boat Nemo H2 in Amsterdam, watertaxi MSTX22 in Rotterdam and the Windcat Workboats in IJmuiden.[70] The canal boat is not operational and experienced problems with bunkering hydrogen due to the lack of necessary permits. Hydrogen for the watertaxi is being transported by truck from Amsterdam to Rotterdam. However, the watertaxi will only be included in Watertaxi Rotterdam's service schedule as soon as hydrogen can be bunkered in the Port of Rotterdam.[71] The Windcat Workboat is being used in a pilot out of the Port of IJmuiden to deliver crew to offshore windfarms while running on hydrogen. Windcat, the municipality and other relevant partners have done joint research for the necessities to obtain the permit. However, just as with methanol, there are currently no dedicated hydrogen bunkering solutions for IWT in the Rhine region. This can also be explained by the lack of demand and the lack of regulation for hydrogen and methanol as fuel for IWT and the certification of engines (Stage V). This would need to be resolved first as well as creating much stronger incentives or obligations to create a level playing field for the usage of renewable fuels in comparison with the usage of fossil

[64] https://www.reinplusfiwado.com/nl/bunkerlocaties/zwijndrecht/
[65] PPM representing the amount of Sulfur present in diesels.
[66] Sometimes for simple reasons, because only one type of fuel is supplied or there is only one pipe system.
[67] https://www.slurink.nl/netwerk/dordrecht/
[68] https://titan-cleanfuels.com/
[69] https://www.fastwater.eu/images/fastwater/news/FASTWATER_D71.pdf
[70] https://www.parool.nl/nieuws/boot-lovers-van-2-miljoen-ligt-stil-te-verouderen~b8fc9d23/?referrer=https%3A%2F%2Fwww.google.com%2F / https://www.schuttevaer.nl/nieuws/actueel/2022/08/23/wethouder-zeegers-doopt-30-augustus-eerste-waterstof-watertaxi-rotterdam/ / https://www.portofamsterdam.com/nl/nieuws/eerste-waterstof-bunkervergunning-van-nederland
[71] https://www.watertaxirotterdam.nl/nieuws/artikel/rotterdamse-primeur-de-eerste-watertaxi-op-waterstof

diesel. If there is no market demand, there is no economic basis to develop bunkering facilities either. Moreover, it also appears that obtaining permitting for hydrogen bunkering is not always that straightforward.[72]

An example with hydrogen bunkering in Germany had a similar outcome as those in the Netherlands, but because of other problems. FCS (Fuell Cell Schiff) Alsterswasser was in operation between 2008 and 2013. The 26-meter-long vessel built in 2007 was the first commercially used passenger vessel powered by fuel cells through Hydrogen. The Alsterswasser used Fuell Cells in combination with a 300-600 kW electric motor. For at least two seasons the vessel was in full operation in Hamburg. However, in 2013 operations had to stop because the bunker station that serviced the vessel had to close down. The bunkering station was built under EU funding, but after that project ended no business case could be found to keep it in operation. The owner of the station mentioned as reason that his only customer was the Alsterswasser, a vessel that only needed bunkering every three days[73]. Although the owner and operator of the Alsterswasser were very willing to continue hydrogen operations, a new location to bunker hydrogen was apparently not found. The vessel seems to have been out of operation ever since[74]. Technically the proof that hydrogen works, the Alsterswasser also proved the economic difficulties of taking up alternative fuels.

As regards electricity supply, and in contrary to the maritime sector, the use of Onshore Power Supply (OPS) is more mature in the IWT sector. Especially in the Rhine region as compared to the rest of Europe, there is a high concentration of OPS points. For example, there are approximately 2,500 up to 3,250 public berths in the Netherlands for IWT and around 1,000 of them are equipped with shore power. The port of Rotterdam has some 480 points.[75] These numbers will increase even more in the coming years, also pushed by the proposed AFIR[76] and TEN-T revision and national/local ambitions. The proposed AFIR sets the objective of at least one OPS per inland port. There also ongoing initiatives in the region to further roll-out the OPS infrastructure.[77] However, it should be noted that the focus seems to be mainly on OPS meant to be used for auxiliary power during berth. In light of the transition to zero-emission IWT, it will be relevant that these OPS points and/or additional electric infrastructure can also provide for (fast) charging of batteries needed for the propulsion.

Finally, there is currently momentum in the market of energy containers for batteries and hydrogen. There are ongoing research projects and initiatives focussing on this topic, such as CurrentDirect, RH2INE and HyEkoTank. The company Zero Emission Services (ZES) already provides battery containers with a pay-per-use model and is aiming to increase the number of swapping and charging

[72] Based on expert consultations
[73] https://www.hzwei.info/blog/2014/09/30/das-brennstoffzellen-schiff-alsterwasser-liegt-still/
[74] https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=3081
[75] https://www.schoneluchtakkoord.nl/publish/pages/206664/onderdeel-1-walstroom.pdf
[76] On 28th of March a provisional political agreement was reached between the Council and the European Parliament regarding the alternative fuel infrastructure. Source: https://www.consilium.europa.eu/en/press/press-releases/2023/03/28/alternative-fuel-infrastructure-provisional-agreement-for-more-recharging-and-refuelling-stations-across-europe/
[77] See for examples initiatives in the Netherlands and Germany: https://www.schuttevaer.nl/nieuws/actueel/2022/10/26/walstroom-in-alle-binnenhavens-is-onontkoombaar/ & https://www.nt.nl/binnenvaart/2019/05/13/120-nieuwe-walstroompunten-voor-schippers-aan-de-duitse-rijn/

points for their battery containers in the coming period. The ambition is to have around 14 charging stations by 2026.[78,79] Initially, it is expected that mainly terminals located along busy shipping lanes will be possible candidates to facilitate battery container loading.[80]

Given this analysis, it can thus be concluded that the current state of the energy infrastructure relies largely on fossil diesel and is also almost completely set up for this purpose and can hardly be exploited for supplying renewable energy in carriers such as green methanol, green hydrogen and electricity/batteries. As for the alternatives mentioned, there is some momentum in the market and ongoing research and pilot demonstrations, but there is certainly no tangible uptake yet, mostly due to lack of economic incentives and lacking regulations to enable the use of these new energy carriers on board of vessels.

[78] https://zeroemissionservices.nl/en/charging-infrastructure/
[79] https://www.schuttevaer.nl/nieuws/actueel/2023/03/31/project-condor-volgt-het-voorbeeld-van-zes-50-waterstofschepen-binnen-10-jaar/
[80] https://elaad.nl/onderzoek-naar-opkomst-elektrische-binnenvaart-veelbelovend-maar-nog-niet-op-koers/

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5. Impact of energy transition on IWT energy infrastructure

The previous chapters show that, mainly driven by (inter)national targets, the IWT fleet will need to make the transition towards zero-emission by 2050. The applicability of different energy carriers and technological solutions have been analysed and presented. Given the many uncertainties regarding price and technological maturity, scenarios and assumptions have been made. But there is a common view about the general direction and thus which technologies and energy carriers forms of energy the IWT infrastructure may need to prepare for.

On the supply side, developments show that Europe is strongly committed to increasing renewable energy through increased continental renewable energy production, e.g. through large projects for primary forms of energy such as wind, solar, hydro, bioenergy, geothermal and nuclear. Also, increasing numbers are seen in production facilities for secondary forms of renewable energy such as sustainable and advanced biofuels. Finally, major seaports in the Hamburg-Le Havre range have large-scale plans for importing renewable energy and becoming large hubs for e.g. renewable hydrogen. Related infrastructure investments such as building (import) terminals, laying pipes and cables are therefore planned and underway. Imports are going to play a major role in meeting renewable energy demand.

Whether and to what extent this renewable energy can also be used to fulfill demand from IWT is not entirely clear at present. In the run-up to 2050, i.e. in the coming years, there may be limited availability. This will also depend on the exact demand from IWT and how this will develop in coming years. However, given the clear targets for the transport sector and thus also IWT, it is assumed for the purpose of this study that IWT will also be near zero-emission by 2050, i.e. will reduce at least 90% of all GHG emissions and air pollutants compared to 2015. For the purpose of this chapter, it is also assumed that applicable renewable energy carriers will also be sufficiently available to the IWT sector.

This foreseen transition to zero-emission will have an impact on the energy infrastructure for IWT. Chapter 4 illustrated that the current energy infrastructure mainly consists of bunkering stations and bunker boats to provide fossil diesel and to a lesser extend biodiesel and GTL. There is minimal bunkering infrastructure in place for LNG. As for the alternatives such as renewable hydrogen, methanol and batteries, there is little movement in the market but certainly no significant uptake yet.

Assuming that one of the two scenarios for zero-emission transition pathways as outlined in Chapter 2, or one similar to it, becomes reality, means that significant interventions will be needed to the current energy infrastructure for the IWT sector. A grasp of technical interventions include:

- Swapping locations for swapping battery and hydrogen energy containers, including the facilities to store, potentially charge and move the containers with a crane.
- Realising charging points for (fast) charging of fixed batteries on board of vessels and/or adapting existing OPS points to enable (fast) charging of batteries.
- Bunkering facilities for green methanol should be realised. This may involve building new bunkering stations and boats and/or adapting existing bunkering stations and boats.

For these technical interventions, it remains to be seen to what extent it is technically, legally and, above all, economically feasible. Furthermore, the energy carriers may further develop, such as LOHC as hydrogen carriers. Moreover, it may turn out that some energy types will not reach a critical mass because of too high costs or too low TRL. Finally for the further future, it may not be ruled out that also ammonia could be energy (hydrogen) carrier for inland vessels.

Existing bunkering infrastructure such as bunkering stations and bunker boats do not lend themselves to the storage and transfer of clean forms of energy such as hydrogen and methanol, and certainly not the transfer of energy containers. As regards OPS points, it does appear that it is technically very complex and requires a lot of infrastructural modifications to make a regular OPS point ready to serve as a charging point to charge batteries on board of vessels used for the propulsion of the vessel. The most obvious location to establish swapping sites is at existing container terminals, along the Rhine there are around 97 container terminals.[81] However, large parts of the IWT fleet never visit a container terminal and there may be capacity restrictions and waiting times at container terminals to be able to take on the additional handling of energy-containers.

Towards realising the clean energy infrastructure, there will therefore be gaps and challenges on the path. Annex 1 lists a total of 52 gaps and challenges which were identified in recent existing literature.[82] These gaps and challenges will have a technical, legal and perhaps foremost, economic nature. Since the most important bottleneck for realising the renewable energy infrastructure for IWT is an economic one. Currently, there is simply not enough demand from the IWT fleet for clean forms of energy to justify any sizeable investments into the clean energy infrastructure.

The main technical challenge is the fact that it is often not possible to facilitate the bunkering, charging and swapping of clean energy on existing bunkering stations and bunker boats. This is due to technical complexities, since alternative forms of energy such as hydrogen require different types of storage, piping, physical size limitations, etc.

The main policy challenge is to ensure a corridor approach and align the regional and national strategies and deployment plans for clean energy infrastructure along the Rhine region. In addition, there is currently a regulatory lack to cover the bunkering of clean energy, and there is a long and/or complicated process to obtain the necessary permits to start clean energy bunkering operations. Moreover, also incentive schemes and regulations such as revision of RED2 and possible an opt-in for IWT to the new ETS for mobility need to be coordinated with respect to the application for inland waterway transport. This is needed to ensure a level playing field and effective European transport policy regulations in this field.

The listed gaps and challenges indicate that the impact of the foreseen energy transition on the IWT

[81] 20 container terminals in Belgium, 3 in France, 41 in Germany, 7 in Switzerland and 29 in the Netherlands https://theses.ubn.ru.nl/bitstream/handle/123456789/3856/Wursten%2C_Robert_1.pdf?sequence=1 (p.23)
[82] The PLATINA3 project analysed the gaps and challenges for realising the clean energy infrastructure for IWT. Source: https://platina3.eu/clean-energy-infrastructure/

energy infrastructure will be significant. Many technical adjustments need to be made to the infrastructure and large infrastructure investments are involved. Legislation and regulations must act as facilitators in this; here is a role for policymakers to act proactively with, for example, simplifying/shortening permit procedures wherever possible. On the other hand, the IWT energy infrastructure and investments in it are also dependent on demand from the inland fleet for renewable energy, but also from the primary producers and suppliers of clean energy. The majority of all the gaps and challenges related to the development of the clean energy infrastructure are interrelated and require an integrated approach to overcome them.

Whether the Rhine region will be able to adapt to the foreseen transition towards a zero-emission IWT fleet by 2050, will depend on the ability to overcome the aforementioned bottlenecks and the coordination between countries on implementation of regulations and incentives. Here there is a role for both public and private stakeholders to take action, but an important note must also be made of external dependencies, for example with regard to price developments of renewable energy relative to fossil diesel. As long as a level playing field is not created in this area, demand for renewable energy will fail to materialise and with it investment in clean energy infrastructure.

An adoption of the Fit For 55 proposals, revision of the TEN-T as well as the relatively recent REPowerEU action plan contain actions that can address some of the identified gaps and challenges.

Furthermore, there are developments in the market in terms of (pilot) demonstrations with ships on renewable energy such as hydrogen and batteries and further development by OEM's of technologies. Such initiatives and a further deployment of clean vessels will need to be accelerated in order to create a sizeable demand for clean energy to justify investments in the clean energy infrastructure.

6. Conclusion

This deliverable assessed the potential of the wider Rhine region for supporting renewable and clean energy use in the IWT sector. The findings are presented below.

Applicability of different energy carriers and solutions

A broad set of possible alternatives to fossil diesel are currently being considered. There is no so-called "silver bullet". The most promising and likely feasible solutions in time towards the year 2050 have been identified. These solutions are:

- HVO and LBM to be used in Stage V certified ICE's.
- Green H_2 in combination with fuel cells and ICE's.
- Green methanol in combination with fuel cells and ICE's.
- Green electricity in combination with Batteries

Given all uncertainties regarding developments in prices and availability, techniques and energy carriers are best allocated to subsegments in the IWT fleet by means of scenario analysis. A distribution was made for the technologies and forms of energy by fleet family for two pathway scenarios.

Depending on technological developments, for example in the field of hydrogen energy carriers and battery technology, this overview may of course change over time with the addition of new energy carriers and technologies and the omission of existing ones, or ones which may not be implemented (e.g. due to too high costs or lack of maturity).

Potential upscale of renewable energy production

The current energy mix in the Rhine region still mainly consists of fossil sources. Policies such as the proposed Fit For 55 package and REPowerEU will accelerate the transition to a zero-emission economy by substituting fossil fuels and will for sure have an effect on the energy mix of the EU and the Rhine countries.

Investments in renewable energy projects have already been made for years in the Rhine countries. The steady increase of renewables and biofuels in the total gross available energy have been shown. Furthermore, there are currently a large number of sizeable renewable energy projects on the drawing board and under implementation, especially also in the wider Rhine region. This concerns projects in the field of wind energy, solar energy, hydropower, nuclear power, geothermal and bioenergy, with production plans for secondary forms of energy such as renewable diesel, hydrogen and methanol.

However, the (expected) demand for renewable energy will also have to increase exponentially, especially in view of the energy transition targets of the EC and national governments in the Rhine region. It is therefore expected that the EU cannot be self-sufficient, as is currently the case in fossil energy. Regionally, this is especially true for the Rhine region, given all the heavy logistic and industrial activity there.

Depending on the exact future demand for renewable energy, imports to the Rhine area from other regions and continents are already expected to be needed. These imports need to be facilitated by existing and new infrastructure. There is a real "battle for hydrogen"[83] going on to supply Northwest Europe with green hydrogen. Several ports in the Hamburg-Le Havre range already have plans to become major hydrogen hubs. This also applies to other forms of green energy, such as green ammonia, green methanol and green electricity whose cables come ashore in the port area.

Given the developments in the production and import of primary and secondary clean energy, the actual question with this is to what extent these forms of energy can be shaped into forms of energy that can be applied to power inland vessels and whether there can be sufficient supply for the IWT sector, or will other sectors such as heavy industry and aviation be prioritised by market dynamics.

Eventually, renewable energy will also find its way to IWT, just as is happening today with fossil fuels. However, competition from other sectors and a limited supply of renewable energy, will cause relatively high prices especially in the run-up phase towards 2050, i.e. in the coming years. In such situation, it stands to reason that the IWT sector may experience difficulties in obtaining renewable energy in a dynamic market. Reasons for this are the lack of incentives, the relatively small size of the IWT sector as compared to other transport modes and non-transport energy demanding sectors, and its fragmented structure. Large sectors and the ones under ETS will need large volumes and might be more willing to pay.

Although there may be some challenges in the lead-up phase towards 2050 with making renewable energy available to the IWT sector, it is expected that further towards 2050 this problem will be remedied, provided the demand side to renewable energy from the fleet also develops sufficiently.

IWT energy infrastructure and impact of energy transition

In addition to the supply of renewable energy, it is obviously also necessary for the IWT energy infrastructure to develop so that the actual bunkering, charging and swapping of energy containers can be facilitated. There will be a need for new and/or adapted energy infrastructure for IWT. The current state of the energy infrastructure relies largely on fossil diesel and is also almost completely set up for this purpose and can hardly be exploited for supplying renewable energy in carriers such as green methanol, green hydrogen and electricity/batteries. As for the alternatives mentioned, there is some momentum in the market and ongoing research and pilot demonstrations, but there is certainly no tangible uptake yet. Towards realising the clean energy infrastructure, there will therefore be gaps and challenges on the path. A total of 52 gaps and challenges were identified, some of the most important are as follows:

1. Development of demand side for alternative energy still very marginal. Framework conditions to stimulate investments by vessel owners in clean propulsion techniques and energy are missing.

[83] https://drift.eur.nl/app/uploads/2020/06/KSD_DRIFT_HavenbedrijfRotterdam_vDEF_lores.pdf

2. Often not possible to facilitate bunkering, charging and swapping of alternative energy on existing bunkering stations.
3. Probably no sufficient supply of clean energy across European IWT countries to enable the sector to achieve the GHG target of 55% reduction by 2030.
4. Clean energy in the form of batteries, H2, methanol, etc. has lower energy density than fossil diesel. Eventually more need for bunkering and charging points for a small IWT market.
5. Permits and procedures for construction of alternative energy infrastructure will be very complex, fragmented and differ between regions/countries.

Whether the infrastructure side in the Rhine region will be able to timely adapt to the foreseen transition towards a zero-emission IWT fleet by 2050, will depend on the ability to timely overcome the identified gaps and challenges and on the coordination between countries on implementation of regulations and incentives. Here there is a role for both public and private stakeholders to take action in a timely manner.

An adoption of the Fit For 55 proposals, revision of the TEN-T as well as the relatively recent REPowerEU action plan contain actions that can address some of the identified gaps and challenges. Furthermore, there are developments in the market in terms of (pilot) demonstrations with ships on renewable energy and further development by OEM’s of technologies. Such initiatives and a further deployment of clean vessels will need to be accelerated in order to create a sizeable demand for clean energy to justify investments in the clean energy infrastructure.

Annex 1 – Gaps and challenges for development of clean energy infrastructure

Realising the clean energy infrastructure for IWT faces gaps and challenges that are technical, economic and legal in nature. A list of in total 52 gaps and challenges are listed below.[84]

Technical gaps and challenges

The following enumeration contains 16 gaps and challenges with a technical nature, to be taken into account for the development of clean energy infrastructure:

1. It is often not possible to facilitate the bunkering, charging and swapping (with containerised energy storage systems) of clean energy on existing bunkering stations. This is due to technical complexities, since alternative forms of energy such as hydrogen require different types of storage, piping, physical size limitations, etc.

2. Available space in ports is scarce and may limit the realisation of bunkering, charging and swap sites, especially for forms of energy that have a low energy intensity and require relatively more storage space.
3. Currently, bunker boats are often used to supply fossil diesel to inland vessels. These existing bunker boats are not equipped to provide alternative forms of sustainable energy such as green hydrogen, electricity, methanol, etc.

4. Thanks to studies, insights have been gained in terms of the possible future fuel mix for IWT. But fuel suppliers also need some flexibility in case of possible technological breakthroughs (e.g. in battery technology) that could change today's expected fuel mix for the future. This uncertainty complicates infrastructure investment decisions.

5. Currently, a majority of vessel operators is active on the spot market. This will make it difficult for clean energy suppliers to provide (full) geographic coverage for their customers. Because a large proportion of vessels will have varying sailing trajectories and may not be able to bunker and charge clean energy always on the same place.

6. There will probably not be a sufficient supply of clean energy in all European IWT countries and regions to enable the sector to achieve the GHG target of 55% reduction by 2030.

7. Although the climate goals are the same, the pathways for ports to reach them are different and depend on many factors such as port traffic, hinterland connections, industrial and energy sectors in the port area, stakeholder commitment and engagement, etc.

8. The navigability of the Danube is a challenge, which complicates the planned increase in modal split for IWT. The reliability of the navigability and strong commitment from all public and private parties involved are seen as important for the realisation of the clean energy infrastructure.

9. Containerised batteries and H2 containers for fuel storage seem to be feasible options (and possibly also for other forms of clean energy), at least on the short term. However, not all types of vessels might be technically suited to use containerised energy storage and large

[84] https://platina3.eu/clean-energy-infrastructure/

parts of the inland fleet, e.g. passenger vessels and tankers, never visit container terminals.

10. Not all terminals will be able to take on the handling of alternative-fuel/energy-containers. A lot of terminals in the hinterland are still operated by one crane only, and it is far from certain that the owners of the terminals would be able and willing to add another task (additional container handlings) to that crane. This would decrease the normal handling capacity of the terminal.

11. Charging points (energy for propulsion) should be located close to loading/unloading areas, and the infrastructure behind them should allow to charge/swap batteries during loading/unloading operations.

12. Deployment and usage of OPS by the IWT sector will be very dependent on three aspects that can pose a challenge. This relates to how much energy an energy producer can provide, the capacity of the grid transporting electricity to the port and whether the port area has the right electric cables at the berths. This is a challenge related to both the port infrastructure and outside the port infrastructure.

13. Inland cruise vessels require substantially more electric energy. The existing grids are not always able to address these demands.

14. There is no uniform concept for the operation of shoreside power connections, and no agreement on a commonly accepted payment method.

15. Battery-electric propulsion systems and accumulators for self-sufficient power supply bear the risk that shoreside power/OPS connections providing electricity during berth operations might become a bridging technology in the future, especially if battery technology greatly increases battery/battery containers capacity. In the middle to long term, the energy demand of certain vessels for berth operations could be met by onboard batteries, meaning existing shoreside power infrastructure might not be required any further for this specific purpose. To avoid dead-end investments, shoreside power infrastructure should be planned to be as flexible and as service-oriented as possible to allow adaptation to future needs. These multipurpose service platforms could then not only be used for shoreside power but also for giving access to water, internet, communication, and other services when at berth.

16. The current way of operations in IWT requires a change in mindset and the way of shipping. Most of the clean alternative forms of energy require a mind shift for how to operate the vessel, especially regarding aspects such as flexibility, time between bunkerings, safety, etc. This means that existing logistical operations have to be adapted once using clean alternative forms of energy. The future clean energy infrastructure must be tuned to this.

Economic gaps and challenges

The following enumeration contains 17 gaps and challenges with an economic nature, to be taken into account for the development of clean energy infrastructure:

1. The development of the demand side for clean energy in the overall European IWT sector is still very marginal. This was being regarded as the main bottleneck for realising the clean

energy infrastructure for IWT by the audience during the PLATINA3 5th Stage Event.[85] There are initiatives and projects for applying clean energy on dedicated routes (e.g. for container transport) and for specific type of ships (e.g. harbour tugs, ferries). But in general there is still a strong preference for diesel and ICE's. The framework conditions to stimulate investments by vessel owners in clean propulsion techniques and energy are insufficient. With lacking demand suppliers of clean energy will be hesitant to invest in the clean energy infrastructure.

2. Currently, the bunkering market is characterized by very small margins requiring large quantity sales to enable a positive business case for the energy supplier. With alternative forms of energy, which have a significantly lower energy density, there will eventually be a need for more bunkering and charging points than the current number of bunker points for fossil diesel, which would put even more pressure on the business case.

3. The current status of bunkering fossil diesel is one of high availability on short notice, high service, flexibility and low prices. It will, especially in its initial phase, be difficult for the alternative clean energy infrastructure to compete with.

4. Bunkering during sailing by bunkering boat is not possible for alternative forms of energy, which is at the expense of time efficiency and having a negative economic impact for vessel operators used to this way of bunkering.

5. Operational profiles in the IWT sector are for a large part very flexible. Large portions of the sector are active on the spot market and do not know always where they will be going after they finish their current trip and are thus only capable to plan bunkering moments very roughly and with short notice. Future clean energy infrastructure must be able to meet this flexibility demand and/or vessel operators must adjust their bunkering behaviour.

6. Experience with the construction of the LNG bunkering station in Cologne showed that the construction process of the clean energy infrastructure for IWT can be very complex, time-consuming and costly compared to conventional infrastructure.

7. It will be of key importance to boost the demand side/market for alternative fuels in order for fuel suppliers to invest in the infrastructure. Demand and supply should develop in a balanced way though. Policies and incentives (i.e. grants) should stimulate combined projects that will work on ensuring a first critical mass, i.e. an initial consumption of alternative clean energy which is large enough for suppliers of clean energy to invest in the required energy infrastructure. Although the clean energy market is a difficult one in economic terms, both for suppliers and users, when the right market conditions are met, clean energy suppliers can move relatively easily given their financial capacity, as compared to small individual vessel owners, and invest in infrastructure once there is a prospect of a market. But as of now, there are not much developments in this regard, there are too few newbuilds and retrofitted vessels to sail on alternative forms of energy.

[85] 32 out of the 45 participants to the Wooclap session inserted an answer and most of them highlighted "demand" as the main bottleneck for realising the clean energy infrastructure for IWT. See also Annex 7.

8. It remains uncertain if enough green hydrogen can be produced locally- and if not, imported hydrogen will be less competitive and cannot be applied everywhere.

9. It will be complex to ensure reliable access for both inland vessel operators and service provides to container terminals for swapping energy containers, since there may not always be an (economical) incentive for container terminal operators to offer these services, especially to vessels that are no clients of the container terminal and exclusively arrive to swap energy containers.

10. Terminal operators and other players in the port area may not always welcome bunkering, charging and swapping operations in their immediate environment without any objection.

11. Within a small and fragmented market like the IWT, only a limited number of forms of clean energy can be supported. Otherwise, the infrastructure becomes too costly with potentially a negative impact on factors such as price and availability of the supplied energy.

12. A level playing field should be established across regions and investments should be coordinated in time, so that certain countries and regions don't leap behind in the clean energy infrastructure deployment. This should prevent the situation in which a certain fuel is provided in one geographical area but not in another and hence vessels can only use the fuel in just that part of the region supplying the particular fuel.

13. Substantial amounts of public funding will be required to realise the clean energy infrastructure for IWT. Corresponding stimulation instruments may not always and everywhere be available in the required amounts.

14. There are currently not too many projects in European ports, which can demonstrate active uptake of the innovations with regards to alternative fuels/green electricity production and serving as green energy hubs.

15. Vessel operators have strong preferences for fluid fuels that can be handled (i.e. stored, bunkered, etc.) in practical ways similar to diesel. (Drop-in) liquid biofuels and e-fuels such as HVO and green methanol are suitable for this purpose. However, this will pose a challenge for other alternative forms of clean energy such as green hydrogen and electricity, which will require a different approach.

16. A corridor approach is required for the development of the clean energy infrastructure. Fixed alternative fuels infrastructure in all ports could lead to oversupply in some areas and undersupply in others, as inland ports are not evenly distributed. Fixed targets for all ports would not always make economic sense and could result in underutilised or stranded assets. Instead of going for "island solutions" there has to be a coordinated and harmonised approach which works on the corridor level.

17. Cost factors related to the production and procurement of alternative clean energy, for transport, storage and supply and other regular cost factors are currently seen as very high from the perspective of energy suppliers. Inland vessel owners/operators will, in most cases, not be willing and able to pay a high enough price to outweigh these costs for the energy supplier. Hence, the current economic conditions may prevent a wide uptake of the clean energy infrastructure.

Legal gaps and challenges

The following enumeration contains 19 gaps and challenges of a legal/regulatory nature, which need to be taken into account for the development of clean energy infrastructure:

1. Permits and procedures for building conventional bunkering infrastructure (i.e. bunker stations and boats) are very fragmented and may differ between regions and countries. This process will be even more complex for the construction of the clean energy infrastructure.[86]

2. Existing bunker station supplying fossil diesel will not be able to store and supply alternative forms of energy such as green hydrogen, methanol and electricity without permits from (local) authorities, due to legal/safety reasons.

3. Supplying multiple forms of clean energy, physically, next to each other might not be possible due to safety reasons and permits.

4. Reserving a quay for a truck-to-ship delivery of clean energy is cumbersome and takes a relatively large amount of time and administrative effort for a vessel operator.

5. Not all (container) terminals have a relevant exploitation authorization for handling dangerous goods, which is necessary to have though for swapping energy containers such as H2 containers. The same will apply to quays on which energy containers will be swapped.

6. There is a limited amount of dangerous goods allowed at a terminal, this should be considered with facilities for swapping energy containers.

7. Harmonised bunkering procedures/checklists need to be drafted for inland vessels bunkering/charging clean energy.

8. Port Bye-Laws need to include provisions for bunkering of clean energy.

9. Regulations and IWT legislation (e.g. police regulations) will need to be adjusted/developed to allow bunkering, charging and swapping clean energy to the extent that this is not already possible.

10. It will be crucial to align the national and regional strategies for the clean energy infrastructure with EU objectives. National and regional authorities will need to coordinate investments on both sides of the border as vessels operate internationally and cross borders. The TEN-T corridors, together with their coordinators, need to play a facilitating role in this respect.

11. Not all member states, and relevant regional authorities, have clear strategies yet for the deployment of the clean energy infrastructure for IWT.

12. Not all IWT country representatives surveyed have an equally good understanding of how the energy demand of the IWT sector will evolve towards the future, even though this is an

[86] The Commission proposals to accelerate permit-granting procedures for renewable energy projects may have a positive effect and eventually (partially) eliminate this bottleneck. This concerns the proposals for an amending directive on RED (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0222&from=EN) and a Council Regulation (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0591)

important starting point for discussions on the required clean energy infrastructure for IWT.

13. Drop-in biofuels like biodiesel and renewable diesel and biomethane are actively being promoted or prescribed in some but not all surveyed European IWT countries. This difference could have an unbalanced impact on the development of the clean energy infrastructure, in which there are e.g. more bunkering facilities for drop-in biofuels in some of the countries and other countries provide more for other forms of energy.

14. Inland ports are often located close to densely populated urban areas and often have to balance the development and management of port activities with the preservation of natural habitats and the quality of urban life. This may stress the development of the clean energy infrastructure on sites close to urban areas.

15. Port authorities/administrations can decide on the greening of their own activities and jurisdiction, but have limited possibilities to influence green behaviour of port users (terminal operators, transport companies, etc.).

16. In the past, suppliers of LNG to IWT and its customers experienced inconsistency in regulations, i.e. related to initial support for the roll-out of LNG which subsequently fell away and led to a decrease in the number of bunkering spots where LNG bunkering is possible by truck, due to revoked permits. This experience may make some parties reluctant to invest in clean energy infrastructure for IWT.

17. In order to enable cross border projects, funding for projects in neighbouring non-EU will also be necessary. It needs to be ensured that co-funding of neighbouring countries under CEF needs to continue in the revised TEN-T proposal.

18. A number of points not explicitly addressed in the proposed AFIR are seen as gaps that may lead to challenges in the realization of the clean energy infrastructure. These are the following:
    a. The proposed AFIR focuses relatively much on shore-side electricity supply but less on infrastructure for other fuels. Furthermore, with on shore-side electricity supply, the focus for IWT should be increasingly on recharging points to charge and swap batteries used for propulsion of the vessel and less on on-shore electricity supply for the hotel function (i.e. power required during idling).
    b. The proposed AFIR does not address specific technical challenges, such as the fact that the deployment and usage of OPS will be very dependent on the reach and capacity of existing electric grids. Member States could take the necessary measures to ensure that the electricity grid is sufficiently extended, in connectivity and capacity.
    c. The proposed AFIR should emphasize more explicitly the role of the European Coordinators to coordinate and assist Member States in the creation of joint policy frameworks on the strategies to use alternative clean energy and deployment of the corresponding infrastructure.

19. There are two potential shortcomings in the proposed revised TEN-T regulation that could pose potential challenges, these are:
    a. An inland port should be part of the comprehensive network when it has an annual freight transhipment volume exceeding 250.000 tonnes instead of 500.000 tonnes,

since smaller inland ports might not be able to meet the threshold of 500.000 tonnes as foreseen in the current proposal. Furthermore, no mention is made about passenger traffic either as threshold condition to be part of the comprehensive network. Whereas the IWT passenger sector itself is a front runner in terms of greening and adaptation of its fleet to the energy transition and highly depending on the publicly accessible recharging and waste collecting infrastructure along the trans-European transport network. Hence, sector representatives indicate that a reference amount for passenger traffic volume should be included as well, being a total annual volume of passenger traffic volume exceeding 500 000 persons.

b. The proposed regulation should foresee requirements for maintenance of clean energy infrastructure (as per form of energy) to ensure that the TEN-T network will continue to function properly during its operational life cycle. Currently there are no regulations or technical investigations, which shall be applied to future maintenance of clean alternative fuels bunkering / recharging infrastructure in ports and on the waterways, especially from the point of view of safety requirements.