DNV·GL

With input from

eurelectric
powering people

Ports: Green gateways to Europe

10 Transitions to turn ports into decarbonization hubs

About DNV GL

We are the independent expert in risk management and quality assurance. Driven by our purpose, to safeguard life, property and the environment, we empower our customers and their stakeholders with facts and reliable insights so that critical decisions can be made with confidence. As a trusted voice for many of the world's most successful organizations, we use our knowledge to advance safety and performance, set industry benchmarks, and inspire and invent solutions to tackle global transformations.

In the power and renewables industry

DNV GL delivers world-renowned testing, certification and advisory services to the energy value chain including renewables and energy efficiency. Our expertise spans onshore and offshore wind power, solar, conventional generation, transmission and distribution, smart grids, and sustainable energy use, as well as energy markets and regulations. Our experts support customers around the globe in delivering a safe, reliable, efficient, and sustainable energy supply.

About Eurelectric

Eurelectric is the federation for the European electricity industry. We represent the power sector in over 32 European countries, speaking for more than 3,500 companies in power generation, distribution and supply. We contribute to the competitiveness of our industry, provide effective representation in public affairs and promote the role electricity in addressing the challenges of sustainable development. We draw on more than 1000 industry experts to ensure that our policy positions and opinions reflect the most recent developments in the sector. This structure of expertise ensures that Eurelectric's publications are based on high-quality input with up-to-date information.

CONTENTS

1

WHY THIS REPORT?

1.1 PORTS AS HUBS FOR CO_2 REDUCTION

The race to reduce greenhouse gas emissions to limit global warming is on. The energy transition towards a clean energy future is essential in winning this race. DNV GL's forecast, the Energy Transition Outlook (1), finds that although the energy transition is gathering pace more quickly than previously thought, the rate is still too slow to limit global temperatures rising by well below 2°C as set out in the Paris Agreement.

The global challenge of climate change and environmental degradation requires decarbonization of many sectors. The technology already exists to curb emissions enough to hit the climate target. Unfortunately, technology is not the only aspect to consider. Economic feasibility and social acceptance as well as political viability, resulting in an efficient regulatory framework, are other important factors.

For Europe, the Green Deal is going to be one of the main enablers to transform the EU economy so that it is fit for a sustainable future. This requires a rethinking of policies for clean energy supply across the economy, industry, production and consumption, large-scale infrastructure, transport and many other sectors. Ports can play a key role in this context.

Today transport accounts for one-third of EU CO_2 emissions. Road transport is responsible for 72% of transport CO_2 emissions, water transport for 14%, and air transport for 13% and the remainder mainly for railroad transport (2). It is estimated that due to CO_2 targets imposed on vehicles the relative contribution of water transport will increase significantly if emissions from water navigation are not tackled in time.

At the intersection of land and sea, ports can play a pivotal role in Europe's decarbonization agenda and the much-needed energy transition. Ports host many industry sectors including maritime, oil & gas, cruise-tourism, heavy transport, bulk transfer, manufacturing industries, power generation, electricity grid operators and offshore wind.

Port activities themselves can be decarbonized. Moreover, decarbonizing seaside and landside transport will also have a significant impact on ports. There are several options for decarbonization of transport depending on the type of vessel or heavy truck and travel distance. Direct electrification is one option (via cold ironing, electric ships, electric trucks), using carbon-free fuels like ammonia or biodiesel is another one. It will require other more diverse service and bunkering/charging infrastructure. Additionally, ports are often co-location sites for (chemical) industries and electricity plants as these profit from easy access to bulk transportation and from the advantages of an industrial-type site (e.g. suitable environmental regulations). Port sites therefore present a significant decarbonization potential.

All stakeholders connected to a port have their own key drivers for reducing CO_2 emissions. Port authorities want to decarbonize operations, reduce energy cost and provide a competitive gateway for attracting the maritime industry as customers. For the maritime sector it is the need for emissions reductions, in response to national and international regulations based on for instance the International Maritime Organization (IMO) CO_2 reduction target, and the access to compliant fuels and technologies at a competitive cost. For utilities it is providing reliable energy and heat and responding to increasing energy demand through electrification of transportation, port-related activities and industrial activities in the vicinity and increasing the value of the energy they provide to their customers.

To unleash the potential for decarbonization in and around European ports, DNV GL and Eurelectric have joined forces to develop this report. By bringing together DNV GL's global expertise from the power, renewables, maritime and oil & gas industries and Eurelectric's network and knowledge of Europe's electricity industry and EU policies, this report uncovers the opportunities and provides policy advice to EU policy makers, the power industry, port authorities and all other industry stakeholders. It also gives new insight and inspiration for all parties working in and around ports to help them create strategies for business development to ensure we all act quickly to secure a more sustainable future.

This report explains how ports could become hubs for decarbonization. It describes the ten Green Transitions which will lead to decarbonization in and around ports, starting with the current situation and describing the port's position as a decarbonization hub in the future.

However, ports will only become 'green gateways' if all sector players join forces, strategies are coordinated and the relevant policies at all levels in society are developed and implemented by governments and authorities.

The energy transition and COVID-19

In the next few years, ports will also need to overcome big challenges, such as adapting to new requirements including the increased size and complexity of the fleet and requirements on environmental performance and alternative fuels. It's important to note that the impact of lockdowns in many countries worldwide, as we see today caused by the spread of the Coronavirus, will be significant on several industries including on ports.

Today we do not yet know the full implications that the COVID-19 global shutdown will have on emission levels. It may be a temporary dip and not a structural change, in which case industry cannot afford to decrease its decarbonization ambitions to address climate change. It may also be a structural change, which may alter the way we live, work and travel, and thus, will have a huge impact on the energy transition and the ports of the future.

The forecasts used in this report are based on DNV GL's Energy Transition Outlook 2019 (1) and do not yet include COVID-19 effects.

1.2 TEN GREEN TRANSITIONS TOWARDS DECARBONIZATION

Understanding the decarbonization potential of port sites starts with understanding the transitions that will take place in and around ports. We assessed ten Green Transitions towards decarbonization that directly or indirectly affect port sites. These are summarized in Figure 1.

Most transitions are general, and ports are just one of the locations where these transitions make an impact. For instance, electrification of industry is a general trend that will impact ports because they are advantageous co-location sites for some types of industries. The same holds for the phase-out of fossil fueled power plants, which impacts electricity generation. Transitions specifically for ports include fuel switch for maritime and electrification of port-related activities. The transitions create opportunities for decarbonization strategies if coordinated well and with the right policies in place.

Quantifying the effect of Green Transitions: Port 1.0 and Port 2.0

The ten Green Transitions affect ports and port related activities. The impact will be different per port as ports differ in size, in location and in type of activities. In this report we propose a typical European port, Port 1.0, based on data from actual European ports. Port 1.0 is quantified in terms of size, goods, industries etc. We also propose a Port 2.0, the green future of Port 1.0 projected in approximately 2050. Port 2.0 visualizes and quantifies the effect of the Green Transitions on carbon related activities. The differences are expressed in energy consumption, carbon emissions and the need for electricity and electricity infrastructure.

The potential for electrification in ports

It is expected that the decarbonization of ports will be met for a significant part by direct and indirect electrification of port related activities (cranes, container transport, etc.), of co-located industries and of maritime and inland ships. This will set demands on future electricity demand and supply, infrastructure, coupling with other energy sectors and standardization.

Most of these electrification challenges are not unique to ports, but at ports they come together, involving many sectors such as maritime, oil & gas, energy, industry and (local) governments. This convergence makes ports front runners in the energy transition.

Figure 1 Ten Green Transitions towards decarbonization of ports

1.3 SCOPE AND READING GUIDE

This report aims to substantiate and assess the decarbonization potential of ports. The main questions addressed are:

1. What is the decarbonization potential in European ports including industry and water transport?
2. What is needed to transform and decarbonize ports and co-located industries?
3. What are the barriers and the necessary measures (regulatory, economic and technical) to unleash this potential?
4. What policies can accelerate the decarbonization of ports using electrification?

Before diving into the decarbonization potential of European ports, it is important to address the decarbonization pathway towards 2050. Electrification is envisioned as an important step to decarbonize energy use, for instance in industrial processes. To what extend we expect decarbonization can be realized by 2050 will be discussed in chapter 2.

Chapter 3 characterizes current ports in Europe, with focus on seaports. Chapter 4 introduces ten Green Transitions which will each contribute to the decarbonization of the European ports. These Green Transitions will have different impacts on different types of ports. Therefore chapter 5 introduces two “typical” European ports:

- A large European Industrial Port (e.g. located near the North Sea or the Baltic Sea) - this port is based on the average size of the 20 largest ports in Europe. It is mainly focused on bulk goods and containers. It has a large crude-oil and chemical industry cluster, co-location of power plants and a large potential of connecting offshore wind, mainly focused on bulk goods and containers.
- A smaller European Transport Port (e.g. located near the Mediterranean Sea or the Atlantic Ocean) – this port is one tenth of the size of the industrial port and represents the average size of a port in Europe. It has a limited industrial cluster, mixed container and passenger transport and no offshore wind connection potential.

Both the Industrial Port and Transport Port are defined today, i.e. the so-called Industrial Port 1.0 and Transport Port 1.0, and projected in 2050, i.e. the Industrial Port 2.0 and Transport Port 2.0, in order to illustrate the impact of the Green Transitions. We use a scenario approach to visualize this impact. An analysis of barriers and economic feasibility is not included as this depends heavily on the actual and local situation.

Chapter 6 describes the impact of the Green Transitions on the power sector, including opportunities and challenges. Chapter 7 gives policy recommendations for the EC and national and local government. The outline of this report is illustrated in Figure 2.

Figure 2 Changing ports into decarbonization hubs for a greener Europe

PORT 1.0

Definition of PORT 1.0 and environment

GREEN TRANSITIONS

Major Green Transitions leading to decarbonization

PORT 2.0

Definition of PORT 2.0 and environment

IMPACT OF PORT 2.0 ON POWER SECTOR

Opportunities and challenges of green transitions on power sector

ACTIONS FOR POWER SECTOR TO REALIZE PORT 2.0

Actions for power sector to realize PORT 2.0

2

TOWARDS A CARBON-FREE FUTURE

Forecasts and pathways

The urgency of reducing our carbon emissions to limit global warming is clear and the goal to reach it in 2050 reflects this urgency. Many pathways towards 2050 describe a future that shows that a zero-carbon emission energy system is technologically possible if certain conditions are met compared to business as usual scenarios. These pathways are important as they express a vision towards a decarbonized future and provide guidelines for policy, regulatory and technology development. Eurelectric developed three decarbonization pathways showing that the European Union can reduce up to 95% of CO_2 emission by 2050 thanks to decarbonized electricity (3).

Unfortunately, technology is not the only issue. Economic feasibility and social acceptance as well as political viability, resulting in an efficient regulatory framework, are other important factors. This adds to the uncertainty of pathways that are primarily technology based. DNV GL's Energy Transition Outlook (1) is an example of a forecast. This forecast is based on our best knowledge of the current energy system and expected developments towards 2050. The outcome of this forecast does not reflect what we want to happen but what we think will happen given current knowledge and projections.

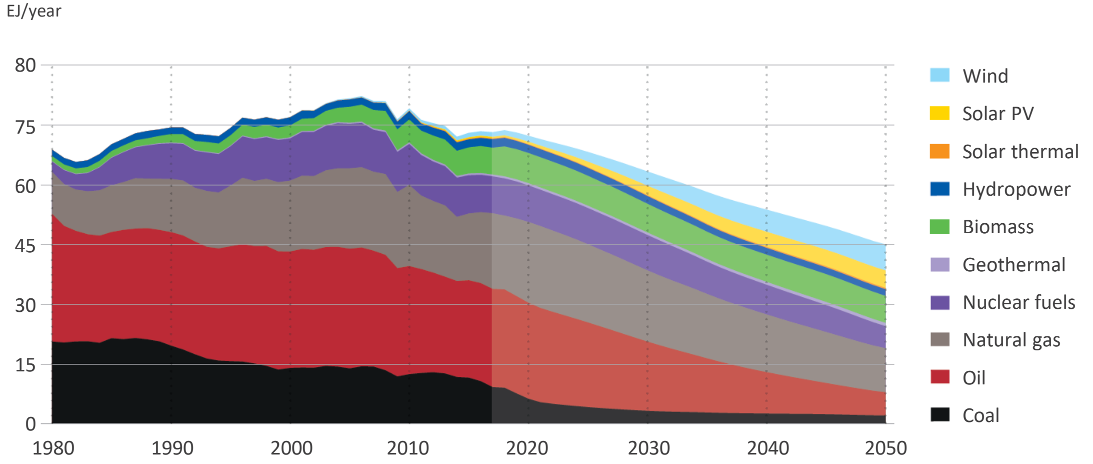
In the next sections we will briefly describe the DNV GL Energy Transition Outlook and the Eurelectric decarbonization pathways. To forecast the expected impact of the ten Green Transitions on ports we use DNV GL's Energy Transition Outlook.

A rapid transition but not fast enough

The DNV GL Energy Transition Outlook forecasts a rapid energy transition, but this transition is not fast enough to bring global warming well below 2°C by 2050. Globally, the share of fossil fuels in the primary energy consumption will decrease from 85% today to 56% by 2050 and fossil fuel use will reach its peak around 2025. In Europe, the share of fossil fuels in primary energy consumption is forecasted to be less than 50% (Figure 3) but still significant. In this light, a fully decarbonized port in 2050 is a challenge and thus we assume that, unless additional policy measures are agreed, ports in 2050 will not be fully decarbonized, despite their potential in terms of direct and indirect electrification.

Additional drastic measures are needed to change the forecast and speed up the energy transition to meet the Paris climate goals. DNV GL is committed to tackle the challenge of a faster energy transition through its daily work in all industry sectors and by providing fact-based information to all interested parties.

Figure 3 European primary energy consumption by source (1)

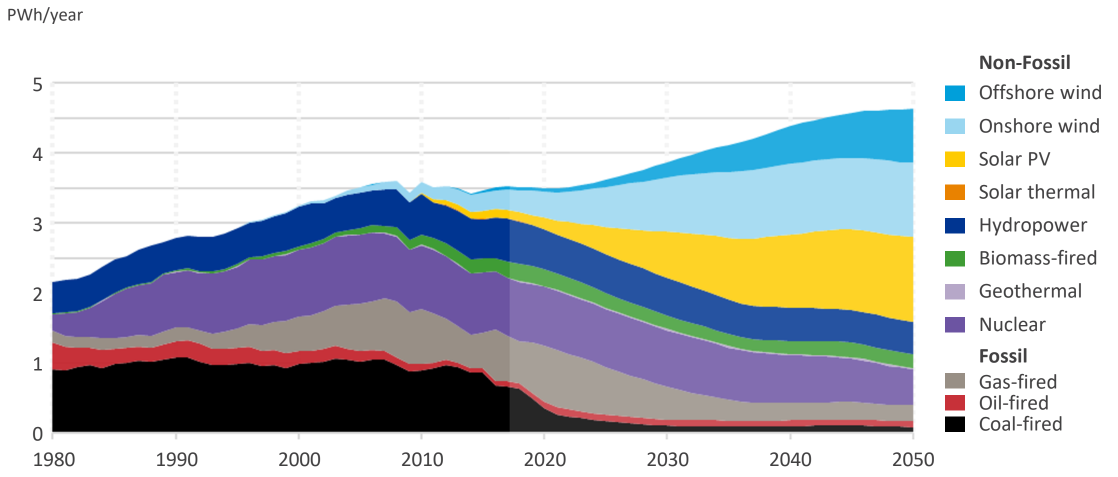


The power generation mix

The power generation mix forecast in figure 4 shows a rapid decrease in coal-fired power generation and a steadier decrease in total fossil fired power generation in Europe. By 2050, variable renewable energy sources (VRES) such as wind and solar will generate more than 60% of the total electricity demand. This forecast differs from the Eurelectric pathway as discussed later this chapter. Fossil fuels are still present in the generation mix with a share of less than 10%.

Due to the massive increase in variable energy sources, the aim is and will be to secure a constant electricity supply at all times and to ensure system stability. Storage technologies, providing flexibility as well as essential system services, can and will compete on the market with other flexibility providers such as dispatchable generation assets and demand side management. Consequently, there will still be gas-fired power plants in 2050, in the best case only fired by green gases. The impact on the CO_2 emission is twofold as both the decrease in fossil fuel use and the change in fuel mix due to coal phase-out result in lower emissions.

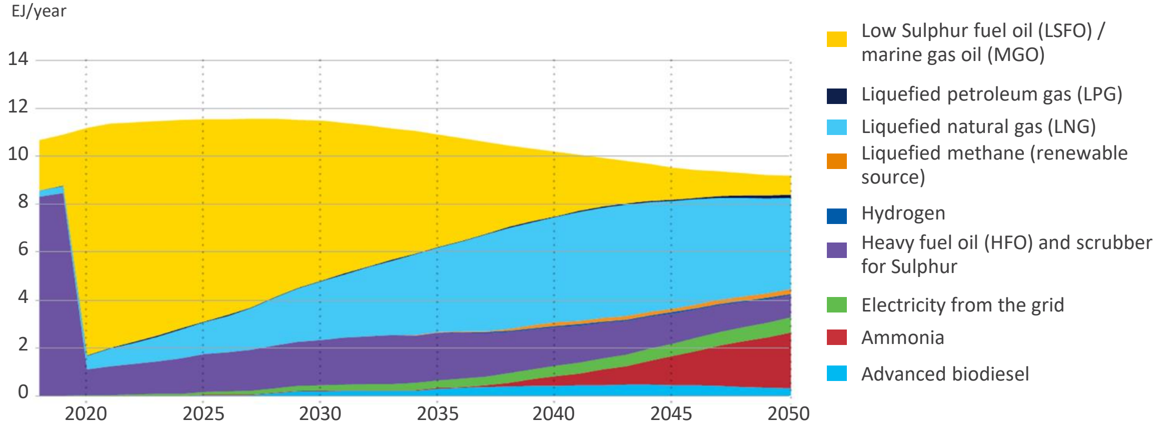
Figure 4 European power generation by power plant type (1)



Maritime transport

The energy mix for maritime transport (Figure 5) reflects the expected implementation of environmental regulations, e.g. the IMO (International Maritime Organization) greenhouse gas strategy of a 50% reduction in absolute emissions by 2050. It shows a large decrease in the use of traditional marine fuels and an uptake of alternatives, most dominantly liquefied natural gas (LNG) and ammonia. The direct use of hydrogen as a maritime fuel is negligible but indirectly, renewable hydrogen will be used to produce ammonia fuel. Direct use of electricity has a small but non-negligible share in the maritime fuel mix, but it will be important to produce e-fuels, most notably ammonia and synthetic methane.

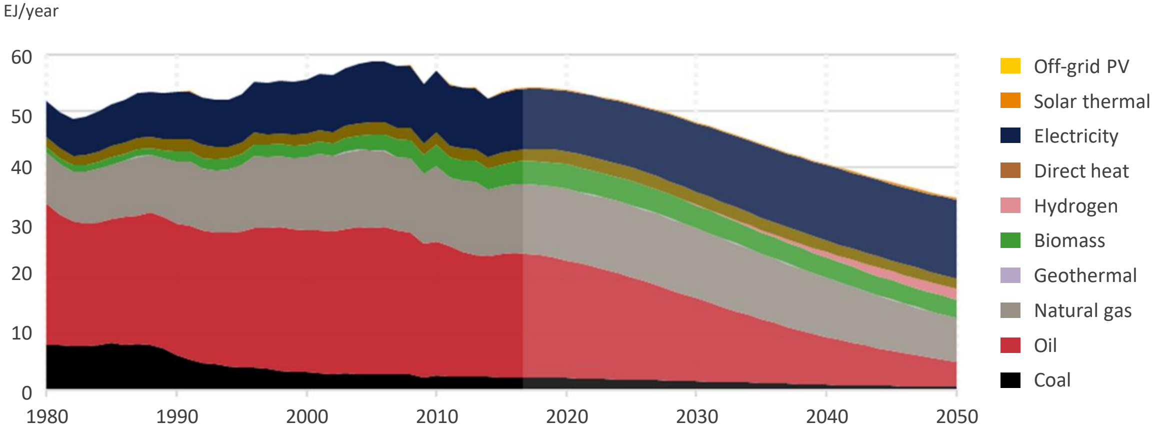
Figure 5 Maritime energy demand and projected fuel mix (1)



Hydrogen and carbon capture and storage

The use of hydrogen and carbon capture and storage (CCS) can be subject to much debate. History shows fluctuating opinions regarding the importance of hydrogen and CCS in the energy transition. For a fully decarbonized society, only carbon-free hydrogen from renewable sources is viable. In our Energy Transition Outlook forecast, a discernable but limited role for hydrogen, as shown in Figure 6, is foreseen. However, full decarbonization in 2050 is not forecasted and hydrogen from natural gas combined with CCS can still be used*. Figure 6 shows the share of the final hydrogen use in Europe. Hydrogen used as feedstock by industry is not included in this graph, so actual production of hydrogen will be larger.

Figure 6 European final energy demand by carrier (1)



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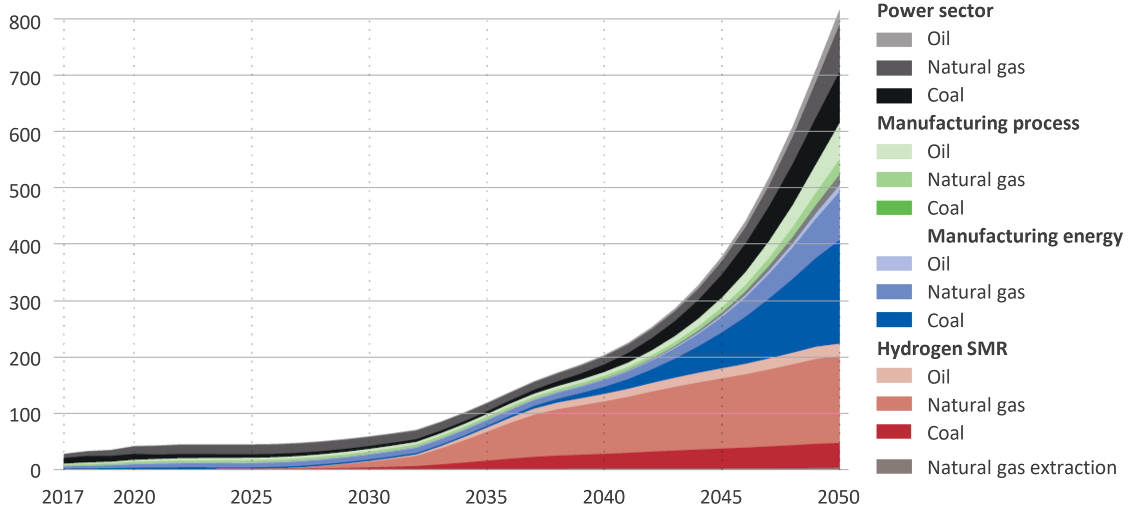
*Eurelectric favours indirect electrification via electrolysis as the key strategy for production of hydrogen.

Figure 7 shows the forecasted global uptake of CCS. Europe will capture 20% of the global volume. This is approximately 160 Mt/yr or 14% of the energy-related CO_2 emissions in 2050. The application of CCS depends heavily on the carbon price. The initial limited uptake of CCS is a function of high abatement costs versus weak incentives to reduce emissions. We expect a push to drive uptake in the 2040s with an increase in carbon prices and a concurrent fall in costs due to a growing number of projects.

The efficiency of CCS depends on the industrial process of the power plant type it is applied to. In general, a 100% efficiency is not economically feasible. For instance, blue hydrogen, produced from natural gas with CCS is therefore not fully carbon-free.

Figure 7 World CO_2 emissions captured by CCS (1)

$MtCO_2$/year



Green, blue and grey hydrogen

Hydrogen is a carbon-free energy carrier. However, using hydrogen may indirectly cause carbon emissions because of the emissions related to producing hydrogen. Generally, a color scheme is used to discern between hydrogen of different origins:

- Grey hydrogen is produced from fossil fuels, currently predominantly from natural gas with steam methane reforming (SMR).
- Blue hydrogen is also produced from fossil fuels but combined with carbon capture and storage (CCS). It is not economically feasible to fully capture and store all carbon emissions. Generally, a CCS-efficiency of 90-95% can be achieved.
- Green hydrogen originates from low carbon energy sources, for instance biomass or biogas or from electrolysis with low carbon or carbon-free electricity.

Low carbon electricity can be allocated to hydrogen production by means of certificates or can be physically used for electrolysis (e.g. by combining a solar PV plant with an electrolyser). There is some debate about this. Some argue that green hydrogen is only carbon-free when production does not cause carbon emission, also not indirectly. In this report, we use the term green hydrogen to indicate carbon-free hydrogen produced from renewable sources.

Eurelectric favours indirect electrification via electrolysis as the key strategy for production of hydrogen.

Eurelectric Decarbonization pathways

The power sector, represented by Eurelectric, is committed to leading the required energy transition and secure cost-effective decarbonization that support European competitiveness in the global marketplace. In its new vision published earlier in 2018, the power sector made a pledge to become carbon neutral well before mid-century, considering different starting points and commercial availability of key transition technologies.

The association has completed a comprehensive study to assess the potential contribution of the power sector on economy-wide decarbonization (3). In the first phase of the study, Eurelectric has developed three EU electrification scenarios towards 2050 that achieve 80%, 90% and 95% decarbonization of the main energy-using sectors: transport, buildings, and industry. In the second phase of the study, Eurelectric has analyzed the decarbonization pathways to drive the power sector towards carbon-neutrality well before 2050 at the lowest possible cost for each of the three electrification scenarios defined in phase 1.

The study shows that electrification coupled with full decarbonization of the power sector is a direct, effective and efficient way of reaching the decarbonization objectives for society as a whole. 80 - 95% decarbonization of energy used in the EU economy requires a strong step-up across a portfolio of decarbonization levers, in which direct electrification of end-uses in buildings, industry and transport can play a significant role. Energy efficiency measures and other carbon-neutral fuels will complement electrification to deliver on these ambitions.

The study by Eurelectric shows that it is possible to meet increased electricity demand, and at the same time fully decarbonize the power sector well before 2050 in a cost-effective way. While DNV GL's Energy Transition Outlook aims at forecasting how the energy future is going to look like on a basis of the trends currently observed, the Decarbonization Pathways shows the ways in which the power sector can get there, exploring the necessary enablers to provide a carbon-free future for electricity and electrifiable sectors.

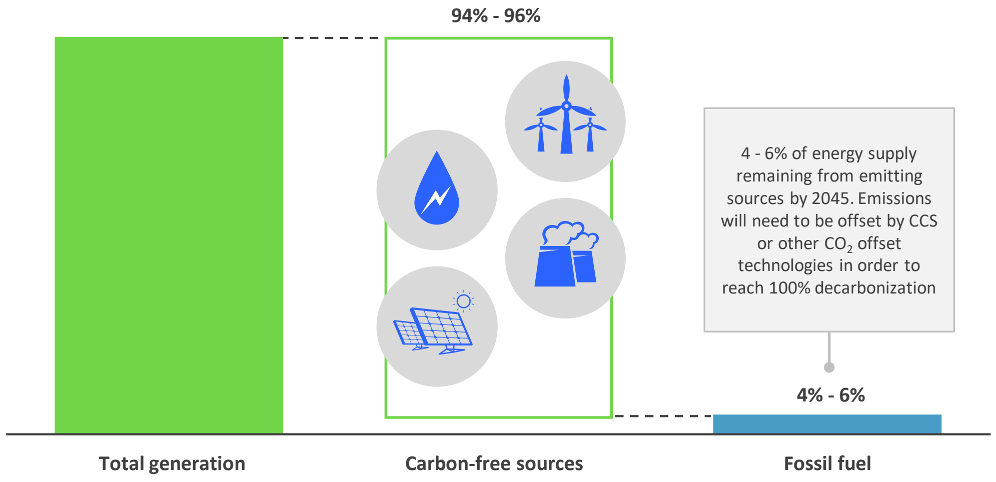
What would carbon-free electricity look like before 2050 according to Eurelectric?

The power mix envisaged in Eurelectric's scenario is more decarbonized compared to DNV GL's ETO. The least-cost energy systems that can achieve carbon neutrality are characterized by 4 factors:

1. **Very high penetration of renewables and high transmission build.** Renewables, including hydropower and sustainable biomass will represent more than 80% of energy supply by 2045 driven by rapid cost decline, increasing capacity factors, and large untapped resource potentials. Solar and wind will account for ~15 % and ~50% of supply respectively. This will be enabled by significant transmission build within and between regions, which allow the benefits of renewables to be shared across Europe
2. **Important need for system balancing and flexibility provided by multiple sources.** A system-wide shift from dispatchable generation to renewables require hour-to-hour as well as seasonal balancing to respond to the variability of production. In a high-renewables future this will be provided by competing sources from both within and outside the power sector. Traditional sources include conventional firm generation capacity such as hydro and nuclear power. In addition, Eurelectric will see a much larger role played by demand side response from dispatch of new electric end-uses such as electric vehicles, as well as storage and flexible production of electric fuels such as hydrogen and power-to-gas or power-to-liquids.
3. **Changing role of fossil generation.** Fossil energy supply will be gradually phased out and represent only ~5% of total energy supply by 2045. However, gas will still account for ~15% of total installed capacity in order to secure system reliability, especially in regions that don't have access to hydro or nuclear. CCS can be a solution to abate emissions from centralized fossil generation that is operating at sufficient utilization to justify the high upfront costs required for these installations. While CCS is still an immature and expensive technology, there are potential synergies in technology development and scale advantages as it is also likely to be needed for other sectors where no other solution is feasible.
4. **Decreasing costs of carbon neutral technologies as well as innovation to develop technologies that can abate the last tons of CO_2 emissions.** Uptake of renewables will rely on continued technological development and cost improvements for these technologies, especially in less developed industries such as offshore wind.

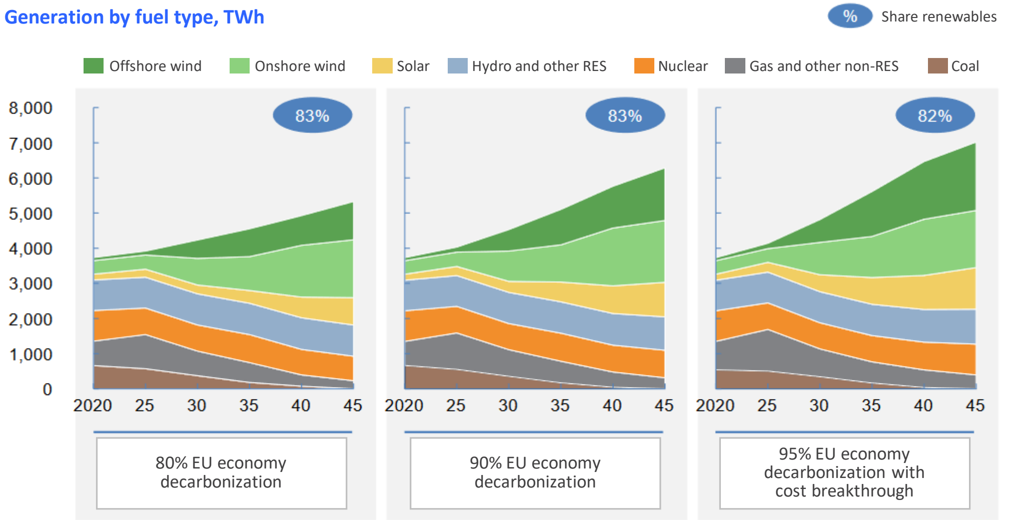
Figures taken from Eurelectric's Decarbonisation Pathways

95% of emissions are abated through a transition to carbon neutral electricity supply



4 - 6% of energy supply remaining from emitting sources by 2045. Emissions will need to be offset by CCS or other CO_2 offset technologies in order to reach 100% decarbonization

Generation by fuel type, TWh



The necessary enablers according to Eurelectric

Achieving this ambitious objective will require the fast implementation of six enablers across society:

1. Political commitment to deep decarbonization across all sectors of the economy and across regions. Continued efforts to integrate the European energy system
2. Active involvement of citizens e.g. through demand response and prosumers and increased social acceptance for high renewables build out and new transmission lines
3. Synergies with other sectors. For example, P2X and H_2 production enable decarbonization of other sectors while providing balancing capabilities to the power system. Existing gas pipeline infrastructure can be repurposed for power to gas and hydrogen transport and storage
4. Efficient market-based investment frameworks and adequate market design to trigger investments in a high renewables-based system. For example, resources must to a larger extent be valued based on their contribution to system reliability. Meaningful CO_2 price signals will also be required to sufficiently incentivize full decarbonization
5. A smarter and reinforced distribution grid that integrates new market participants (e.g. decentralized solar PV and local flexibility sources), and plays a significant role in consumer empowerment through managing local congestions and redispatch security of supply and grid resilience issues
6. The path and investments required to reach full decarbonization differs by country as European regions have different existing electricity mix and resources available. To ensure just energy transition, support and dedicated EU funding will be required for Member States that face a more difficult starting point in the electrification and energy transition journey.

3

CHARACTERISTICS OF EUROPEAN SEAPORTS

The role of ports as logistic hubs for transport of cargo and people

In this study we focus mainly on seaports in Europe, even though we refer to ports only. Ports are essential for different types of transport across the whole of Europe, for various reasons. First, ports provide support to numerous ships and vessels (transferring people or cargo), allow for transshipment of cargo and offer space for industrial and commercial activities. Ports also host the interconnection of different sectors, such as maritime and inland transport, energy generation and nearby industrial processes.

All ports face big challenges to accommodate expected trade growth

The Port 2030 report (4) concludes that all ports across the trans-European network (TEN-T) will be needed to help accommodate the expected growth in traded goods. Ports also need to adapt to new requirements like:

- The increased size and complexity of the fleet, in particular ultra-large container ships, new types of Ro-Ro ferries and gas-carriers.
- Requirements on environmental performance and alternative fuels (e.g. cold ironing and LNG). The EU’s Clean Power for Transport initiative and the proposal for a Directive on the deployment of alternative fuels infrastructure requires that all maritime ports of the TEN-T Core network are equipped with LNG refueling points according to common technical standards by 2020.
- Requirements related to trends in the fast-growing cruise industry and in logistics and distribution systems have led to an increased need for value added services within the area of the port
- Requirements related to developments in energy trades, with a shift from oil and refined products towards gas; a need for significant gasification facilities in ports; potential volumes of dry biomass and CO_2 transport and storage.

European port are an essential part of the Trans European transport network

According to the EC study Motorways of the Sea (5) there are 331 seaports in the TEN-T core and comprehensive network. These ports processed 3.5 billion tons of throughput in 2016, of which 2.6 billion tons were handled in the 84 ports situated on the Core Network Corridors (CNCs). Core ports are ports that are essential for the cargo handling to the European mainland and are nearby or well-integrated in the main international transport corridors (road, rail and inland waterways). Comprehensive ports primarily have a national or regional role.

European ports differ substantially in the cargo they handle

European ports handle different mixes of cargo. Valencia can be typecast as a container port because over 50% of the cargo handled in the port is container transport. In the Port of Bergen 90% of the cargo is liquid bulk. In Amsterdam and Immingham, UK dry bulk (minerals, grains) is dominant with a 45% share. According to the EC study Motorways of the Sea (5) the average share of dry bulk and container transport in the main 331 European seaports is 22.5% for both. Liquid bulk has a share of 38% and roll on-roll off 12.5%. The remaining 4.5 % is labelled as other cargo.

European ports differ in access to the sea

Most European ports are located either at an embayment or an engineered coastline and therefore have direct access to the sea, for example Barcelona. Others are located at estuaries, with sea access via some river-navigation, such as Rotterdam, Antwerp and Hamburg.

Dwelling time differs per vessel type and region

According to the European Port Industry sustainability report 2017 (6) the stay of vessels in European ports differs a lot per type of vessel and per region/sea. Average dwelling time is between 0.99 days for tankers and 2.75 days for bulk carriers. The average dwelling is the lowest in the Scandinavian-Baltic regions (0.96 days) and highest in the black sea (2.37 days).

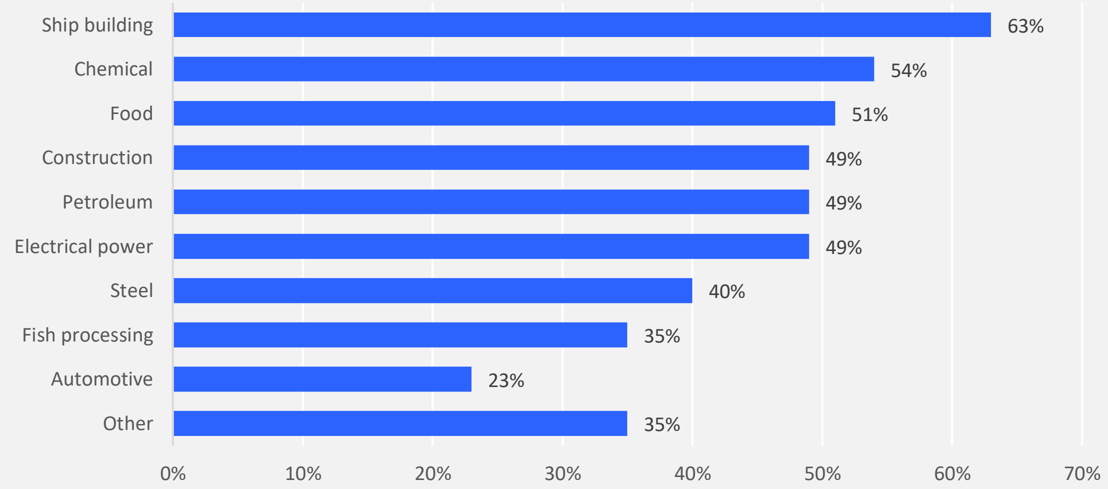
European ports are often home and key partners of industrial clusters

In 2016 the European Sea Ports Organization (ESPO) published a fact-finding Report ‘Trends in EU ports governance’ (7). 86 port authorities from 19 EU Member States, Norway and Iceland completed a web-based survey. Together, they represent more than 200 ports and more than 57% of the overall volume of cargo handled in the European Union. According to this survey 66% of the respondent ports are host to industrial plants. Industrial partners may lease the port land from port authorities through lease agreements or mixed contracts (i.e. including works) or own at least partially the land where they are located. The contracts of the port authorities with industrial companies are usually for a period of 20 to 30 years. See Figure 8. The percentages indicate the fraction of ports hosting this type of industry.

European ports are often main entry points of energy commodities

Energy commodities represent a substantial part of the traffic volumes of many European ports. Ports play a key role in the import, export, storage and distribution of fossil- and other energy sources (crude oil, gas, LNG, coal, biomass). For example, 25% of port respondents said over 50% of the cargo volume they handle is energy related (coal, oil, gas, biomass). The ESPO survey also showed that 50% of respondent ports have energy production plants located in the port area (see Figure 9). Next to traditional fossil-fuelled energy plants, ports are increasingly hosting sustainable energy generation with wind and solar, biomass and waste-based energy production plants. The figure shows that 38% of the ports have wind generation on their land (7). 31% of the ports have coke & coal and oil & petroleum (CCPG and or CHP) based power plants.

Figure 8 Sectors of industry in ports (7)



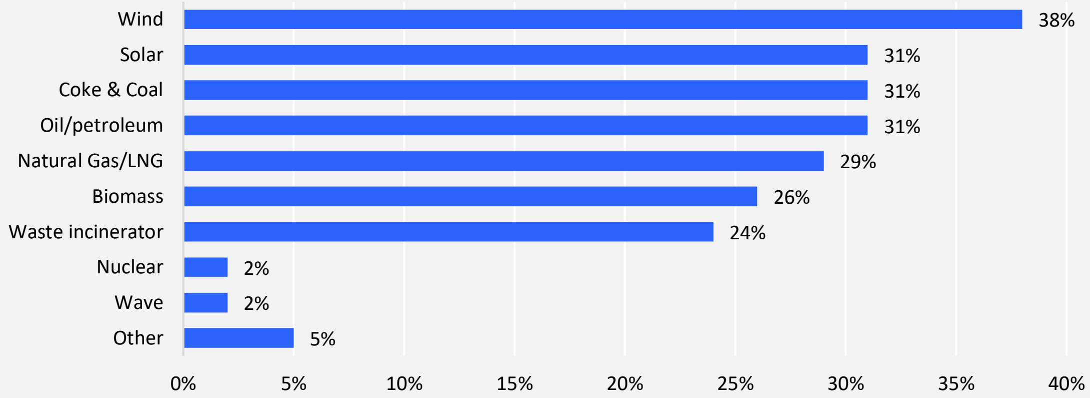


Figure 9 Energy generation sources in ports (7). The percentages indicate the fraction of ports that have a specific energy source

Governance: the important role of port authorities

According to the ESPO survey (7) almost 90% of the port authorities in Europe are publicly owned. When asked which option describes the goals of the port authority best, 63% of respondent ports chose the balance between public and private interests. For 28% of the respondents, the realization of public interests is the main goal. Port authorities pursue multiple objectives (See also Figure 10).

The main power demand comes from cargo handling, cooling and cold ironing

Focusing on electrification, the different types of cargo must be in sync with the electric energy demands of ships at berth. In particular, and mostly regarding core ports, this demand comes from

- cargo handling, directly related to the energy demands of cranes and pumps used for loading and unloading
- cooling supply to reefers (refrigerated shipping containers) with temperature sensitive goods
- cold ironing, covering idle energy demands of the ship at berth. In this case, passenger ships and cruise ships (serving 500-5000 people) have by far the greatest energy demands.

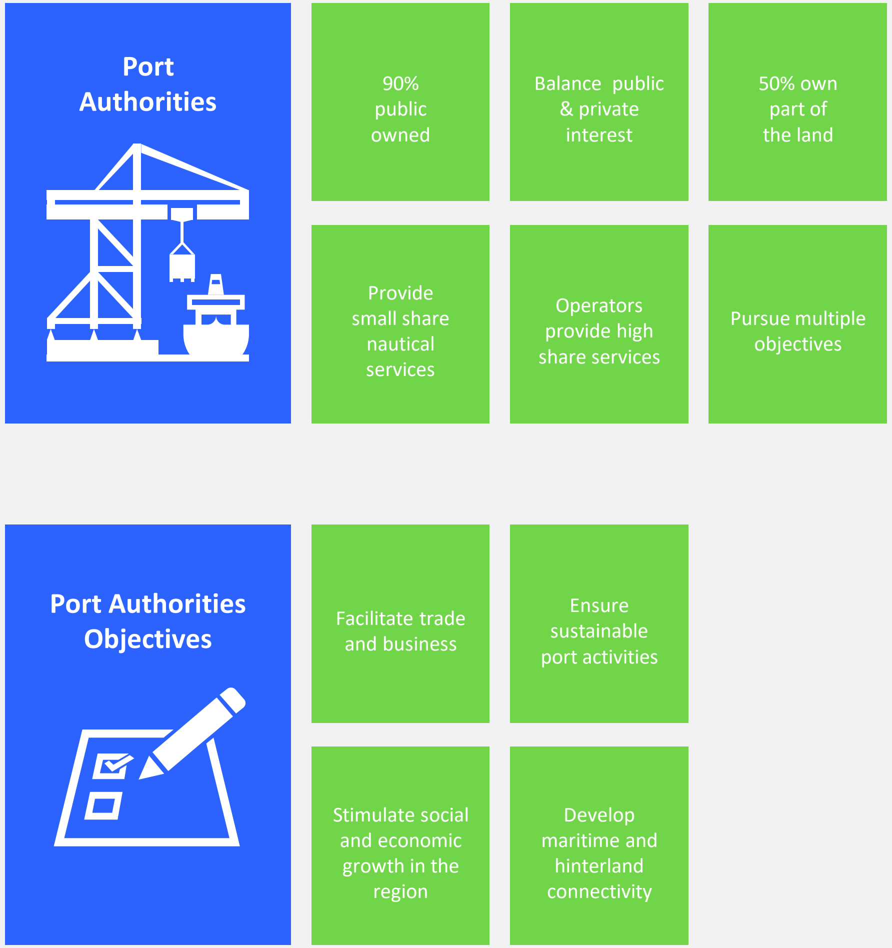
Regarding comprehensive ports, charging of short-sea shipping battery vessels could be the most energy demanding activity from an electrification point of view.

External drivers for ports

This report focusses on ten Green Transitions towards decarbonization that impact the developments of European ports. But besides and above the impact of these ten transitions the future of ports will be influenced by global trends that impact trade volume and intercontinental trade patterns and main trends in the shipping sector. Here we list the main trends that impact future ports, but do not directly lead to decarbonization:

- Economic growth (global and in Europe)
- Population growth
- Geopolitical tension (threat of trade wars)
- Internet of Things, Artificial Intelligence and robotics
- Industry 4.0: Additive manufacturing, 3D & 4D printing and robotics
- Climate change (resilient, adaptive cities)
- Oil prices
- Pandemics

Figure 10 Port authorities: roles and objectives



Port Authorities

- 90% public owned
- Balance public & private interest
- 50% own part of the land
- Provide small share nautical services
- Operators provide high share services
- Pursue multiple objectives

Port Authorities Objectives

- Facilitate trade and business
- Ensure sustainable port activities
- Stimulate social and economic growth in the region
- Develop maritime and hinterland connectivity

4

TEN GREEN TRANSITIONS TOWARDS DECARBONIZATION

In the following chapter we describe ten Green Transitions which enable the decarbonization of ports and nearby industries. Some transitions are specific for ports such as the fuel switch for maritime and electrification of port-connected activities. Others are more general, such as electrification of industry and the phase-out of fossil fuels for power generation.

4.1 ELECTRIFICATION OF PORT-CONNECTED ACTIVITIES

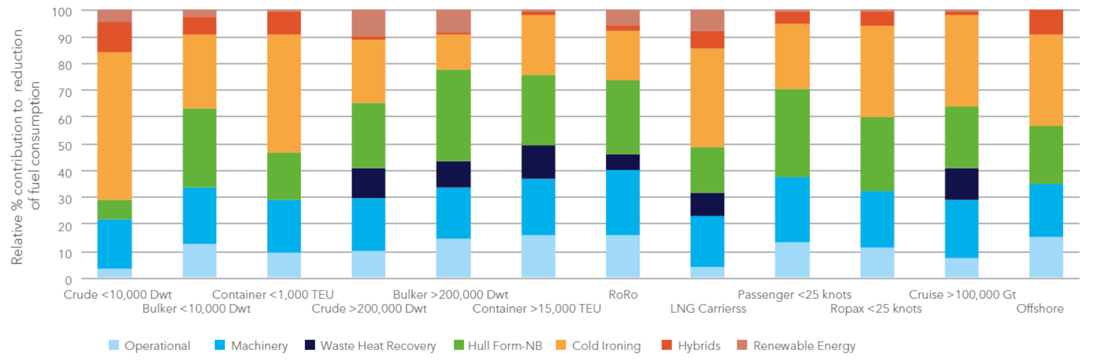
What and why

With the increased penetration of renewable energy sources such as solar PV and wind power, the carbon intensity of electricity generation will decrease significantly. Switching from fossil fuels to renewable electricity will therefore reduce carbon emissions on a global scale.

There are other benefits to electrifying processes and activities. Such as, fewer local emissions, higher reliability, efficiency and lower maintenance costs when using electromotors instead of internal combustion engines. Activities in ports provide ample opportunities for decarbonization through electrification. These activities include; bunkering; logistics and freight handling with cranes and logistical vehicles; (cold) storage; service vessels, such as pilot boats and tugboats; and offices and buildings. Initially only ‘wired’ equipment could be electrified, such as static cranes and rail transport. However cheaper and better batteries have increasingly allowed electrification of mobile—non wired—applications, such as vehicles.

A specific topic for ports is cold ironing, also called shore-to-ship power (SSP). The term cold ironing means that a ship docked at the port is supplied with electricity from shore and thus can avoid running its engines or diesel generators to power on-board activities. Cold ironing has the benefit that local air pollution, noise and carbon emissions are reduced. This can result in a significant reduction of carbon emissions for existing ships, especially for smaller ships, that on average stay longer in port (see (8)).

Figure 11 Cold ironing has a significant impact on reducing fuel consumption of existing ships, especially for smaller ships that stay longer in port (8)



The electrification of port-connected activities will result in an increase of port electrification and therefore a reduction of local emissions. Other, global trends, such as electrification of road transport might also have a major impact on logistic hubs, such as ports. Developments in logistic optimization, will have a significant impact on energy efficiency and emissions, though not always directly in the port itself. An example of such optimization is slow steaming, a ‘Just-In-Time’ (JIT) solution that works by adjusting the cruising speeds of ships based on availability and scheduling of available berths, resulting in significant fuel savings.

Challenges

Today most port-connected processes and activities that can easily be electrified, have been. More difficult to electrify activities include local logistics, such as mobile cranes, trucks and lorries, cold ironing and activities that are costly or difficult to reach with electric cables, such as some cranes.

Ports are large logistic hubs and are greatly affected by the electrification of other sectors, such as nearby industry and electric road, river, and short distance sea transport, which needs to be charged in the port. The electricity infrastructure does not only need to facilitate the electrification of processes within the port itself, but also needs to facilitate the electrification of transport. This means that a huge capacity upgrade is required for the local electricity distribution infrastructure. This requires major investments as well as sufficient space to deploy the necessary infrastructure, such as cables and charging stations for electric vehicles and ships.

Impact on ports and the power sector

A quantification of the impact of electrification of port-connected activities can be found in chapter 5. Because of constraints in the infrastructure and in available space to expand this, ports need to prioritize which activities are most worthwhile to electrify first, and some ports look at LNG as an intermediate solution.

A port is called ‘shore power ready’ when its electric infrastructure has sufficient capacity. While major progression has been made (9), standardization of the power supply between the port and the ship is not finalized. Ocean going ships will dock in multiple ports in different regions around the world, thus cold ironing needs a global standard, which needs to be compatible with the different electricity infrastructures around the world. While requiring a major effort in coordination and international standardization, ports might invest prematurely in cold ironing infrastructure, pushing this forward. There might be some risk involved in this move, because this infrastructure might be underutilized, as most ships are not yet ready; the technology might not be compatible with developments of a possible future standard; and because it might affect the competitive advantage compared to competing ports. Still, ambition and local emission targets may cause ports to make cold ironing obligatory for visiting ships to use.

4.2 FUEL SWITCH FOR MARITIME TRANSPORT

What and why

Maritime transport is expected to grow significantly till approximately 2035 and then remain stable towards 2050 (10). In 2050, bulk carriers will likely continue representing the largest share of seaborne trade followed by container ships. The contribution of LNG and LPG carriers increases sharply and despite the expected high degree of electrification of road transport, oil transportation is still a significant part of the total seaborne trade in 2050.

In 2018 the estimated global emission of energy related CO_2 was 33.1 Gtonnes (11). The estimated emission from the world fleet is 870 Mtonnes (10) accounting for 2.6% of the global energy related CO_2 emissions. Reducing maritime transport related emission is therefore significant in reducing the global carbon emissions.

Fuel switch is the transition from conventional maritime fuels to carbon-neutral fuels. The easiest way is to blend in low-carbon drop-in fuels, e.g. in the form of biogas and small amounts of hydrogen for LNG-powered vessels. Other fuels, like ammonia or electricity, will require more extensive modifications in the vessels themselves and in the shore-side fuel infrastructure.

Challenges

The International Maritime Organization (IMO) has set a target of greenhouse gas emission reduction of 50% in 2050 compared to 2008. Given the expected uptake or maritime transport this translates to a 70% reduction of CO_2 intensity (CO_2 emission per tonne-mile) in 2050.

Multiple actions can be taken to reduce greenhouse gas emissions, as shown in Figure 12. This figure shows one of the pathways towards 2050 with a focus on design requirements. It is one of the three pathways explored in DNV GL's Maritime Forecast to 2050 (10). Figure 12 shows that fuel switch is a significant contributor. This is emphasized in Figure 5 (section 1.3) where carbon-free fuels (electricity, ammonia, advanced biodiesel) make up for a significant share of the maritime fuel mix.

An alternative pathway focusses on biofuels and carbon-based electrofuels. These drop-in fuels require only limited or no modification to engines and fuel systems to replace or blend with traditional fuels used by internal combustion engines. Nitrogen-based electrofuels such as ammonia can also be produced from hydrogen; but they require more moderate modification to engines, and to fuel storage and supply systems, to replace traditional fuels. While electrofuels have clear advantages with regards to technical application and GHG-footprint, producing them is currently expensive and energy intensive. For biofuels, the challenges are related to price and sustainable production in sufficient volumes.

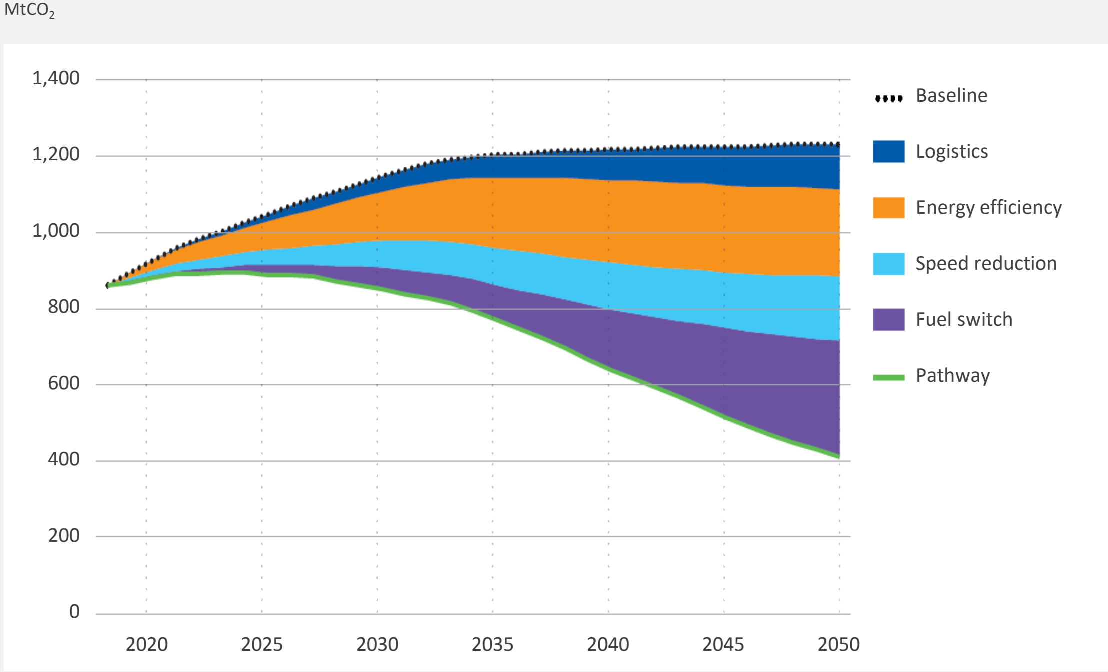
Widespread adoption of low-emission and carbon-neutral fuels could potentially take a long time, factoring in the time needed to properly develop low-carbon fuels, production capacity and infrastructure and to scale this.

Electrification of ships may not only become important because of CO_2 emission reduction. Electrification of ships increases the overall energy efficiency, the flexibility of operations and enables the option to become zero emission, not only for CO_2 but also for Nitrogen Oxides (NOx) and Sulphur Oxides (SOx), for instance near and within a port area. A hybrid option, where ships switch to full electric mode in and near ports or other emission sensitive locations could become a feasible option, e.g. if port emission regulations are tightened. An example is the "fjord" mode for cruise ships (12).

Challenges for the electrification of ships:

1. Technical barriers
   - Insufficient grid quality, stability and capacity
   - Non-standardized shore power systems
   - Fast development of ship, charger and battery technology compared to the long lifetime of a shore power system
2. Financial
   - High initial investment in the system in a market with an uncertain growth
   - High grid connection cost
   - Low potential savings for electrification compared to alternative fuels
3. Regulatory
   - Shore power is not mandatory
   - No level playing field (e.g., difference in taxation of fossil fuels and electricity)
4. Market
   - Split incentives between the ship owner (investor) and the charterer (who pays the fuel)
   - Start-up challenge: how to break through the no-users-no-chargers impasse

Figure 12 Example of a pathway to achieve the IMO GHG reduction target (10)



Impact on ports

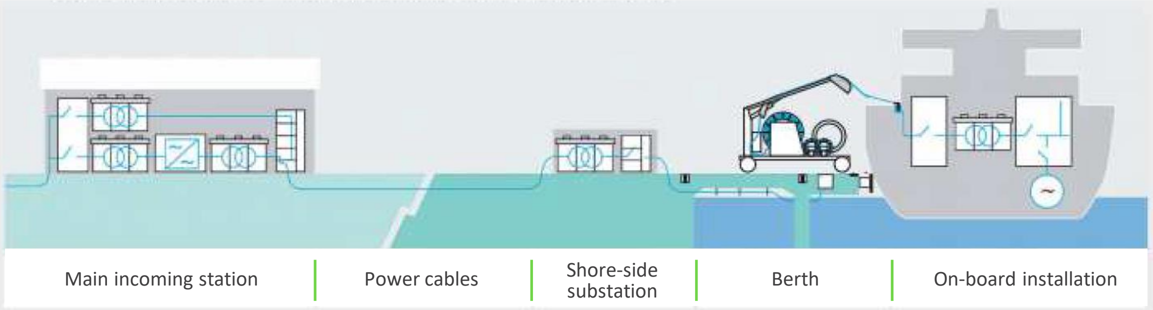
The impact of fuel switch on ports will be mainly in changes of bunkering facilities. Regular facilities for heavy and medium fuel oil will be complemented with bunkering/charging facilities for liquefied gasses (LNG, LPG) or hydrogen-based fuels (such as ammonia) and electricity, both for transport and cold ironing (see section 4.1: Electrification of port-connected activities). This will require additional investments in storage facilities and infrastructure. The lower energy density of the alternative fuels may also require a much finer granularity of bunkering facilities as ships will have to bunker more often. This poses a challenge to port authorities as they have to decide in which fuel infrastructures to invest. Shore power systems potentially to be used for both cold ironing and charging of batteries on board ships seem a no-regret option as electricity is a common denominator in decarbonizing ports.

Impact on the power sector

The impact on the power sector is mainly twofold:

1. The required grid capacity is expected to increase significantly. Chapter 5 will present the results of quantifying the need for additional electricity for fuel switch.
2. The quality and stability of the grid may be adversely affected by heavy charger equipment. These are semiconductor type of equipment and may for instance cause resonances in the grid that decrease the grid stability.

Figure 13 Example of a charging structure of electric ships



4.3 ELECTRIFICATION OF INDUSTRY

What and why

As described in chapter 3, several European seaports host industrial clusters. In order to reduce overall greenhouse gas (GHG) emissions in the EU, as mandated by the amending Directive on Energy Efficiency (2018/2012), industries must reduce GHG emissions with 45-55% by 2030 and 80-100% in 2050. Main emitters are the sectors refineries, iron & steel, chemical and non-metallic minerals (13). They are responsible for almost 75% of the emissions. An important enabler of emission reduction in industry is electrification. Electrification of industry will be enabled by innovations in wind and solar PV, energy storage (e.g., batteries), low-carbon hydrogen production, heat pumps and the growing availability and declining prices of wind and solar based electricity. Besides electrification, part of the industrial emission reduction will be in more energy efficient technologies and processes.

Electrification of industries will lead to:

- Replacement of fossil-based boilers and furnaces and steam producing appliances by electricity powered alternatives.
- Increased focus on heat integration and use of ambient heat (water, soil, air) plus accompanied heat pump (leading again to growth in electricity consumption).
- Use of electricity for Carbon Capture Storage & Utilization (CCS&U) and hybrid hydrogen production (electrolysis).
- On site power generation: solar, wind, hydro, geothermal.

Challenges

The main challenges for electrification are:

- High upfront costs and lack of a level playing field. Electrification is currently leading to high investments (and thus relatively long pay back times compared to other investments) and higher energy bills in some countries (in particular higher grid tariffs and higher taxes compared to gas).
- Immature appliances and/or value/supply chain for some technologies. This includes the lack of skilled workers to develop, install, operate and maintain the new electrical appliances.
- Lack and/or cost of electricity infrastructure (capacity). A further expansion of the electricity network to distribute the additional electricity is expensive in densely populated areas with big industrial clusters. The process of permitting, planning and implementation is long, up to 10 years in some countries.
- Risk averse attitude. The transformation to innovative (immature) electrified appliances comes with risks during installation and operation. Industries tend to avoid these kinds of risks for their integrated production processes/lines.
- Reliability of electricity supply and loss of flexibility compared to the current situation. The cost of storage of electricity (as a back-up) is still high compared with storage of gas or oil.
- Low prices of fossil fuels, which often don't pay any CO_2 related tax, when compared with prices of electricity.

Impact on ports

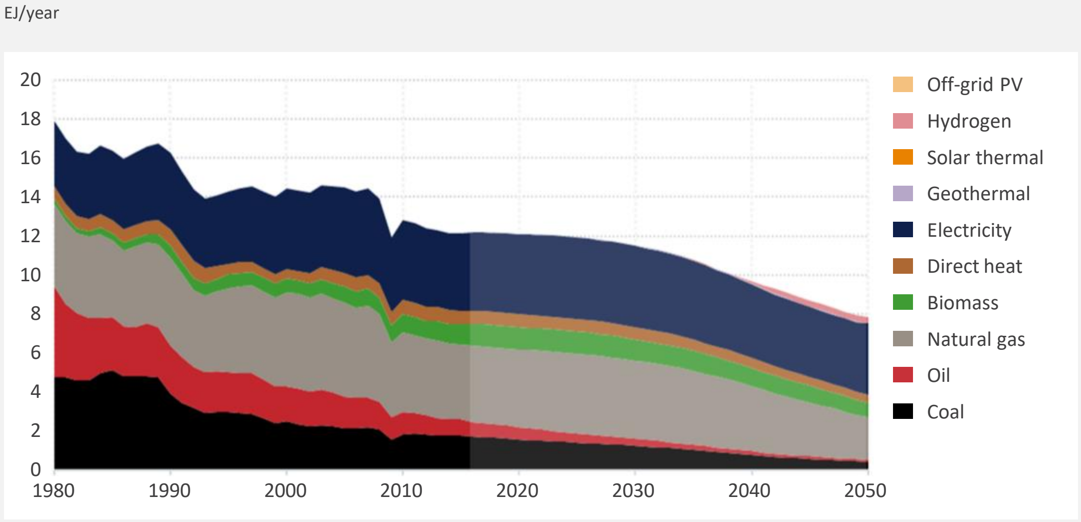
Electrification of industries could have the following impact on ports:

- Up to 50% decrease of 'fossil cargo' (oil, gas, LNG) with impact on terminals and industry
- Improving local energy grid and the need to enable and/or provide utility services
- Facilitating industrial symbiose to enable industry to lower primary energy demand further.
- Providing flexibility services.
- Providing land for electricity and other energy production facilities (solar, wind)
- Providing land for hydrogen production (electrolysis) leading to extra electricity demand.

Impact on the power sector

- Growing electricity demand depending on pathways. According to DNV GL's Energy Transition Outlook the current share of electricity use of the industry in Northern Europe is 33%. The forecasted share in 2050 is almost 50% (see Figure 14).
- High investments needed in electricity port infrastructure.

Figure 14 Expected energy consumption of European manufacturing industry (1)



4.4 INTEGRATION OF OFFSHORE WIND

What and why

Another development that will have a major impact on the port's energy system is the connection of offshore wind to the grid. According to DNV GL's Energy Transition Outlook, offshore wind will grow in Europe from 16 GW in 2017 to 56 GW in 2030 and 168 GW* in 2050 (1). The strongest growth in European offshore wind is expected to happen in the North Sea, since the conditions are suitable there; a relatively shallow sea combined with strong and consistent wind speeds. However, the growth numbers vary strongly per country. Therefore, the way that this transition impacts the port and the port's electrical power system varies strongly across different European ports.

Challenges

One of the biggest challenges with integration of offshore wind is the connection to the onshore electricity grid. For Northern European countries, where offshore wind is feasible because of relatively shallow water depths, the wind capacity may exceed hosting capacity of the average substations at the shore, and the grid behind these substations. Expansion of the grid and substation capacity is expensive and often takes years, lagging the fast-growing offshore wind capacity. In addition, even when the grid would not be a limiting factor, the moments at which wind power is supplied does not always match electricity demand, leading to an imbalance in the electricity system. Therefore, in the long-term, only expanding the grid capacity is often not a viable solution for connecting offshore wind and a combination of measures is needed.

Impact on ports

The conventional role of ports is to support the delivery and shipment of cargo transport activities. However, ports around the North and Baltic Seas may play a major role in the development of offshore wind activities for two main reasons. Firstly, ports often have strong grid networks, connect large electricity consumers, and are the natural landing point for the huge planned capacity of offshore wind. This offers the opportunity to connect large quantities of renewable electricity to the port's grid and directly consume it, e.g. by electric heating. In addition, ports often have strong industrial clusters, which have the potential to offer flexibility that can be used to have a better match with offshore wind electricity production profiles. In addition, many industrial processes make use of hydrogen, which is currently in most cases produced using natural gas. By locating an electrolyser close to large ports, industry would get access to large quantities of hydrogen, directly produced from wind power. In addition, so-called "Power to X (P2X)" can potentially be used for further processing to make other feedstock products from the hydrogen. The facilities to do this chemical processing are naturally present in large ports. This extended role for ports should be compatible with existing and future regulatory framework.

The second reason why ports are vital for the development of offshore wind is their potential to support the construction and operation activities of the offshore wind farms. Not only the installed capacity of wind turbines, but also the size of individual wind turbines will significantly increase. To manufacture and transport the materials needed for these large wind turbines, large lay-down areas and heavy lift equipment is required, at locations close to the shore. The only logical locations to do this are ports. This raises opportunities for ports to contribute to the offshore wind manufacturing industry, but also imposes large technical challenges. It requires efficient design and infrastructure of ports to deal with the storage, assembly and (un)loading of the components prior to the offshore wind installation (14). 4C offshore, a market research organization focused on offshore wind, identified 46 European ports that are suitable for assembling offshore wind turbines. Some examples are the ports in Esbjerg in Denmark, Cuxhaven in Germany, Hull in the UK and Rotterdam in the Netherlands (15).

We identified here a role for ports in avoiding grid investments for offshore wind integration. This role should be compatible with existing or future regulatory frameworks**.

Impact on the power sector

Ports may offer a suitable location for connecting offshore wind to the electricity grid. Especially industrial ports, which already have strong grid connections to industry. Ports also offer opportunities for onsite hydrogen production from renewable electricity, by use for port industries or for export. These developments point towards a heavy electricity grid in impacted ports to accommodate offshore wind connection, industries and hydrogen production. This grid might be privately owned because of its specific use. Issues to address are:

- Is it advantageous to connect wind parks to port industries with a direct line?
- How do we integrate the role of the DSO and TSO of the electricity system with the relationship between ports and offshore wind parks?

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* Eurelectric believes that the build out of offshore wind will happen faster than what the ETO concludes. By 2045 offshore generation can reach 1945 TWh (and 467 GW of capacity), according to Eurelectric Decarbonisation Pathways.

** It is worth noting that some geographical regions of the EU will find it easier to develop and roll out offshore and CCS technologies compared to others, for instance, Southern European countries. The role of hydrogen In areas areas where there are constraints to offshore or CCS developments may therefore be more limited

4.5 ENERGY SYSTEM INTEGRATION

What and why

Energy system integration (or sector coupling) describes the trend that the value chains of different sectors are becoming more interconnected. Typically, this originates from coupling of energy vectors between sectors that previously were characterized by one dominant energy carrier e.g. electricity for power application, natural gas for (industrial) heating and feedstock and oil for transport and off-grid electricity generation. Energy system integration is driven by renewable penetration, the increased need for flexibility in energy demand and supply, efficiency gains and optimization – it is the object of upcoming EU legislation as well. The trend is beginning to gain traction because of the increasing pressure to decarbonize; to become more efficient and sustainable; to optimize energy infrastructure, and to reduce or eliminate waste by using the waste (including waste heat) as feedstock.

Energy value chains have always been connected. For example, because of competition, power prices on wholesale markets are determined by the power generation with the highest running cost that is necessary to satisfy demand. This is directly coupled with the price of the ‘fuel’, such as coal, gas, or free ‘fuels’ such as solar and wind. Another example is Combined Heat and Power (CHP) generation. Combined heat and power plants are very efficient, because their ‘waste’ heat is their main product, thus the electricity they produce at the same time can be considered to have a relative efficiency of almost 100%.

Energy system integration is gaining more interest because of ongoing electrification of final energy use that would normally be served by other fuels (e.g. natural gas). This includes the electrification of road transport by electric vehicles; electrification in industry; and electrification of heating of buildings by heat pumps. Electrification increases efficiency and reduces (local) carbon emissions, and the ongoing decarbonization of electricity supply by renewable electricity will automatically result in the decarbonization of electrified demand.

Challenges

Electrification is an attractive, efficient, and uncomplicated way to decarbonize energy use. The increase of renewable electricity generation makes carbon-free electricity available. However, the variability of renewable electricity production by wind and solar power will make electricity prices more volatile. Electricity prices will drop and rise depending on the availability of renewable power generation.

This means that energy demand that is flexible will be able to reduce energy costs. Demand response, flexible generation and electric mobility will anticipate and react to price variations. Energy demand that requires low investments to be electrified, and can fall back to its original energy carrier, will emerge to benefit from periodic very low electricity prices. For example, opportunity heating with electric boilers can utilize this cheap electricity, while avoiding the peak prices by switching back to the natural gas boilers.

In 2050, periods with excess variable renewable generation grow to be more than one third of a year, if demand does not adapt. Naturally demand will adapt, and this energy will partly be absorbed. This demand will include electric vehicle charging and grid connected batteries. It will also include flexible demand that derives its flexibility from being able to switch back to another energy carrier. This includes opportunity heating and hydrogen production, which can fall back to gas as feedstock (see Figure 15).

Impact on ports

As well as connecting different sectors through transportation and logistics, ports are now emerging as energy hubs where many trends driving energy system integration are coming together:

- Landing of large feeding of offshore wind;
- Bottlenecks in the electricity networks;
- Larger electricity demand due to fuel shift within both maritime and land transport;
- Carbon capture and storage opportunities offshore (especially in the North Sea);
- Changing shipping infrastructure, for example terminals for LNG, hydrogen, and biomass.

Around the North and Baltic Sea, ports are the natural landing point for the huge planned capacity of offshore wind. A large part of this power cannot be transported inland and will need to be absorbed in and near ports by industry through opportunity heating and hydrogen production. As this demand is only flexible because it can fall back to natural gas, it will benefit from nearby CCS facilities to avoid carbon emissions. Other drivers also impact ports in the Mediterranean and at the Atlantic, and challenges in infrastructure also emerge because of electrification of inland and short sea transportation that needs charging.

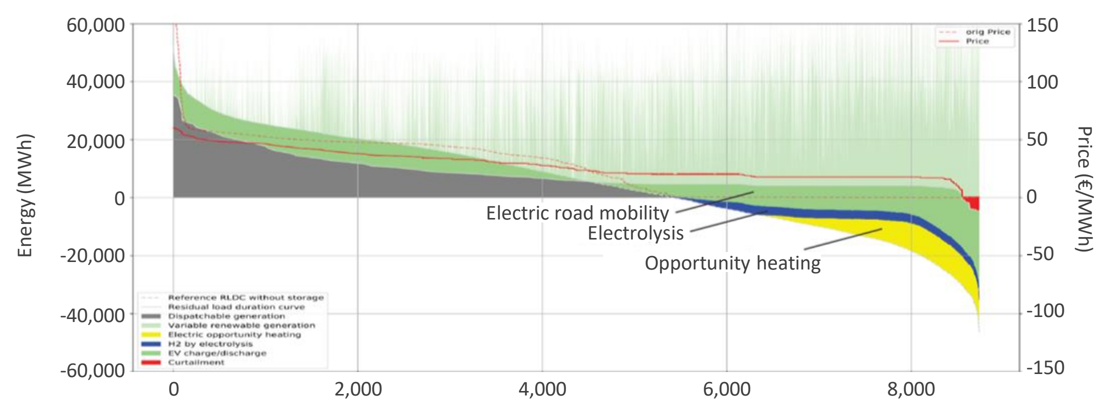
Impact on the power sector

Challenges regarding energy infrastructures are already manifesting themselves, both with regards to necessary investments and in operating and managing them. Energy system integration does not only couple sectors, but also energy infrastructures and their regulatory frameworks. Regulations for managing and operating these infrastructures are not optimal for such specific and interactive infrastructure system as supplying the energy for an industrial or logistics port. This means that regulated network operators, might struggle to facilitate this optimally.

An example is opportunity heating. This requires a large grid capacity, but also needs to be very cheap. It is designed to switch back and forth between cheap renewable electricity and natural gas. Therefore, grid capacity supporting opportunity heating does not need to be n-1 redundant (this implies that the failure of one component should not affect power supply). Instead opportunity heating can support n-1 redundancy by having a special load shedding contract.

To integrate infrastructures and optimize planning, investments, and operation, a specialized system operator might be set up by the port authorities or a traditional infrastructure operator. This port energy system operator can look at the integral energy infrastructures of the port, including demand and supply. It can manage and optimize the total energy system as one integrated system, avoiding the excessive investments that would be necessary if infrastructures would be managed individually.

Figure 15 Impact of energy system integration on the electricity residual load duration curve in NL 2050, i.e. the load that is not covered by variable renewable energy, sorted by size (16)



4.6 HYDROGEN AS FEEDSTOCK AND ENERGY VECTOR

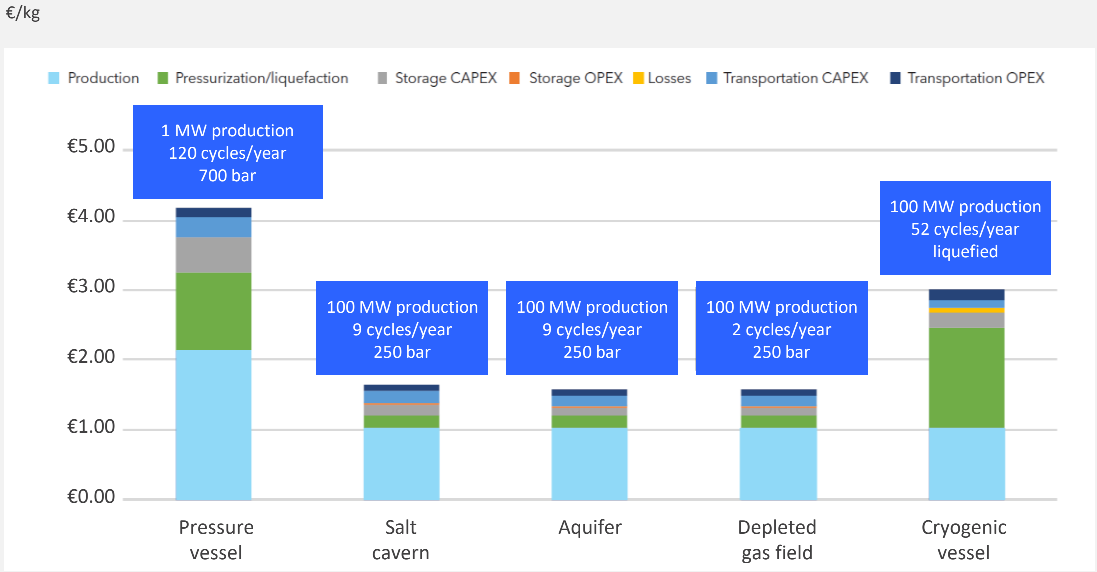
What and why

As mentioned in the European Green Deal, electrification is the most efficient and sustainable way to decarbonize the economy. However, with current technology, it cannot reach all sectors. The so called hard-to-abate sectors, are not currently possible to electrify and hence to decarbonize. Technologies such as advanced biofuels, biogas and biomethane and hydrogen could play an important role in the decarbonization of these parts of the economy.

Hydrogen, depending on how it is produced, is a carbon-free energy carrier that can complement electricity in these areas, such as large scale and long duration energy storage, high capacity energy transport or to decarbonize residential heating in areas where more efficient options, such as electrification with heat pumps or district heating is difficult to realize. Hydrogen can also be used as feedstock to produce carbon neutral fuels for difficult to decarbonize sectors, such as aviation and intercontinental shipping. When produced from electricity these fuels are called electro or e-fuels and include ammonia, methanol, formic acid, synthetic methane (SNG) or higher hydrocarbons so-called synthetic fuels (syn-fuel). Except for ammonia these fuels require a sustainable carbon source to be produced as well, such as biomass.

Hydrogen is currently predominantly used as feedstock for the chemical and petro-chemical industry and produced from natural gas through steam reforming or partial oxidation. Hydrogen is mostly produced onsite, though hydrogen infrastructure does already exist, for example between the ports of Antwerp and Rotterdam. It has potential to decarbonize industrial processes, such as replacing cokes as a reduction agent to reduce iron oxide to iron, and replacing natural gas as fuel for industrial high temperature, high volume heating (17).

Figure 16 The levelized cost of hydrogen storage, depending on application (cycles per year) (18)



Hydrogen, produced via electrolysis, has a huge potential to facilitate the energy transition, characterized by a rapid increase of variable renewable energy in the electricity mix. Electrolysis can absorb large quantities of renewable energy to be stored in the form of hydrogen.

Impact on ports

Hydrogen is a potential feedstock for carbon neutral fuels for ships, predominantly ammonia. Industry focused on producing and storing ammonia from hydrogen might emerge in bunkering ports. Though without government support it will be unlikely that this whole value chain will be powered only with excess renewable energy, because of low utilization.

Some ports are natural hubs for connecting offshore wind. Capacity constraints in the transmission networks will make transporting this energy further inland a challenge. This means these ports are places where an excess of renewable energy caused by offshore wind will be likely. Therefore, industrial areas near these ports are possibly the first places to benefit from excess renewable wind power. Converting this power into hydrogen (as well as heat) through electrolysis might first become economically feasible near ports, assuming industry can benefit from the products hydrogen, oxygen, heat.

Besides synergy between hydrogen production from electricity and hydrogen production from natural gas to produce a continuous supply of hydrogen, industry can benefit from other advantages offered by the port as well. This includes LNG supply through shipping, industrial clients for the produced hydrogen and synergies with existing infrastructures, such as for natural gas and possibly hydrogen and—around the North Sea—CCS infrastructure using depleted gas fields at sea (see chapter 4.8).

Impact on the power sector

The large-scale integration of variable renewable energy sources, leading to periods where it is not sufficient to meet demand and periods where it exceeds demand, is a major challenge. Flexibility from dispatchable generation, such as hydropower, demand response and battery storage, such as from smart (dis) charging electric vehicles, will be able to solve a significant part of this mismatch, but periods with excess and shortage of renewable energy remain. Excess electricity causes low electricity prices which will induce additional demand, assuming the duration of these periods are long enough to justify the necessary investments. This includes hydrogen production from electrolysis (see energy system integration Figure 15).

This opportunity demand will be integrated to supply existing hydrogen demand. Hydrogen electrolysers will be built next to traditional production installations based on natural gas. Production of hydrogen switches back and forth between electricity and natural gas, depending on electricity prices. This hybrid hydrogen production can offer significant flexibility to the power system and might become economical feasible well before 2035 (18).

In some EU Member States, hydrogen might play a role in large scale energy transportation. Large scale offshore wind requires huge transmission capacities to transport the energy to shore and further inland. For instance, the planned capacity of offshore wind in the North Sea is comparable to the entire capacity of most transmission grids in the countries bordering the North Sea. Industry, flexible enough to absorb part of this energy by converting it to hydrogen near landing points of offshore wind will have a direct positive impact on the necessary investments in the electric transmission grid inland.

Storing energy for months, to level mismatch in the electricity balance between seasons, is called seasonal storage. In the aforementioned example, seasonal energy storage in the form of hydrogen can help decarbonize dispatchable power. Stored hydrogen can be used as fuel for power production with (combined cycle) gas turbines or fuel cells (18). This requires large scale hydrogen storage, such as in subsurface salt caverns or aquifers to minimize storage costs (see Figure 16). Storage in depleted gas fields will still lead to carbon emissions because of contamination with natural gas. Whether or not seasonal storage becomes economical feasible before 2050 depends mostly on regulation and the cost of carbon emissions (16).

4.7 PHASE-OUT OF FOSSIL-FUELLED POWER PLANTS

What and why

Co-location of large fossil fuel or biomass-fired power plants in large ports is common because it has several advantages:

- There is an abundance of cooling water for power plants
- There is a large-scale bulk transportation infrastructure available for coal and biomass
- Co-location of industrial clusters in port areas results in both a significant electricity demand and the availability of a heavy electricity infrastructure.

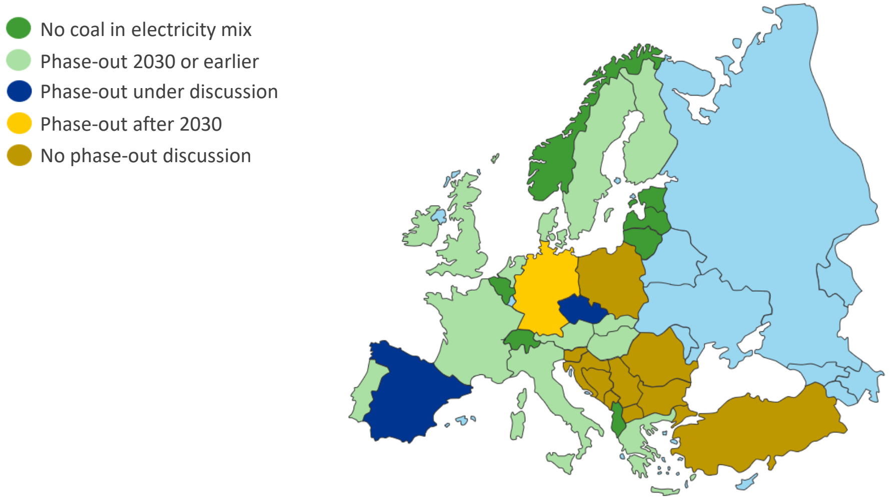
Fossil fuel fired power plants are a large contributor to carbon emissions in Europe. In 2017, the total fossil CO_2 emission in Europe was approximately 3.7 Gt of which 1.4 Gt (approximately 40%) related to the power industry (19). Based on the fuel mix shown in Figure 4 more than 60% of the power industry emission was related to coal-fired plants (including lignite). This is due to the share of coal-fired power production, the high specific CO_2 emission of coal and the lower efficiency of coal-fired plants compared to gas-fired plants.

Challenges

Phasing out fossil-fired power plants and especially coal-fired plants is a fast way of decreasing carbon emissions. Not surprisingly, it is an important topic in many European countries and emission reduction policies. Figure 17 provides an overview of the status of the coal phase-out discussion in Europe per January 2020.

Phasing out natural gas is less evident. In the Netherlands natural gas use is actively discouraged but this has additional reasons beyond CO_2 emission reduction. Other countries see natural gas-fired power plants as a good (low emission) replacement for coal-fired plants, but this is not a carbon-free alternative. To reach carbon neutrality by 2050 in the EU, fossil fuel phase-out should be a priority not only for the power sector but also for the entire European economy (including buildings, transport, industrial processes).

Figure 17 Status of coal phase-out discussion in Europe (61)



Impact on ports

The phase-out of fossil-fired power plants has multiple impacts. An important European wide impact is the potential decrease in grid frequency stability and a loss of adequacy (sufficient reserve and emergency capacity). These issues transcend the port area and are addressed on a national or European level.

The phase-out of fossil fuel fired power plants will have other impacts that are specifically important for ports. Depending on the type and age of the power plant, it will be retrofitted or preliminary amortized, leaving valuable land space to use for other purpose. Several options are viable to retrofit a relatively new coal-fired plant, such as converting the power plant to a natural gas-fired plant, a hydrogen-fired plant, or a biomass-fired plant. This is mostly a fuel supply side change as coal is replaced by biomass, hydrogen or natural gas.

For biomass, it means that the existing coal transport infrastructure must be replaced with a biomass infrastructure. This will have some volume impact (larger storage area, more transport volume) as the energy density of biomass is lower than that of coal. Biomass will require pre-processing before it can be used in an existing coal-fired boiler. The availability of biomass and the competitive use for biofuels and as future feedstock and carbon source are important issues that will limit the number of retrofits to biomass.

Conversion of a coal plant to hydrogen requires a hydrogen transport infrastructure and a source of carbon-free hydrogen. The coal-fired boiler will have to be retrofitted for hydrogen. This option is in our opinion less likely as hydrogen is more likely used in high temperature industry processes and for mobility applications rather than for producing electricity in a thermal power plant. Conversion to natural gas also requires a gas transportation infrastructure and retrofit of the boiler. This is an easy but non-carbon free alternative.

Another option is the addition of carbon capture and storage (CCS). This is an interesting option as a port location is often advantageous for transport of CO_2 to offshore storage sites. This option is discussed in section 4.8.

Port industries will change as well (less oil-based, more circular/hydrogen based). Closer integration with power production is foreseeable, see section 4.10.

Impact on the power sector

The impact on the power sector depends on the envisioned scenario. In the DNV GL's Energy Transition Outlook, natural gas and biomass are still viable fuels in 2050. There will be a need for firm capacity to keep the electricity system up and running during longer periods of high demand and low production of solar PV and wind (shorter periods can be met with battery storage). We expect the following impacts on the power sector:

- Coal-fired power plants will be phased out. To avoid loss of capital, retrofitting coal-fired power plants to, for example, natural gas, hydrogen or biomass is an option. Whether this option is technically and economically feasible, must be assessed on a case-by-case basis. If not feasible, abolishing coal-fired power plants frees up space for other port related activities, e.g. hydrogen generation.
- Conversion options to reduce the carbon footprint of coal-fired plants while maintaining firm generating capacity include repowering the coal units to biomass or retrofitting them with CCS. Both options are particularly suitable for coal units at port sites, as they provide advantages for transport logistic of biomass and CO_2.
- The market for conventional power is expected to change as part of the energy transition. Traditional base load power will disappear due to more variable renewable energy sources such as solar PV and wind turbines, undermining the business case for coal-fired power plants. Power plants will make less full load hours and require more flexibility (quick start-up and shut-down, good part-load behaviour). Retrofitted coal-fired power plants may provide firm capacity.

4.8 CARBON CAPTURE AND STORAGE

What and why

Capturing carbon dioxide and sequentially storing it is called CCS. CCS involves three major steps; capturing CO_2 from the emitted gas at the source, transporting it to the storage site and then injecting it deep into carefully selected underground reservoirs, where it is permanently stored.

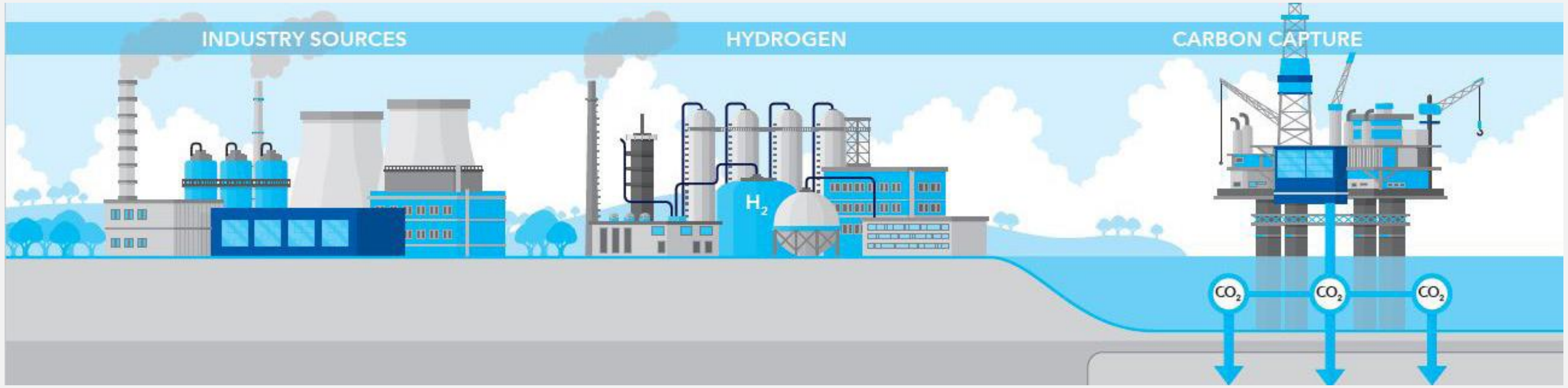
Often, CCS is referred to capture systems applied at coal and gas-fired power stations, however, the range of applications is larger and include major industries like cement, steel, hydrogen and ammonia - namely all processes that release CO_2 in the atmosphere as a result of a combustion or an industrial process.

While in the long run there are opportunities to decrease the use of fossil fuels in industrial processes, for instance by using hydrogen instead of coal in steel manufacturing (17), CCS could be employed as bridging solution to speed up decarbonization of the industries before alternative low-emission solution are implemented.

According to DNV GL ETO, CCS can provide a significant contribution to achieve deep decarbonization at large scale and in a relatively short timeframe in several industries, and it could be a bridging solution to decarbonize industries for which alternative low-emission solutions would require a long lead time to be implemented or which are simply not yet available, like for cement. Still currently there are no large-scale integrated demonstration projects operational.

Findings published in a Special Report on Global Warming 1.5°C produced by IPCC, notes that CCS cannot be disregarded and is needed to achieve the 1.5°C targets (20). The pathways described generally rely on a significant scale-up of CCS in gas-fired power generation and industry, and CCS applied to bioenergy (BECCS, having negative carbon emissions) in order to reach the necessary levels of assumed capturing capacity by 2050.

Figure 18 Carbon capture and offshore storage (17)



Impact on ports

Ports can play an important role in the development of CCS. The North Sea offers a huge potential storage volume for carbon dioxide. By applying carbon dioxide storage offshore in depleted gas fields far from population centers, public support for CCS can be enhanced.

Ports around the North Sea therefore might play an important role as a hub within the carbon dioxide infrastructure. If CCS takes off, they can provide the necessary infrastructure for shipping captured carbon dioxide to empty offshore oil and gas fields. The Port of Rotterdam in the Netherlands, and the Northern Light consortium involving the port of Oslo and Bergen in Norway actively develop CCS.

4.9 DEVELOPMENT OF NEW REGULATION

What and why

Regulation is considered an important enabler for change in general and more specifically for meeting the UN Sustainable Development Goals and the other Green. International, national and local regulations are updated or replaced by new regulations on climate change mitigation (greenhouse gas emission reduction) & adaptation (resilient cities and ports) and on quality of the living environment and more specific air quality, biodiversity and coastal protection. The main drivers are discussed below.

EU Green Deal. As for the European Union, the policies driving change are shaped by the EU climate policy goals for 2030 and beyond, notably the carbon emission reduction target, the renewable energy target and the energy efficiency target. The EC will review all climate related policy instruments before June 2021[1].

IMO regulation on Emission Control Areas (ECA). Extension of Sulphur (SO_2) and Nitrogen ECA zones in Europe. Driven by EU regulation and city pressure the Mediterranean area is expected to be an ECA for Sulphur and maybe also Nitrogen emissions before 2025.

Air quality is regulated by *Air Quality directive, Emission Ceiling Directive*. A growing number of countries and cities lobby for an adjustment of the EU emission limits to the stricter levels of the WHO.

EU and cities aiming for a modal shift in transport. Cities set targets for the modal shift from car to public transport and bikes (for passenger transport). The EU has ambitions of a shift of EU road freight over 300 km to more sustainable modes of transport.

The European Commission new circular economy action plan. The Commission will present a 'sustainable products' policy, which will prioritize reducing and reusing materials before recycling them. See also *Green Transition Circular and Bio-Based Economy.*

Coastal Protection zones and Biodiversity. The European Commission has guidance documents on coastal and transitional waters. Some the European seaports are part of protected coastal zones or nearby *Natura 2000 areas*. In the coming years these ports, cities and states will allocate space for extra dykes and build (artificial) islands and resilient infrastructures to protect port and hinterland. If hydrogen should be produced at ports – water abstraction plays a crucial role (either under the *Water Framework Directive* or under the *Marine Strategy Framework Directive*).

Challenges

The main challenges for a smooth implementation of new or enforced regulations are:

- Getting commitment on goals and legislation
- Implementation and enforcement of regulation
- Integrating policies for different functions (energy, health, housing etc.) or minimizing conflicting rules
- High investment costs with long pay back periods

Impact on ports

The new regulations will bring changes in fueling and inland transport infrastructures of ports because of a growing railway and (inland) shipping transport. See Green Transition fuel switch for maritime transport for the changes in the fueling infrastructure.

While potentially useful in specific cases for some sectors, border tax adjustments would cause additional administrative hurdles to trade, affecting the speed of port operations. For ports, border tax adjustments and new fuel taxes are likely to increase cost and so could reduce international freight transport. Taxes are expected to change due to energy system integration as the need for a level playing field for previously uncoupled energy vectors arises.

Port authorities could stimulate and facilitate GHG emission reduction with specific fees & taxes, onshore power supply, mobile power-to-ship services and improved efficiency of port operations. Figure 19 gives an overview of the situation in 2019 and the plans of port authorities for the coming two years on onshore power supply.

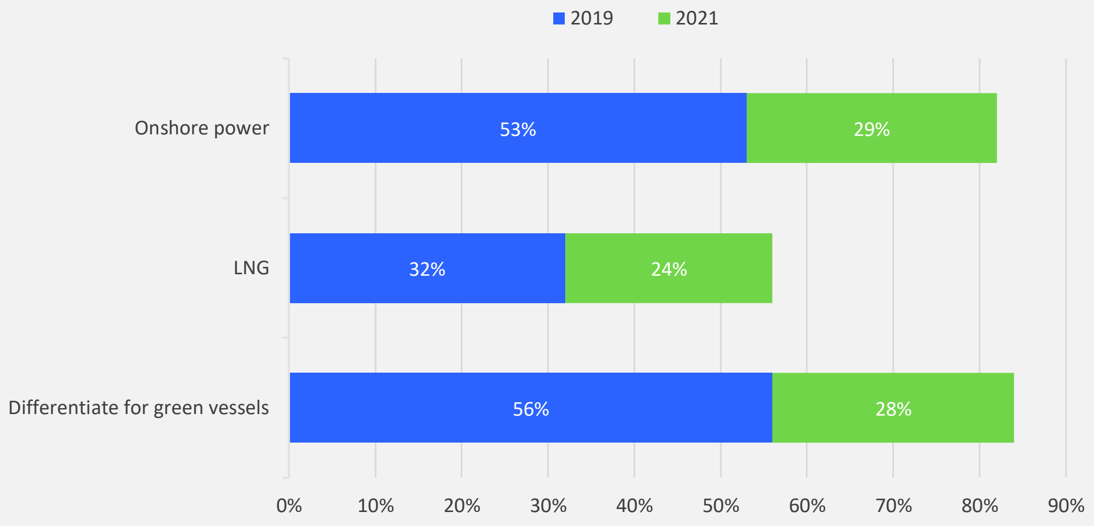
Port authorities could contribute to air and environmental quality with smart sensor systems for air quality, waste collecting and recycling facilities, automated mooring systems and optimization of terminal and ports to reduce at berth time.

Impact on the power sector

New and or enforced EU, national and local regulations will lead to:

- Growing power demand
- Changing energy infrastructure (also for inland transport) and sourcing
- Stricter conditions for onsite energy generation
- Lower support for biomass processing
- Extra electricity use for emission capture and gas or coal for Port CO_2 capturing.
- Electricity wholesale market prices in the EU likely to rise from the historic low of the last decade, according to ETO forecast
- Decentralized electricity generation, from renewable sources, likely to increase in importance, both due to its relative cost competitiveness and favourable regulation. This may at some point be attractive for ports as well.

Figure 19 Port authorities measures to facilitate Green Transitions



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[1] Relevant Energy related instruments are: The Energy Efficiency Directive, the National Emission Ceilings Directive (2016), the Renewable Energy Directive (RED II, implemented in 2018), the Emission Trading System (ETS) and carbon pricing, the Energy Taxation Directive, the directive on alternative fuel infrastructure, the Trans-European Networks regulations (Transport and Energy) and the Clean Air Programme.

4.10 CIRCULAR AND BIO-BASED ECONOMY

What and why

Circular and bio-based economies are both part of the new European Green Deal. For practical reasons we cover both as one Green Transition. The primary focus of this chapter is the circular economy. A circular economy (CE) works within ecological constraints and will deal efficiently and in a socially responsible manner with products, materials and resources, so that future generations preserve access to material wealth. A circular economy will use a decreasing amount of raw materials, therefore, CO_2 emissions will also decrease.

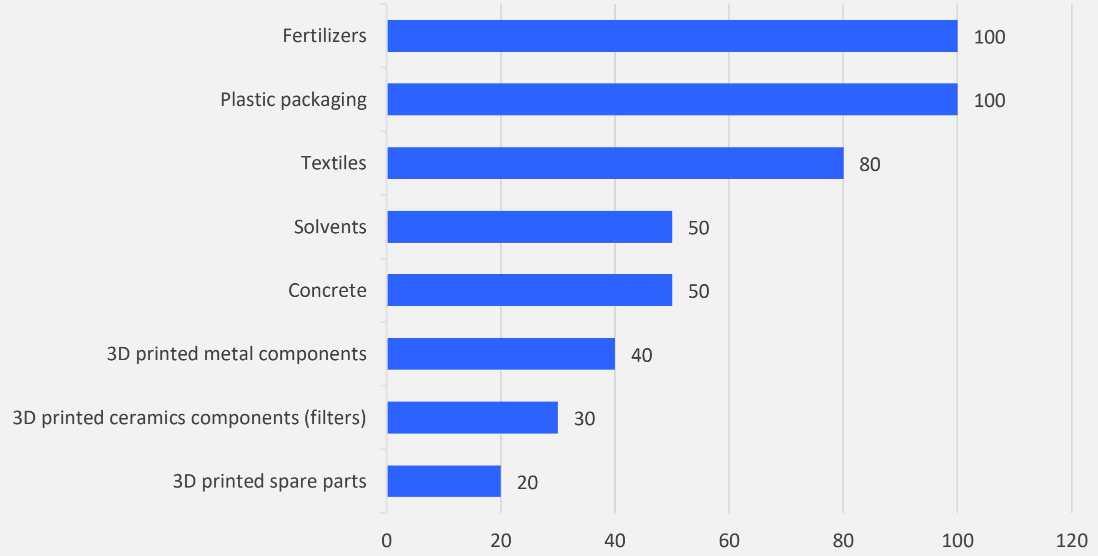
In a circular economy the life span of products is extended and products are designed for repair, reuse and recycling. The recycling sector will grow exponentially. Urban mining for scarce and valuable materials will become common practice. The use of bio-based and bio-degradable materials/resources will also grow. Wood will be considered as construction material. Flax will be used for insulation and packaging.

Finally, we will see a growth of sharing and leasing concepts to reduce the use of primary materials. An OECD study, *Economic features of chemical leasing 2017,* showed for example that chemical leasing can lead to a 50% reduction of chemical (solvents) use (see Figure 20).

The new circular economy action plan of the EC is expected to focus on sustainable products' policy, which will prioritize reducing and reusing materials before recycling them. Minimum requirements will be set to prevent environmentally harmful products from being placed on the EU market. False green claims will be tackled. Efforts will focus on resource intense sectors like textiles, construction, electronics and plastics. The action will stimulate new business models on renting goods and services, digital solutions to monitor air and water pollution and monitoring and optimizing energy and resource consumption and explore benefits for take-back schemes.

Figure 20 Reduction potential in virgin materials in a circular Europe

Units in %



Challenges

The main hurdles for a circular and bio-based Europe are:

- Low cost of primary raw materials/fossil-based feedstock makes it very hard to create a business case for products based on recycled materials.
- Lack of reliable large-scale processing technologies for bio-based or recycled sources.
- Using arable land for feedstock production should be limited to be able to feed the growing world population and to relieve pressure on Europe's ecosystem.
- Immature supply chain for bio-based materials or raw materials from recycling industry.
- Lack of a level playing field for bio-based and circular solutions.
- Lack of necessary regulation enabling European-wide trade of bio-based material.
- Lack of good information (for producers and consumers) on material specs, repairability, footprint and life cycle analysis methods and data.

Impact on ports

- Growth of biomass import for feedstock and energy. Plastics and composites in selected consumer goods, construction and automotive are partly replaced by bio-based plastics, wood and plant (starch) based products. Growing demand of biomass to produce bio-based products. A substantial share of biomass or bio-based raw materials are expected to be imported from other continents. Some biomass will be cultivated and processed in Europe.
- Growing bio-refinery clusters in circular/bio-based hot spots. The port is a natural partner, initiator and facilitator of the hot spot (Rotterdam, Antwerp, Amsterdam).
- Expanding recycling industry although there might be a future ban on (intercontinental) imports of 'waste'. High recycling rates of for examples plastic and composite based consumer products and components will lead to an expanding recycling industry within Europe. Ports are excellent candidates for recycling hubs.
- Decrease of intercontinental trade of raw materials. CE practices will lead to a substantial reduction in the industrial demand for primary raw materials.
- Reshoring and less intercontinental shipping of machinery and consumer products. Additive manufacturing (3D and 4D printing) and circular practices to extend product life span will lead to a decreasing import and probably also the export of machinery and consumer products. Reshoring will also be an opportunity for the industrial clusters at ports.
- Ports could become circular hubs transforming wasted material produced in ships and maritime related processes to valuable products for other sectors like fertilizers in agriculture or raw materials for the cement industry. A typical example can be the remnants of the closed-loop scrubbers.
- Ports as hubs for clean water production. Islands in the Mediterranean face water shortage problems, especially during tourism season. Islands - being at the front of the clean energy transition - can be favourable testbeds for the deployment of innovative technology solutions, and some already serve as best practice examples for the mainland. Many islands have plans of installing additional RES and energy storage capacities, which can also be used for water desalination and purification. Ships also have facilities to desalinate and purify water. Currently old generation of steam-driven LNG carriers have large excesses of pure water (by steam liquefaction) that are released into the sea.

Impact on the power sector

Main opportunities for the power sector:

- Bio-refinery clusters need a diverse set of membrane-based separation and purification processes. The processes use high temperatures and pressures. Significant new energy demand is expected to come from renewable jet fuel for aviation.
- Technologies like super critical gasification, pyrolysis, and thermo-chemical technologies are used to convert plastics to virgin materials (monomers) or alternative fuels. These technologies often require high temperatures and pressures.
- Energy use for water desalination and purification.

5

PORTS OF THE FUTURE

5.1 PORT 1.0 TODAY AND PORT 2.0 IN 2050

The impact of the Green Transitions will differ per port, as they vary in type and volume of goods transported, type and volume of industrial activities, the potential of connection hub for offshore wind and the importance as passenger port. To quantify and illustrate the effect of the Green Transitions we have defined two “typical” European ports:

- A large Industrial Port with a large crude-oil/chemical industry cluster, co-location of power plants and a large potential for connecting offshore wind. This typical port is representative of the three largest industry-based ports in Northern Europe, close to the North Sea, similar to downsized Rotterdam, but sized according to an average of the largest 20 ports in Europe.
- A smaller Transport Port with a limited industrial cluster, mixed container and passenger transport and no offshore wind connection potential. This typical port is representative for an average sized port in Europe, such as Valencia.

For each of these ports we quantify the effects of the ten Green Transitions in terms of energy consumption per energy carrier and CO_2 emissions. This effect is quantified by defining a Port 1.0 (current situation) and a future Port 2.0 (projected on 2050), including the envisioned impact of the ten Green Transitions. This approach is illustrated in Figure 21.

Both ports are described in terms of building blocks that represent main clusters of activities in the port area. For each building block, the effect of the ten Green Transitions is quantified using a dedicated energy and CO_2 model. This allows us to determine the total energy use and total CO_2 emission per port for the current and the future scenario. The building blocks are described in the next section. The following sections present the results of the modelling in terms of (final) energy use and CO_2 emissions.

Figure 21 Quantifying the effects of the 10 Green Transitions by defining “typical” ports

		Port 1.0	**Port 2.0**
		Current situation	Future situation (2050), reflecting the effects of the 10 green transitions
Industrial Port	Typical large industrial port, mainly bulk goods and containers, co-location of power plants and a large potential for connecting offshore wind	**Industrial Port 1.0**	**Industrial Port 2.0**
Transport Port	Typical mid-sized transport port, mainly passengers and containers, no significant industry, no power generation and no potential for connecting offshore wind	**Transport Port 1.0**	**Transport Port 2.0**

5.2 BUILDING BLOCKS FOR PORT 1.0 AND PORT 2.0

Each port is characterised by five building blocks, representing main clusters of activities that impact the energy consumption and the CO_2 emission of ports and together represent the whole port area. These building blocks are generic and can be used in all typical ports. Depending on the port, however, they will vary in significance and in final energy use. The five building blocks are summarized in Figure 22 (fuelling of transport both onshore and at sea is considered as one building block) and are discussed extensively thereafter.

CO_2 emissions of ports are related to the onsite energy consumption in the five buildings blocks of ports. If, for instance, electricity is used for industrial activities, port operation or charging of batteries for electric transport, the CO_2 emission related to the generation of this electricity is attributed to the relevant building block of the port.

The five main building blocks, describing Port 1.0 and Port 2.0, are:

- **Port operation.** Port connected activities require fuelling. We discern four types of port connected activities that require energy: port service vessels, freight handling (cranes, trucks, ship loaders, etc.), buildings (offices, control rooms, storage facilities) and cold ironing. The energy consumption is scaled according to the size of these activities.
- **Fuelling of transport.** Fuelling of transport includes conventional oils, emerging fuels like LNG and LPG and potential new fuels like hydrogen, ammonia and electricity for hybrid or full electric ships and service vessels. It also includes fuelling of heavy trucks and trains. An important issue is which part of emissions related to fuelling of transport use must be attributed to the port. For instance, Rotterdam is the #2 largest bunkering port in the world (after Singapore). As it is not realistic to attribute the energy consumption and emission related to bunkered fuel to the Port of Rotterdam alone, we use an energy-for-energy approach to compare Port 1.0 and Port 2.0 (see text box). We expect that the potential for electrification of deep-sea vessels is negligible. Fuel switch to other maritime fuels (LNG, LPG, ammonia) is not included in the modelling as the focus is on the impact for the power industry. The production of ammonia fuel from green hydrogen is not explicitly modelled.
- **Electricity generation.** This includes generation by fossil fuelled power plants, by onsite solar PV and wind turbines and connection of offshore wind parks to the public grid. The presence of energy intensive industries (chemicals, metal) in the vicinity of the port implies both a large demand for electricity and the existence of a high capacity electricity grid, although part of the industrial electricity and heat need is met by cogeneration that is implicitly included in the energy use of the industrial cluster. A port site therefore offers advantages for co-location of power generation and many large ports include several large power plants. The existence of a high capacity electricity infrastructure also makes ports a likely candidate for connection of offshore wind.
- **Industrial cluster.** The previous section showed that many ports are co-located with industrial activities. These include ship building and construction; chemical, metal, food and automotive industries and automotive. Same as power plants, these industries profit from the advantages of co-location in a port. Their energy consumption is scaled according to the throughput (refineries) and the total value added (other industries).
- **Hydrogen production.** Currently this is mainly done by steam methane reforming (SMR) to serve co-located chemical industries (grey hydrogen). Given the potential of hydrogen as a carbon-free energy carrier and storage medium, its role in the energy transition is expected to increase. Hydrogen may become part of an emerging energy hub function for ports and an export product. Future production methods include SMR and partial oxidation (POX) of natural gas combined with carbon capture and storage (CCS) resulting in blue hydrogen and electrolysis based on renewable electricity (green hydrogen).

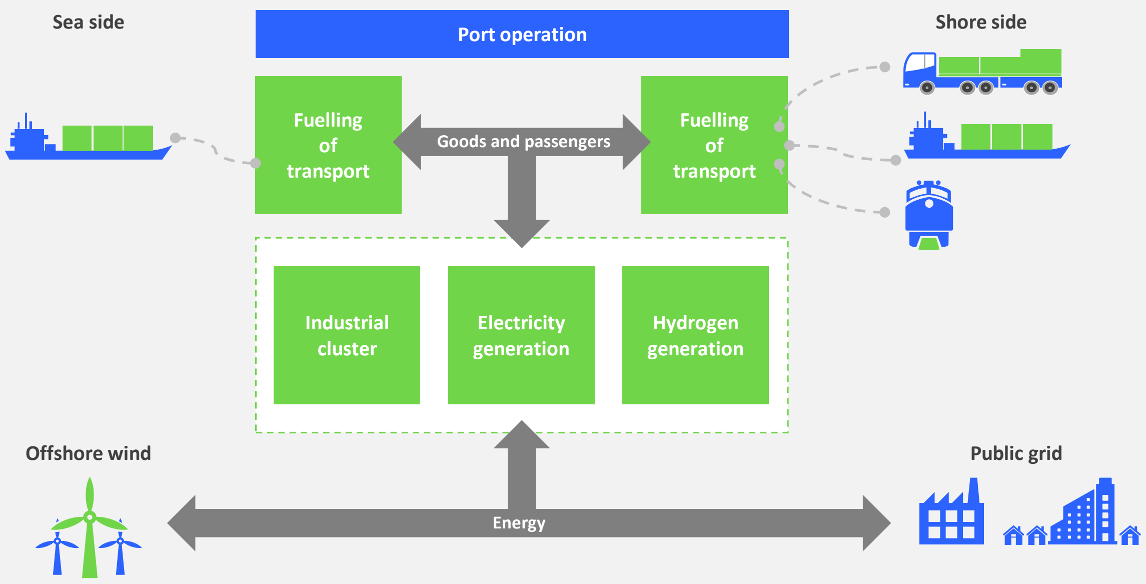
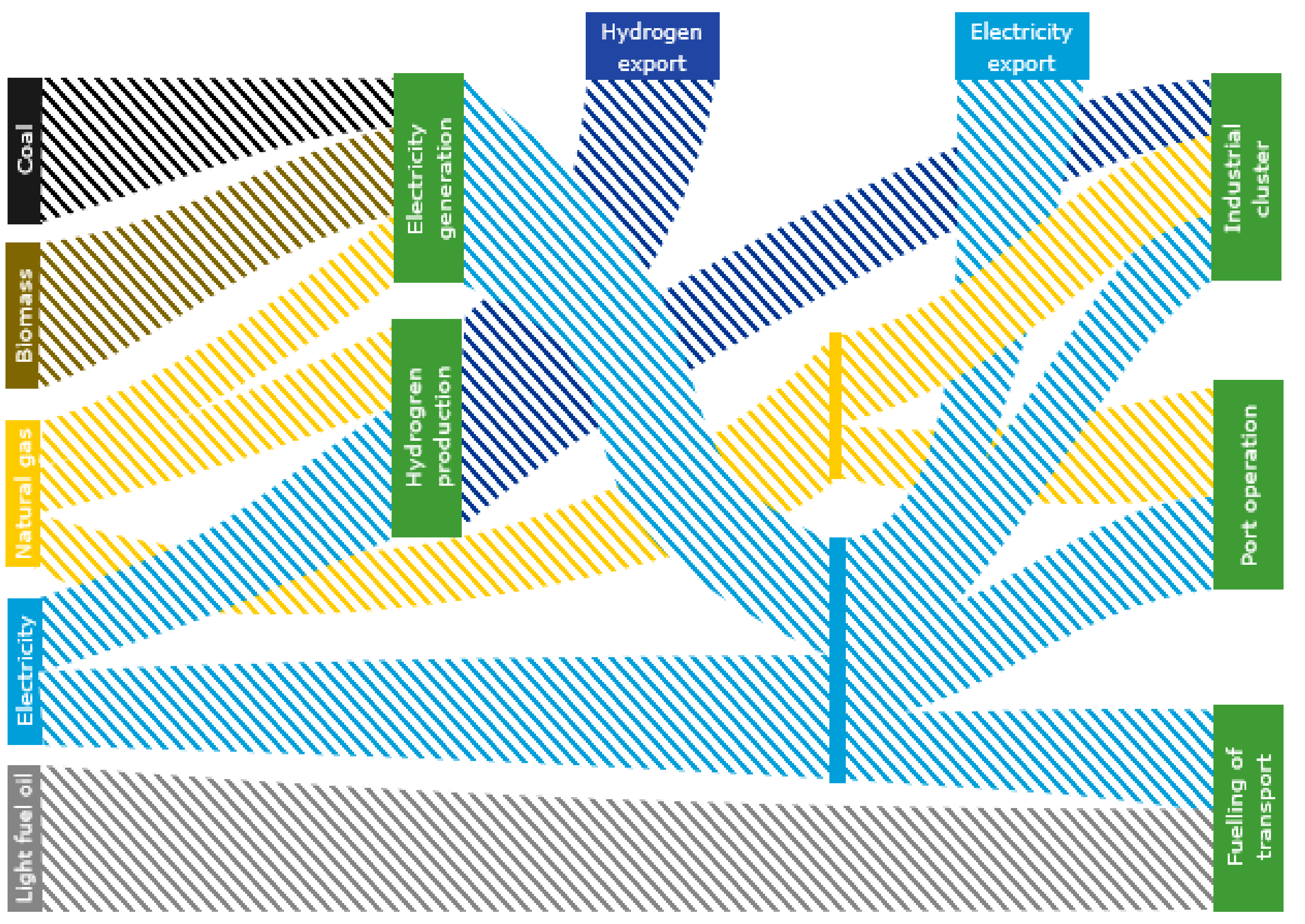


Figure 22 Main building blocks for Port 1.0 and Port 2.0

Part of the electricity and hydrogen generated at a port site will be used by the co-located industry cluster. Electricity is also used for powering the port and charging ships, trucks etc. This energy use and the related emissions are attributed to the end user (the final energy use). Emissions related to electricity production and hydrogen production refer to that part of the electricity and hydrogen that is exported outside the port. The emissions resulting from electricity or hydrogen consumption at the port are attributed to the building block in which the electricity or hydrogen is consumed. This approach avoids the double counting of emissions. The energy flows from and to the building blocks are shown schematically in Figure 23. The size of the flows is tailored for illustration, not for actual consumption and production volumes.

Figure 23 Overview of energy flows to and from port building blocks (size is arbitrary)



Transport related CO_2 emission in Ports

Determining the CO_2 emissions of ports related to the use of transport fuels (ships, trucks) is a specific challenge. The dilemma is which part of the CO_2 emissions related to transport fuels must be attributed to ports. The answer could be “none” but this will obscure the effect of electrification of transport.

To allow for a fair comparison between Port 1.0 and Port 2.0 we have defined an electrification potential for trucks and ships based on an assumed battery size and number of charging cycles. The part of this potential that is used will incur CO_2 emissions based on the CO_2 emissions for generating electricity. The part that is not used leads to the consumption of conventional carbon-based fuels (typically light fuel oil) on an energy for energy basis, including differences in conversion efficiency.

We assume a battery capacity of 0.5 MWh for trucks, 10 MWh for river barges and 15 MWh for short sea vessels. This capacity is meant for hybrid-electric operation.

This graph reflects both the current and future situation and that in a future situation, some energy flows, like coal, are not applicable anymore.

5.3 INDUSTRIAL PORT 1.0

We use the definition of typical ports to illustrate and give a measure of the effect of the Green Transitions on the carbon emissions and energy use of ports. The aim is to gain insight. The typical Industrial Port 1.0 we use in our example is based on the average size of the top 20 largest ports in Europe. Based on the average throughput of goods of the top 20 ports in Europe, the average port has a throughput of approximately 100 million tonnes of goods per year. This is comparable to ports like Amsterdam or Algeciras and about one fifth of the size of the largest European port Rotterdam. Scaling building blocks towards these dimensions is done according to available information from mainly Rotterdam, Antwerp, Hamburg and Amsterdam.

The building blocks for this port are described below. The dimensioning of the building blocks for Industrial port 1.0 is summarized in Table 1.

Electricity generation

Industrial Port 1.0 has a large electricity generating cluster that partly profits from the closeness to fuel transportation facilities (mainly coal) and partly serves the large industrial cluster in this port. We assume 600 MW of coal-fired capacity with 5000 full load operating hours per year, 900 MW of gas-fired capacity (combined cycle gas turbine, 4000 full load hours). One waste incineration plant of 20 MW that operates almost continuously and 100 MW of solar PV and onshore wind with an average of 2000 full load operating hours.

Combined heat and power generation is not explicitly modelled but included in the industrial use of electricity and natural gas.

Hydrogen production

Hydrogen production is based on steam methane reforming and done solely for use within the port industrial cluster. No carbon capture and storage is applied. There is no hydrogen export outside the port area. The final energy use related to this hydrogen production is attribute to the industries that use this hydrogen (mainly oil refineries and chemical industries).

Industrial cluster

Industrial Port 1.0 has a large industrial sector that includes oil refineries, chemical industry, metal industry and other industry. Oil refineries are sized according to their crude oil throughput, the other industries according to their turnover.

Port operation

Port operation is scaled according to the number of vessels served per year, the total throughput of cargo and the port area. We define Industrial Port 1.0 based on 100 million tonnes throughput (seaside incoming and outgoing), with a land area of 2250 ha of which 2% is used for non-industrial building (offices, etc.). The number of vessels determines the potential electricity use for cold ironing. The electricity use for cold ironing depends on the type and size of vessel. We therefore assume a typical vessel with a cold ironing requirement of 27 MWh per port arrival and departure that we will use for all ports.

The electrification of port operation (grid-based electricity) differs per sector. We assume that freight handling (cranes, etc.) is electrified for 50%, for other sectors the electrification percentage is negligible.

Fuelling of transport

The energy use for fuelling of transport is based on the total throughput of the port (seaside, in and out) and the modal shift. Typically, based on available data of actual ports, the sum of goods transported landside does not add up to the total throughput of the port. We did not further investigate this issue. Based on actual data, we estimated the modal distribution (distribution of total throughput to landside transport and short sea vessels). These do not add up to 100% because of the issue mentioned before.

We assume that rail transport is electrified for 80% and other forms of transport are not yet electrified.

Table 1 Definition and dimensioning of building blocks for Industrial Port 1.0

Sector	Unit	Sizing
Electricity generation	Coal-fired	One powder coal unit of 600 MW
	Gas-fired	Two combined cycle units of 900 MW in total (450 MW each)
	Biomass/waste fired	One waste incineration plant of 20 MW
	Offshore wind connection	None
	On site solar and wind	100 MW of solar PV and wind turbine capacity
Hydrogen production	SMR/POX from natural gas	Production for onsite industry: 1.2 PJ/year (9.1 kton/year)
	Electrolysis	No production
Industrial cluster	Oil refineries	Total of 20 million BOE processed oil
	Chemistry	Total of 300 MEUR output value
	Metal	Total of 150 MEUR output value
	Food & beverages	Total of 150 MEUR output value
	Other	Total of 150 MEUR output value
Port operation	Cold ironing	6000 vessels per year, 1% cold ironing
	Service vessels	Based on 100 million tons throughput, no electric charging
	Freight handling	Based on 100 million tons throughput, 50% electric (e.g. cranes)
	Buildings	2250 ha land area, 2% buildings, 0% electrified heat demand
Fuelling of transport	Road	46% of total throughput of cargo, no electric charging
	Rail	20% of total throughput of cargo, 80% electric trains
	River barge	34% of total throughput of cargo, no electric charging
	Short sea vessel	46% of total throughput of cargo, no electric charging

Figure 24 and Figure 25 summarize the final energy use and the CO_2 emissions for Industrial Port 1.0. As discussed in section 5.2, export from hydrogen and electricity is seen as final use outside the port area. Figure 24 shows that electricity export accounts for more than half of the final energy consumption. Industrial Port 1.0 is a large net exporter of electricity. The industrial cluster is the second largest consumer. Port operation and fuelling of transport roughly divide the remainder equally. As hydrogen is generated only for port use in the co-located industry it does not show in these figures.

The CO_2 emission in Figure 25 follows the final energy consumption from the previous figure. The small difference can be attributed to the difference in carbon intensity of the fuels. Electricity generation has slightly higher carbon emissions per PJ, because it includes the use of hard coal, while the industrial cluster has slightly lower emissions because it primarily uses natural gas. Fuelling of transport, using diesel oil, is on par with port operation.

Figure 26 shows the distribution of electricity consumption among the consumers in Industrial Port 1.0. The industrial cluster is by far the largest consumer of electricity. Port operations is the second largest consumer and charging of electric vehicles and vessels (fuelling of transport) is almost negligible.

Figure 27 shows the port electricity generating capacity, including connection of offshore wind to the port electricity grid. Fossil fired power plants dominate. The generating capacity is larger than needed to supply the port site consumers. Only 8.4% of the generated electricity is used on site, the remainder is exported outside the port area through the public grid.

The main conclusions from the Industrial Port 1.0 analysis are:

- The port is a large net exporter of electricity. Most of the electricity is produced based on fossil fuels (coal, natural gas). Renewable electricity generation is less than 5% of the total electricity generation. Less than 10% of the electricity generated is used at the port site, the remaining part is exported outside the port area.
- The industry is the largest consumer of energy and of electricity. The other three sectors have a comparable share in the remaining in energy consumption. The CO_2 emissions mirror this distribution. The electricity consumption for fuelling of transport is almost negligible.
- The main energy carriers for Industrial Port 1.0 are natural gas, coal and light fuel oil.

Figure 24 Final energy consumption per sector including export of electricity for Industrial Port 1.0

PJ/year

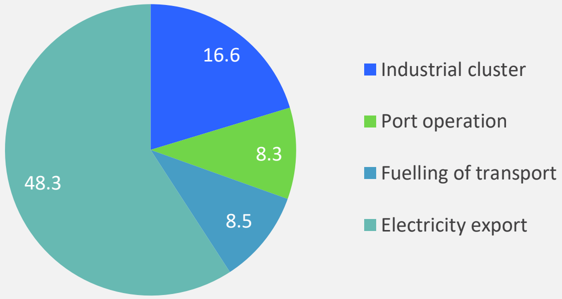


Figure 25 CO_2 emission per sector for Industrial Port 1.0

Mton/year

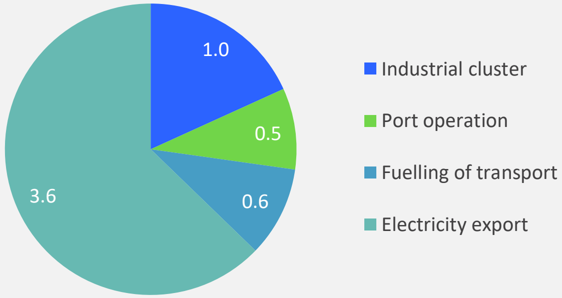


Figure 26 Electricity consumption per sector in Industrial Port 1.0

GWh/year

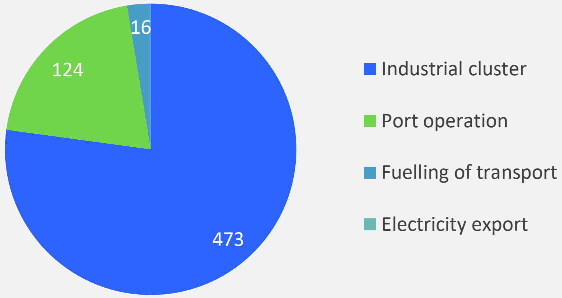
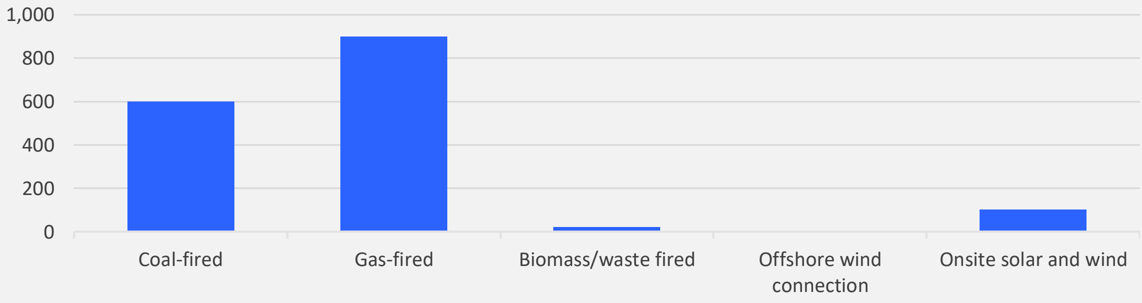


Figure 27 Electricity generating capacity in Industrial Port 1.0

MW



5.4 INDUSTRIAL PORT 2.0

Industrial Port 2.0 is built up based on the same building blocks as Industrial Port 1.0, but the building blocks differ in size and type of fuels used. We will discuss the impact of the Green Transitions on each building block individually, resulting in a picture for 2050: Industrial Port 2.0.

Electricity generation

The Green Transitions lead to many changes in electricity production. The largest impact is most likely the connection of offshore wind to the onshore public grid. In 2050, offshore wind capacity is expected to increase to 168 GW, most of this in the North Sea. Part of this offshore wind will be connected through port sites and some of the generated electricity will be converted to hydrogen and subsequently to other transportable fuels offshore. Still, it is expected that offshore wind connections will significantly change ports. To illustrate this, we assume 10 GW of offshore wind being connected to the public grid through Port 2.0.

Coal will be phased out. We assume that the coal-fired power plant in Port 1.0 is a relatively new power plant that is converted to biomass to avoid loss of capital. This choice is not obvious, as the sentiment towards biomass in general and especially towards using it for electricity production differs per country and is changing negatively. However, the need for firm, carbon-free, dispatchable capacity will increase rapidly with the implementation of more variable renewable capacity. Biomass can be part of this capacity, though it needs to be complemented with other technologies, such as gas-fired generation and possibly batteries to compensate for known limitations in dispatchability of biomass fired plants in start-up time and ramp rate.

The need for firm, carbon-free, dispatchable capacity will be mostly served by gas-fired power plants combined with CCS. Hydrogen is technically feasible, but we expect hydrogen to be used for other higher-value applications such as industrial feed stock and transport fuel (17), (18). The availability of a strong electricity grid to connect offshore wind makes co-location of power generation in Port 2.0 advantageous. We assume 4 GW of gas-fired capacity (40% of the offshore wind capacity) to accommodate future load- and generation swings of which 25% is equipped with carbon capture and storage (CCS). CCS has a serious impact on the dispatchability of power plants and its application is therefore limited to 25%. A fully carbon-free electricity generation is not envisioned in 2050 yet (see section 1.3).

On-site solar and wind will increase in capacity to 2 GW in Port 2.0, 70% of which solar PV. This estimate is based on the available land area.

Hydrogen production

The incentive to produce hydrogen comes from the demand side (hydrogen as feedstock, as transport fuel and to decarbonize industry and other heat demands) and the supply side (availability of potential surplus renewable electricity). The Port of Rotterdam expects more than a doubling of hydrogen production towards 2050, from 40 to 100 PJ/year, though it should be noted that Rotterdam is already an industry intensive port with a head start in hydrogen production. For Port 2.0 we assume an approximate 5-fold increase in hydrogen production. About 40% will be produced by renewable electricity (in line with the capacity factor for wind generation), 60% will be produced from natural gas with carbon capture and storage (18).

Industrial cluster

We expect multiple developments in industries, based on the Green Transitions. There will be a volumetric growth in production capacity in line with the economic growth towards 2050 (expected 1.5% per year). However, energy efficiency measures will be implemented as well. We estimate that energy conservation measures will offset the effect of the growth of production capacity, resulting in an unchanged final energy demand.

For oil refineries, we do not expect a growth in production capacity. The use of oil is expected to drop significantly towards 2050 by almost 80% (1). This will affect related chemical industries, but other types of (non-oil based) chemical industries will arise to fill this gap, so this drop is expected to just affect oil refineries.

The industry will decarbonize by using green hydrogen and electricity instead of natural gas. Low and medium temperature heat (up to 400 °C) will most likely be generated by electricity. High quantity, high temperature heat demand that cannot be served electrically will be generated by hydrogen. Also, the use of hydrogen as a reducing agent in the metal industry will increase, replacing coal. Therefore, the specific natural gas consumption will decrease in favour of hydrogen and electricity on an energy for energy basis.

Electricity will be used partly for direct heating (boilers, arc furnaces) and partly for heating with heat pumps. Heat pumps have a coefficient of performance (the ratio of heat delivered versus electricity used) that ranges from 2 to 4, depending on the temperature required. Depending on the share of heat demand met by electric heat pumps, the required electric energy will be lower than the energy content of the replaced natural gas.

Lastly, the aim towards a circular society will impact industries. It will impact energy use, for instance because recycling goods is less energy intensive than producing them from raw materials. We assume a 20% additional energy efficiency increase for industries because of this circular aspect.

Port operation

Worldwide, seaborne trade is expected to increase from 61,000 Gt-nm (gigatons-nautical miles) to 80,000 Gt-nm (1), an increase of more than 30%. Although seaborne trade in Europe does not have to follow this global trend, we assume it does for Port 2.0. This affects all port operations, requiring more port capacity (cranes, service vessels, buildings, etc.).

The most significant change is most likely the increase of cold ironing, the use of electricity to serve the energy demand of ships in port. This increase depends heavily on the applicable regulatory framework and availability of cold ironing facilities in ports. For ports there is a trade-off between the ambition to reduce emissions and the competitive position of the port. Port regulations to penalize emissions or incentivize emission reductions for ships will be developed with this trade-off in mind. A European or global emission regulation framework will better preserve the level playing field for ports. The IMO-regulations regarding the Sulphur emissions from maritime ships shows that global regulation can be realized. For Industrial Port 2.0 we assume a regulatory framework leading to a significant increase of cold ironing to 50% of the total potential. Other port operations will electrify as well, e.g. natural gas use of buildings is expected to decrease in favour of electric heating (heat pumps).

Fuelling of transport

Transport volumes are expected to increase by 30% according to the global trend for maritime shipping discussed previously, resulting in 130 million tons throughput. This will increase the need for fuelling of transport. On the other hand, energy efficiency of ships will increase. From (10) we estimate this effect to be 15%. For road and rail transportation we do not expect an energy efficiency besides electrification (discussed below).

Fuelling of road, rail, river and short sea transport in Port 2.0 is expected to be electrified. We assume that road transportation will be 80% electrified, rail 90% and ships (river and shallow sea) 50%. This 50% for ships does not mean that 50% of the ships are fully electric. It only assumes that 50% of the ships are equipped with a battery of a given size that will require charging for 80% of the full capacity whenever they are in port.

Lastly, the modal shift will change. Ports actively pursue the shift from inland truck transport to rail and barges as truck transport is less energy efficient (electrified or not). EU ambitions for 2050 are to shift 50% of the road transport from ports to rail and river barges. This assumption is included in Port 2.0, attributing to an even share to rail and river barges.

Industrial PORT 2.0: the effect of Green Transitions

The main changes in the building blocks as discussed in the previous section are implemented in our port model to assess the impact on Industrial Port 2.0 (energy consumption and emissions). The results are discussed in this section.

Figure 28 shows the energy consumption and CO_2 emission for Industrial Port 1.0 and Industrial Port 2.0. To validate the effects of the 10 Green Transitions, the effect of the growth in port size and transport volume, without Green Transitions, is also shown as an intermediate state.

Without the effects of the Green Transitions, the ports final energy consumption would increase by more than 40%. This increase is more than compensated by the effect of the Green Transitions resulting in a Port final energy consumption that is almost half the Port 1.0 energy consumption.

The CO_2 emissions decrease by almost 70%. It illustrates that not only the final energy consumption decreases but that also the carbon intensity of the energy goes down. This is mainly due to electrification and the decrease of CO_2 emissions related to the generation of electricity. Industrial Port 2.0 is therefore not carbon-free. The major reasons ports in 2050 are not fully decarbonized are:

- Only 50% of natural gas use by industries in converted to electricity use or carbon-free hydrogen.
- Port operations and fuelling of transport are assumed to be not fully electrified based on DNV GL's ETO.
- Electricity generation is assumed to be not fully decarbonized according to DNV GL's ETO. However, for Eurelectric's Decarbonization Pathways, a decarbonized electricity use would contribute to further decarbonization of ports.
- Generally, electrification can be pushed to its full potential and yet a part of the energy demand will still need to be met by other less decarbonized solutions.

Figure 28 also illustrates that Industrial Port 2.0 becomes an energy hub and a major net exporter of renewable electricity and hydrogen. The share of renewables in the electricity export increases from approximately 5% to more than 70%. As discussed, this is due to the connection of offshore wind, requiring a strong electricity grid. Both make Industrial Port 2.0 an advantageous location for power generation and hydrogen production.

Figure 28 Comparison of energy consumption and emission for Industrial Port 1.0 and 2.0

PJ/year; Mton/year

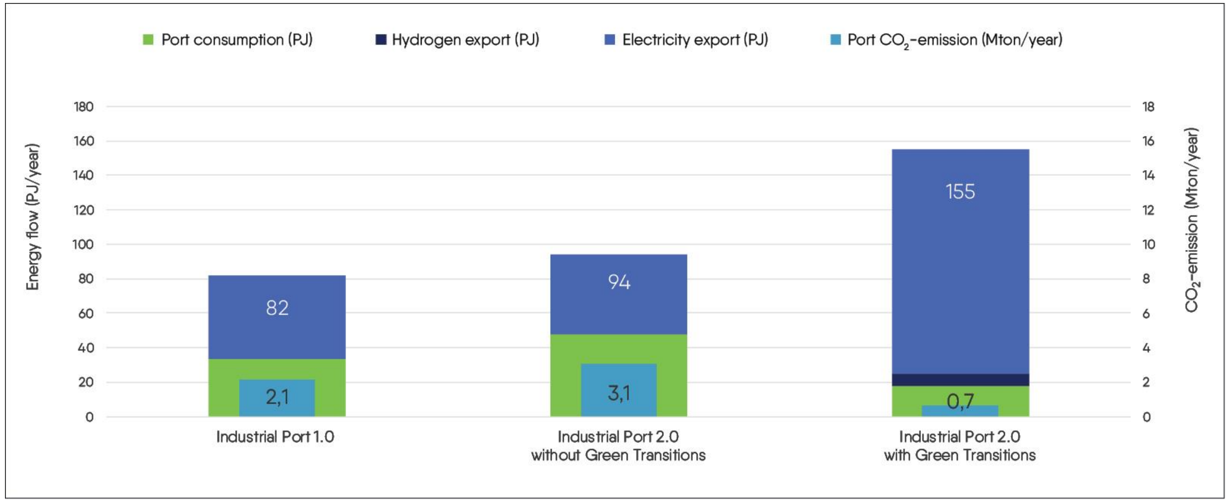


Table 2 Definition and dimensioning of building blocks for Industrial Port 2.0

Sector	Unit	Sizing
Electricity generation	Coal-fired	No coal-fired power plants
	Gas-fired	Combined cycle units of 4.000 MW in total; 25% equipped with CCS
	Biomass/waste fired	One waste incineration plant of 20 MW and refurbished biomass power plants of 600 MW
	Offshore wind connection	10.000 MW
	On site solar and wind	2.000 MW of solar PV (70%) and wind turbine capacity (30%)
Hydrogen production	SMR/POX from natural gas	3.7 PJ/year (26.0 kton/year)
	Electrolysis	2.5 PJ/year (17.6 kton/year)
Industrial cluster	Oil refineries	Total of 4.7 million BOE throughput
	Chemistry	Total of 470 MEUR output value
	Metal	Total of 235 MEUR output value
	Food & beverages	Total of 235 MEUR output value
	Other	Total of 235 MEUR output value
Port operation	Cold ironing	7.900 vessel equivalents per year, 50% cold ironing
	Service vessels	Based on 130 million tons throughput of cargo, 50% electric charging
	Freight handling	Based on 130 million tons throughput of cargo, 80% electric (e.g. cranes)
	Buildings	Assuming 2950 ha land area, 2% buildings, 50% electric
Fuelling of transport	Road	23% of total throughput of cargo, 80% electric charging
	Rail	32% of total throughput of cargo, 90% electric trains
	River barge	46% of total throughput of cargo, 50% electric charging
	Short sea vessel	46% of total throughput of cargo, 50% electric charging

Figure 28 data are detailed per sector in Figure 29. It shows that electricity export outside the port area is the largest contributor to the final energy consumption, hydrogen exports contributes only modestly. The other sectors show a decrease in final consumption of approximately 30-50%. This is due to the shift of fossil fuel use to electricity use.

Despite the large increase in final total consumption (including export) the CO_2 emission in Figure 30 shows an overall decrease. Export of hydrogen and electricity lead to a slightly larger CO_2 emission because of the increase in volume but this is compensated by the CO_2 reduction in the other sectors.

The industrial CO_2 emission reduction is the largest with 62%, followed by Fuelling of transport (50%) and Port operation (31%). Main reason is the shift from fossil-based fuels towards (partly) carbon-free electricity.

The emission due to hydrogen export increases as Industrial Port 2.0 becomes a net exporter of hydrogen. Part of this hydrogen is produced from electrolysis using renewable electricity, part of it is produced from natural gas reforming with carbon capture and storage (CCS). The emissions are mainly caused by the limited efficiency of CCS (assumed maximum of 90%).

Figure 31 shows the electricity consumption per sector. The electricity consumption on port site increases with more than a factor of 4. This is visible in all sectors and most pronounced in the fuelling of transport sector as we assume that in Port 1.0 electrification of transport is almost negligible. In 2050, Industrial Port 2.0 becomes a net exporter of hydrogen. The electricity consumption for producing hydrogen for export is shown in Figure 31. The electricity consumption for hydrogen production for industrial use within port area is included in the sector industrial cluster. Main reasons for the other increase in electricity consumption are electrification of heat demand in industry (industrial cluster), electric charging (fuelling of transport) and cold ironing (port operation).

Figure 29 Final energy consumption (including export of electricity and hydrogen) comparison for Industrial Port 1.0 and 2.0

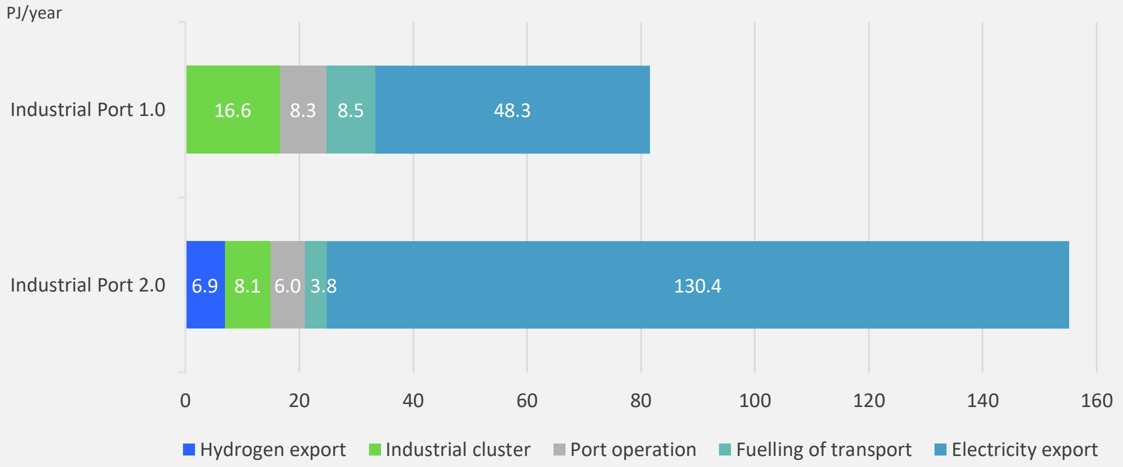


Figure 30 CO_2 emission comparison for Industrial Port 1.0 and 2.0 including export of energy

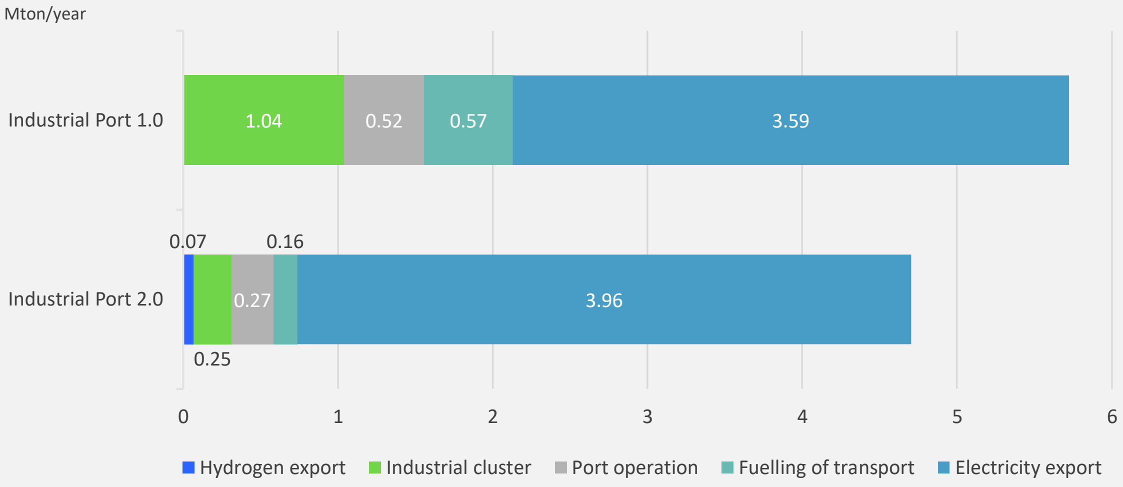


Figure 31 Electricity consumption within port area Industrial Port 1.0 and 2.0 including export of hydrogen

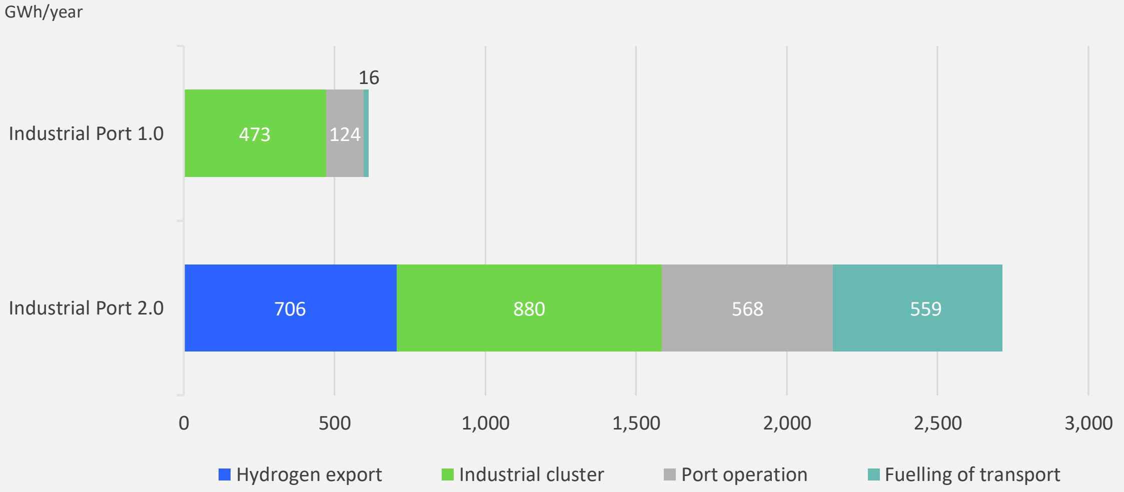


Figure 32 to Figure 34 show how the final energy use is distributed within the sectors Port operations, Industrial cluster and Fuelling of transport. All figures show a consistent electrification of the final demand. The effect on buildings (Port operations) and road transport (Fuelling of transport) is most significant. For road transport part of the effect is caused by the modal shift (less road transport in favour of rail and river transport).

Figure 32 Final energy consumption for port operation in Industrial Port 1.0 and 2.0

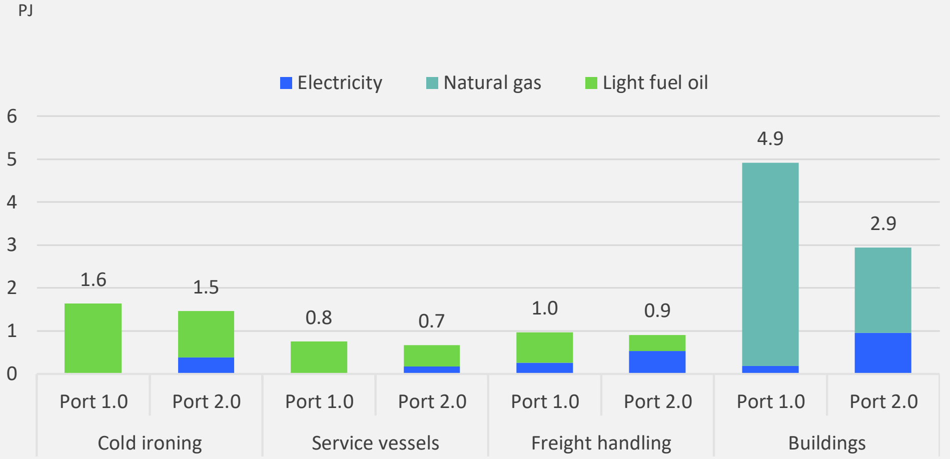


Figure 33 Final energy consumption of transport fuelling in Industrial Port 1.0 and 2.0

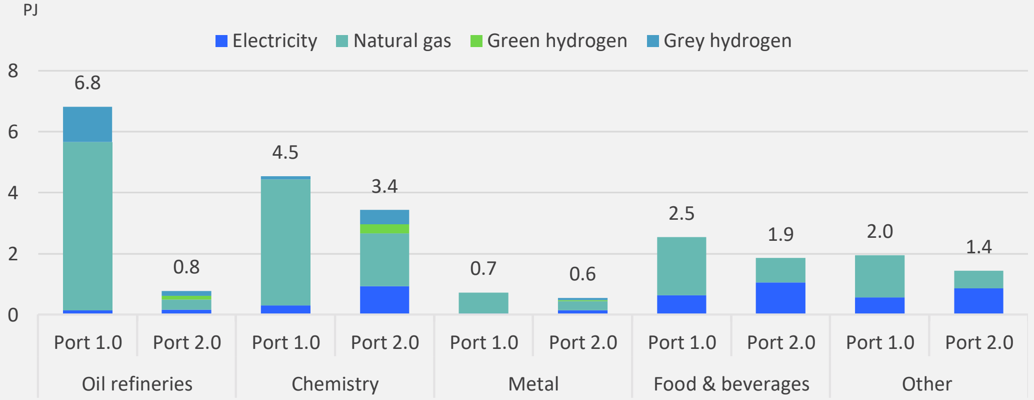


Figure 34 Final energy consumption for industrial cluster in Industrial Port 1.0 and 2.0

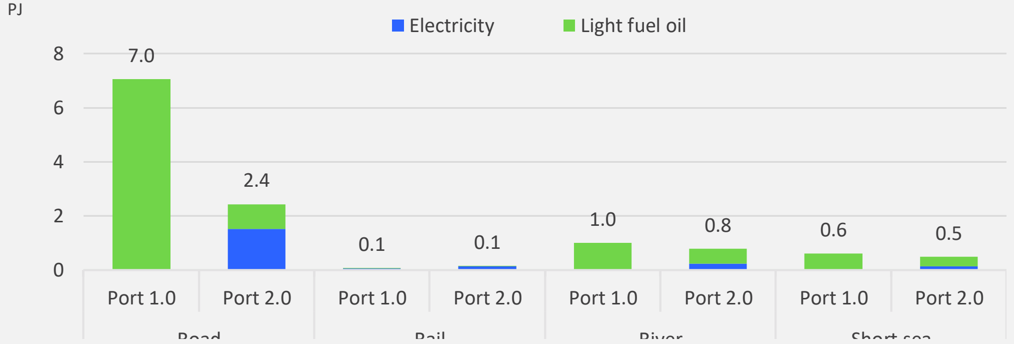
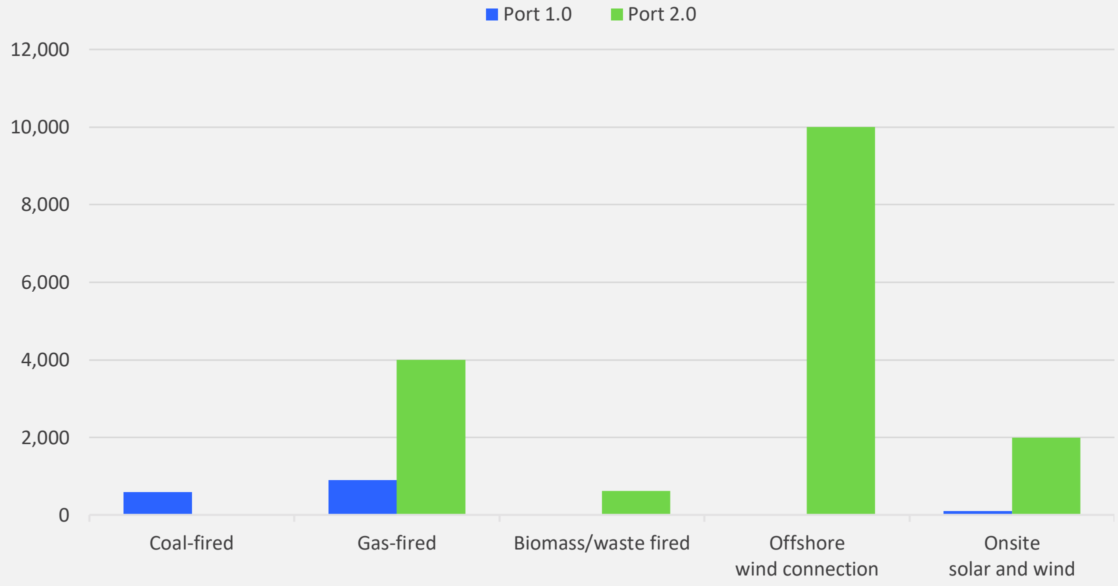


Figure 35 shows the electricity generating capacity in Industrial Port 1.0 and 2.0, including generation by offshore wind connected to the port electricity grid. Industrial Port 1.0 is dominated by fossil fuelled power plants. In Port 2.0 offshore wind dominates followed by gas-fired generating capacity. The generating capacity of Port 2.0 is much larger than needed to supply the port site consumers, resulting in significant export of electricity. Approximately 4% of the generated electricity is used on site, the remainder is exported outside the port area through the public grid. The gas-fired capacity is partly equipped with CCS. Hydrogen fired electricity generation is not included in Industrial Port 2.0. We expect hydrogen to be too much in demand for other uses (transportation, feedstock).

Figure 35 Electricity generating capacity in Industrial Port 1.0 and 2.0

MW



The main conclusions from the Industrial Port 2.0 analysis are:

- Industrial Port 2.0 becomes more of a net exporter of electricity and additionally a net exporter of hydrogen. The expected connection of offshore wind and the required grid enforcements to realize this connection lead to an advantageous position as location for electricity generation and hydrogen production. The total electricity generating capacity increases more than tenfold in the coming 30 years. Renewable electricity generation accounts for approximately 75% of the total electricity generation. Approximately 4% of the electricity generated is used on port site, the remaining part is exported outside the port area. This number is highly influenced by the fact that offshore wind generation is being allocated to port electricity generation. The industrial cluster profits from the available grid facilities and the onsite hydrogen production. The position as an energy hub will become more pronounced.
- Despite the increase in export volume and the growth of port activities, the CO_2 emission decreases. Excluding the emissions related to exported electricity and hydrogen the emission decrease is almost 70%. Industrial Port 2.0, however, is not totally carbon-free. The main reasons are:
  - Natural gas is still used for e.g. industry, buildings and electricity generation. Only part of the related CO_2 emissions is mitigated with CCS.
  - Cold ironing is not fully introduced for all ships, meaning that LFO is still used for ship power at berth.
  - The electrification of transportation is limited to an estimated 50% (ships) to 80% (road transport).
- Electricity becomes the main carrier of final energy use for port services, fuelling of transport and industrial cluster. Natural gas takes the second largest share but just as fuel oil, it decreases in significance by more than 40%. Hydrogen accounts for almost 7% of the on-site final energy consumption. Hydrogen is used for feed stock and for decarbonizing high temperature heat demand in the industry.

5.5 TRANSPORT PORT 1.0

Transport Port 1.0 is of a different nature than Industrial Port 1.0. Focus is on transport of passengers and containers, not so much on industry and electricity generation. The dimensioning of the building blocks for Industrial port 1.0 is described below and summarized in Table 3.

Electricity generation

There is no onsite electricity generation except for 1 MW of solar-PV generation. Transport Port 2.0 is modelled according to a South European port and therefore we assume more full load operating hours of solar PV than in Port 1.0 (1500 per year instead of 1000), but because of the smaller size of the port no onshore wind. We also assume no connection for offshore wind because the location of this port is not near suitable offshore wind locations.

Hydrogen production

A small amount of hydrogen is produced for onsite industries.

Industrial cluster

The industrial sector is less significant than in Industrial Port 1.0. In size (throughput of goods) it is one tenth of the size of Industrial Port 1.0 (10 million ton per year). This port does not include oil refineries and the other industries are one twentieth of the size of Industrial Port 1.0 (38 MEUR of total output value).

Port operation

Port operation is downsized according to the general port size. Freight handling is electrified less than for Port 1.0 (25% versus 50%). For other sectors we assume the same electrification percentage as for Port 1.0. For cold ironing we size the required services with the same equivalent vessel size as used for Industrial Port 1.0. This is for comparison only as smaller ports will on the average be called by smaller ships.

Fuelling of transport

Transport is downsized according to the general size of this port. The modal shift and the electrification percentages are like Port 1.0.

Table 3 Definition and dimensioning of building blocks for Transport Port 1.0

Sector	Unit	Sizing
Electricity generation	Coal-fired	No coal-fired units
	Gas-fired	No gas-fired units
	Biomass/waste fired	No biomass/waste units
	Offshore wind connection	No connection of offshore wind
	On site solar and wind	1 MW
Hydrogen production	SMR/POX from natural gas	4,7 TJ/year (0,033 kton/year)
	Electrolysis	No production
Industrial cluster	Oil refineries	No oil refineries
	Chemistry	Total of 15 MEUR output value
	Metal	Total of 7,5 MEUR output value
	Food & beverages	Total of 7,5 MEUR output value
	Other	Total of 7,5 MEUR output value
Port operation	Cold ironing	980 vessel equivalents per year, 1% cold ironing
	Service vessels	Based on 10 million tons throughput of cargo, no electric charging
	Freight handling	Based on 10 million tons throughput of cargo, 25% electric (e.g. cranes)
	Buildings	Assuming 100 ha land area, 2% buildings, 0% electric
Fuelling of transport	Road	46% of total throughput of cargo, no electric charging
	Rail	20% of total throughput of cargo, 80% electric trains
	River barge	34% of total throughput of cargo, no electric charging
	Short sea vessel	46% of total throughput of cargo, no electric charging

Figure 36 and Figure 37 summarize the final energy use and the CO_2 emission for Transport Port 1.0. Transport Port 1.0 is a net importer of electricity. The final energy consumption (electricity, natural gas, light fuel oil) is roughly equal for port operation and fuelling of transport. The industrial cluster is the smallest final energy consumer. This is in line with our port definition (relatively small industrial cluster compared to Industrial Port 1.0).

The CO_2 emission in Figure 37 follows the final energy consumption from previous figure. The small difference can be attributed to the difference in carbon intensity of the fuels. Port operation and fuelling of transport have a slightly higher carbon emissions per PJ, because it includes the use of light fuel oil, while industry has slightly lower emissions because it primarily uses natural gas.

Figure 38 shows the distribution of electricity consumption by consumers in Transport Port 1.0. The industrial cluster is by far the largest consumer of electricity. Port operations is the second largest consumer and charging of electric transport (fuelling of transport) is almost negligible.

The distribution between the three sectors does not differ significantly from Industrial Port 1.0 despite an industrial sector that is relatively twice as small. This follows from our assumption that the freight transport in Transport Port 1.0 is less electrified.

The main conclusions from the Transport Port 1.0 analysis are:

- The nature of this Transport Port is very different from the Industrial Port. Core port activities (Port Operation, fuelling of transport) are significant in final energy consumption and CO_2 emission. This port is a net importer of electricity. The onsite electricity generation is small.
- As with the industrial port, the industrial cluster remains the largest consumer of electricity, but it is less dominant. In final energy use it is the smallest consumer of the Transport Port.
- The main energy carriers for this port are natural gas and light fuel oil.

Figure 36 Final energy consumption per sector for Transport Port 1.0

PJ/year

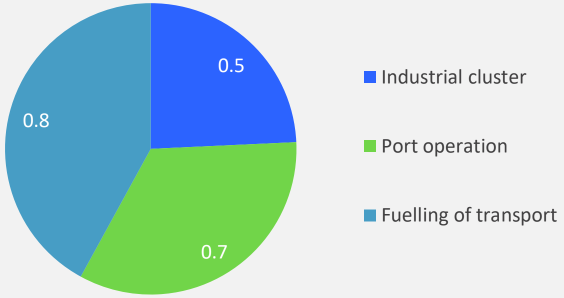


Figure 37 CO_2 emission per sector for Transport Port 1.0

Mton/year

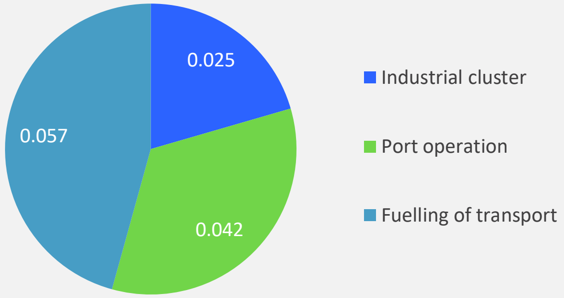
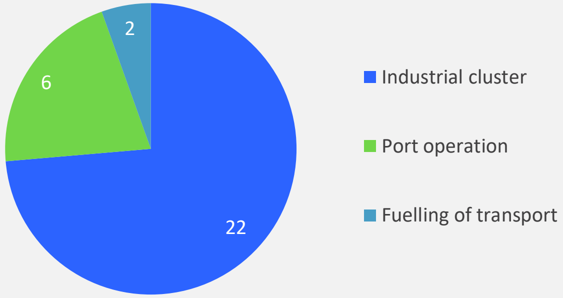


Figure 38 Electricity consumption per sector in Transport Port 1.0

GWh/year



5.6 TRANSPORT PORT 2.0

As for the other ports, we use the same building blocks to define Transport Port 2.0. The building blocks differ in size and type of fuel used.

Electricity generation

In this type of port, we expect only onsite generation by solar PV. The port is too small for conventional power generation or wind turbines. It is typically not situated to accommodate offshore wind. From the 200 ha of port area, we expect that 7,5 ha can be used to install solar PV. This equals to 7,5 MW of generating capacity. We assume 1500 full load hours for solar generation, assuming a more South European port.

Hydrogen production

Small scale onsite hydrogen production to accommodate the chemical and metal industry is expected. It will be natural gas-based hydrogen generation, combined with carbon capture and storage. As there is no excess of renewable power generation (especially no connection of large offshore wind parks), electrolysis to produce renewable hydrogen is not applicable.

Industrial cluster

The impact on the industry is comparable to Industrial Port 1.0. In summary:

- There will be a volumetric growth in production capacity in line with the economic growth towards 2050.
- Energy conservation measures will be implemented as well. We estimate that energy conservation measures will offset the effect of the growth of production capacity, resulting in an unchanged final energy demand.
- The industry will decarbonize by using hydrogen and electricity instead of natural gas.
- The aim towards a circular society will impact energy use.

Port operation

Changes in port operation are similar for the industrial port and the transport port. Most significant will most likely be the introduction of further implementation of cold ironing. As for Industrial Port 2.0 we assume an increase to 50% of the total potential. Buildings and other port operation will electrify as well, but not differently from Industrial Port 2.0

Fuelling of transport

As for Industrial Port 2.0, transport volumes are expected to increase with 30% according to the global trend for maritime shipping discussed previously. Assumptions for the increase in energy efficiency of ships, electrification percentage and change in modal shift are also similar.

Table 4 Definition and dimensioning of building blocks for Transport Port 2.0

Sector	Unit	Sizing
Electricity generation	Coal-fired	No coal-fired units
	Gas-fired	No gas-fired units
	Biomass/waste fired	No biomass/waste units
	Offshore wind connection	No connection of offshore wind
	On site solar and wind	7,5 MW
Hydrogen production	SMR/POX from natural gas	Production for onsite industry (0,044 PJ/year, 0.31 kton/year)
	Electrolysis	
Industrial cluster	Oil refineries	No oil refineries
	Chemistry	Total of 23,4 MEUR output value
	Metal	Total of 11,7 MEUR output value
	Food & beverages	Total of 11,7 MEUR output value
	Other	Total of 11,7 MEUR output value
Port operation	Cold ironing	1.300 vessel equivalents per year, 50% cold ironing
	Service vessels	Based on 13 million tons throughput of cargo, 50% electric charging
	Freight handling	Based on 13 million tons throughput of cargo, 40% electric (e.g. cranes)
	Buildings	Assuming 130 ha land area, 2% buildings, 50% electric
Fuelling of transport	Road	23% of total throughput of cargo, 80% electric charging
	Rail	32% of total throughput of cargo, 90% electric trains
	River barge	46% of total throughput of cargo, 50% electric charging
	Short sea vessel	46% of total throughput of cargo, 50% electric charging

Transport Port 2.0: the effect of Green Transitions

Figure 39 Show the energy consumption and CO_2 emission for Transport Port 1.0 and Transport Port 2.0. The final energy consumption decreases with approximately 35%, the carbon emission with approximately 60%. Not only does Transport Port 2.0 consume less energy, the carbon intensity of the consumed energy is lower also. This is due to the switch towards electricity that can be used more efficiently and is assumed to decrease in carbon intensity because of the increased penetration of solar PV.

As shown in Figure 40 and Figure 41, all sectors contribute to the decrease in final energy consumption and carbon emission. This is primarily due to the electrification of the final energy demand. The contribution of fuelling of transport to this decrease is the largest, especially in carbon emissions. The main reasons are:

- Light fuel oil, used for serving the hotel load, has a relatively high carbon content.
- Conversion of light fuel oil to electricity leads to additional losses.

The total electricity demand in Transport Port 2.0 increases almost fivefold. In line with previous discussions, the main contributor is the electrification of fuelling of transport (electric charging of river barges, short sea vessels, road transport). Port operations, and specifically cold ironing also contribute significantly to the increase in electricity consumption.

Figure 39 Comparison of energy consumption and emission for Transport Port 1.0 and 2.0

PJ/year; Mton/year

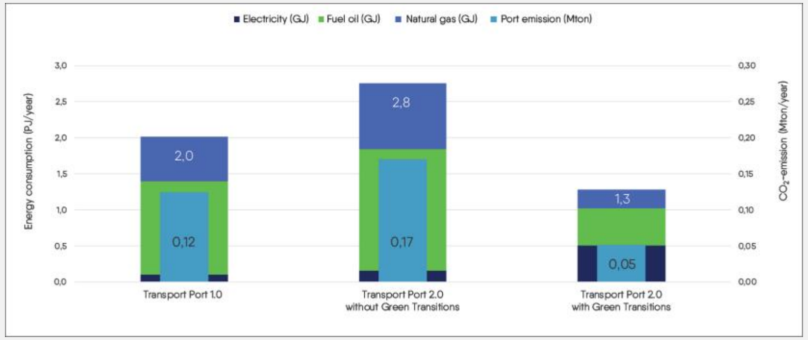


Figure 40 Final energy consumption comparison for Transport Port 1.0 and 2.0

PJ/year

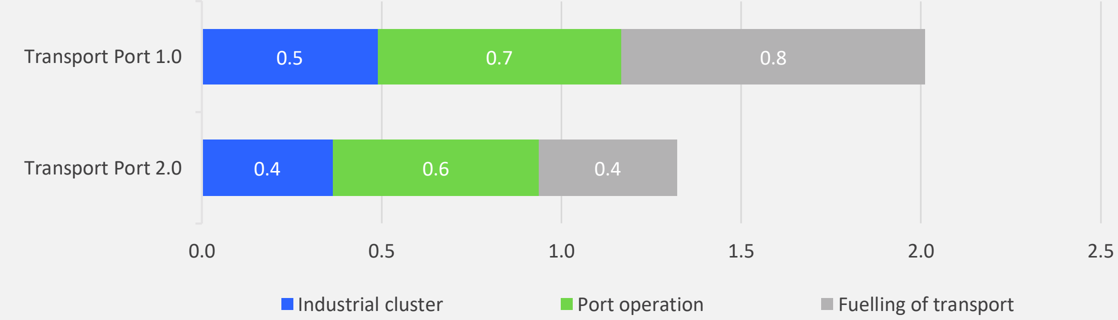


Figure 41 CO_2 emission comparison for Transport Port 1.0 and 2.0

Mton/year

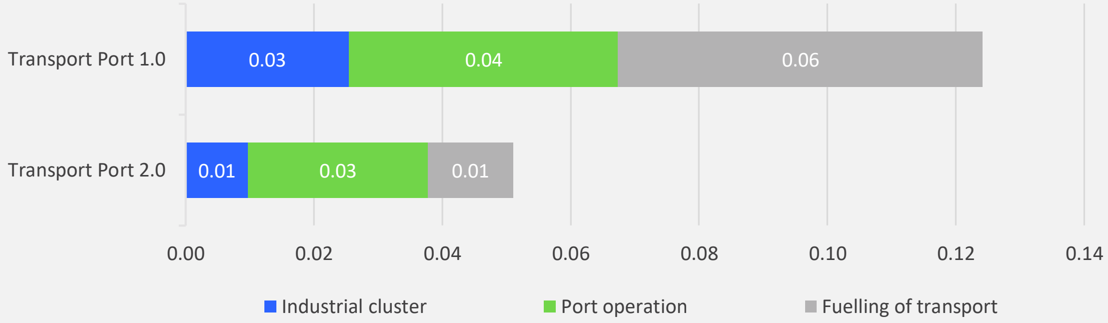


Figure 42 Electricity consumption comparison for Transport Port 1.0 and 2.0

GWh/year

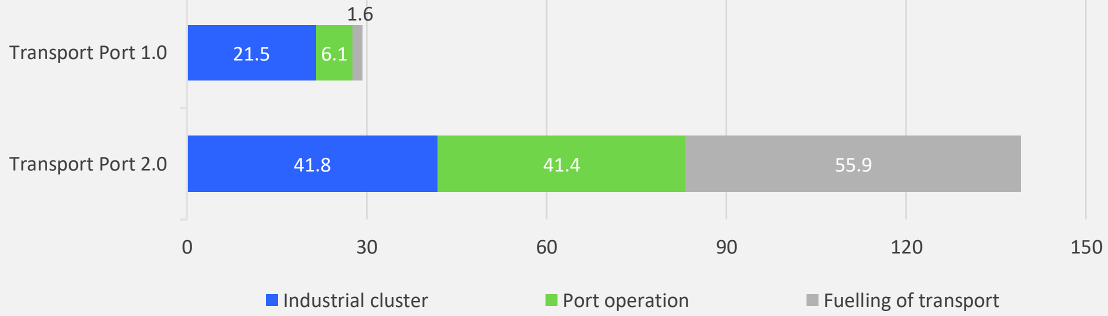


Figure 43 to Figure 45 show how the final energy consumption is distributed among the sectors port operations, industrial cluster and fuelling of transport. As with Industrial Port 2.0, all figures show a consistent electrification of the final demand. The effect on buildings (in port operations) and road transport (in fuelling of transport) is most significant. For road transport part of the effect is caused by a modal shift (less road transport in favour of rail and river transport).

The main conclusions from the Transport Port 2.0 analysis are:

- Transport Port 2.0 has a smaller industrial sector and no significant electricity generation or hydrogen production. It does not export electricity or hydrogen but relies on the public electricity grid and onsite production of hydrogen for industrial use. The effect of development of the industrial sector and core port activities (Port operation and Fuelling of transport) are more pronounced.
- As industrial Port 2.0, Transport Port 2.0 is not fully decarbonized for reasons discussed before (remaining natural gas and light fuel oil consumption and not fully decarbonized electricity from the public grid).
- Electricity is on its way to becoming the main energy carrier.

Figure 43 Final energy consumption of port operation in Transport Port 1.0 and 2.0

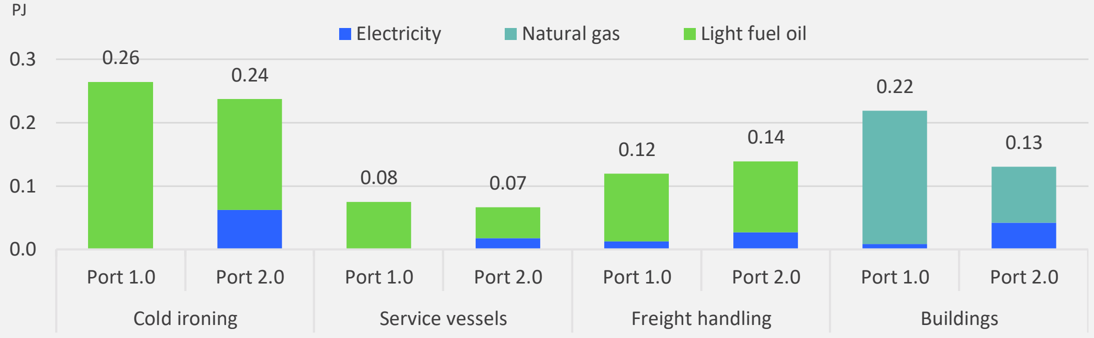


Figure 44 Final energy consumption of transport fuelling in Transport Port 1.0 and 2.0

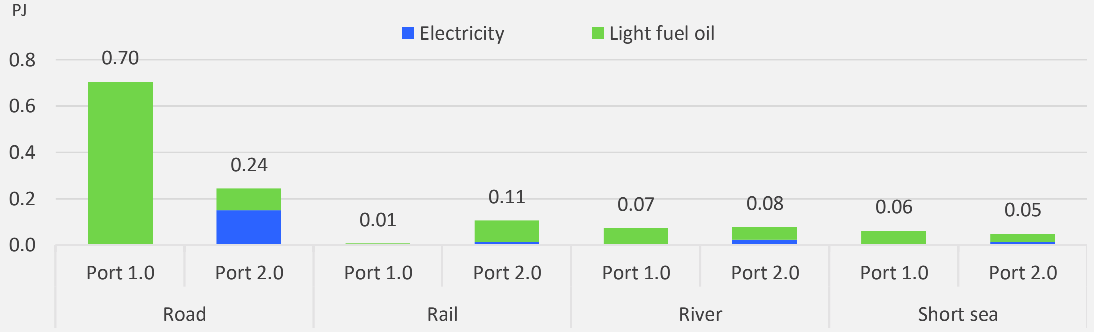
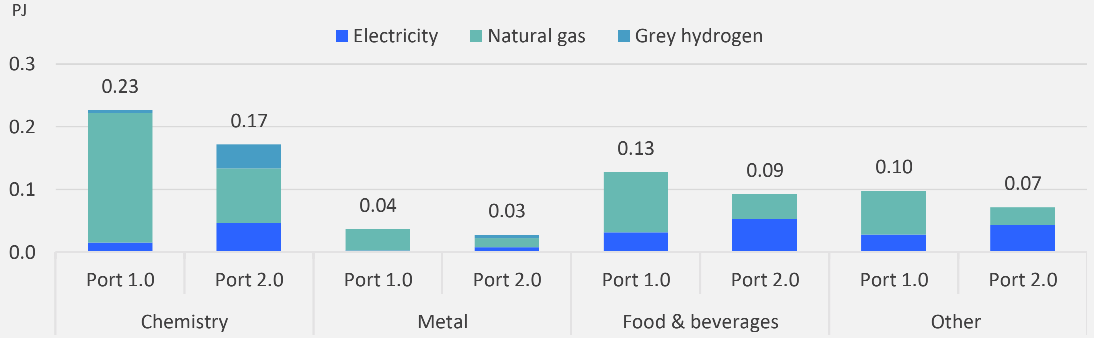


Figure 45 Final energy consumption of industrial cluster in Transport Port 1.0 and 2.0



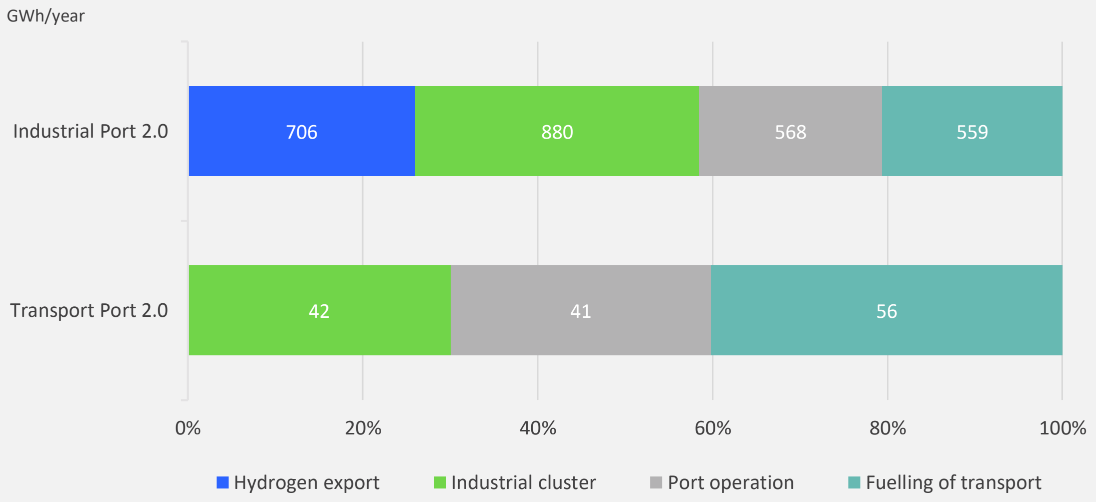
5.7 COMPARISON INDUSTRIAL PORT AND TRANSPORT PORT

Comparing the Industrial Port and the Transport Port the main difference is the size. This size is based on total port area, total throughput of goods, total number of ship and total value of goods produced by the industrial cluster. In 2050, this leads to a difference in electricity consumption of more than a factor 20 (Figure 46). The Transport Port requires 2.7 TWh of electricity per year. Assuming 6000 full load operating hours, this equals to a required grid capacity of 450 MW. For Transport Port 2.0 this is 23 MW.

Electrolysis will only be used in Industrial Port 2.0. It profits from low-priced electricity generated by offshore wind. Assuming 4200 full load hours for electrolysis (comparable to the equivalent full load hours of offshore wind), industrial Port 2.0 requires 200 MW of electrolyser capacity.

The most pronounced difference between the Industrial Port and the Transport Port is the importance of the industrial sector, the power sector and the hydrogen sector. These three sectors are interrelated as industry requires power and some industries also require hydrogen as feedstock or for decarbonization of energy use. Offshore wind provides potentially cheap electricity for hydrogen production. All three sectors profit from a strong electricity grid. The Industrial Port becomes a net exporter of hydrogen and electricity. The importance of core port activities (Port operation and Fuelling of transport) is limited in industrial ports. In transport ports it is a significant source of energy and electricity consumption and the challenge to accommodate the increased electricity demand may be larger than for industrial ports because there is no supporting industrial electricity grid.

Figure 46 Electricity consumption comparison for Transport Port 1.0 and 2.0



6

IMPACT OF GREEN TRANSITIONS ON THE POWER SECTOR

Chapter 4 described the ten Green Transitions that could contribute to decarbonization of ports. In chapter 5 we gave a projection of the energy demand and supply in the ports of the future (2050), due to the Green Transitions and other external drivers. In this chapter we discuss the impact of these Green Transitions in the ports on the power sector.

Most of the Green Transitions are not unique to ports and are very familiar to the electricity sector, but at ports all these transitions come together, interact and strengthen each other, involving many sectors such as maritime, oil and gas, energy, industry and (local) governments. This convergence makes ports potential front runners in the energy transition, where these transitions have the greatest potential impact.

The electricity sector is facing major challenges in becoming carbon neutral. Many of the consequences—and possible solutions—of decarbonizing electricity, and energy system, will materialize at scale in and around ports first. This makes ports very relevant for the electricity sector and the electricity sector very relevant for ports.

6.1 ELECTRICITY DEMAND AND SUPPLY

Electricity consumption in and around ports will see a major increase, as described in chapter 4 and quantified in chapter 5. On the other hand, in many large ports electricity generation also will increase, and those ports will be net electricity producers, even when coal-fired generation will be phased out.

Decarbonization of transport will have an above average impact on the electricity demand. Let’s for example consider the electrification and fuel-switch in shipping or inland road transport, either through green hydrogen or other alternative fuels, or with batteries. Since ships and trucks will use the time needed for loading and unloading of cargo, for fuelling or battery charging, specific energy delivery and fuelling infrastructure will be required. This is for hydrogen or e-fuels that can be used for long range road transport, but also to charge electric trucks for the first leg of their journey at the port. This is unlike electric trains which are powered on-the-go through overhead lines. Most of this increased electricity demand will need to be supplied almost continuously and cannot be significantly postponed or shifted in time.

The increased electricity demand should be balanced with an increase in electricity supply. This is in contradiction with the tendency that existing fossil fuelled power plants should be replaced by power plants running on cleaner fossil fuels like natural gas, or even dismantled. The power sector should prepare for an increasing electricity demand, with decreasing conventional power plant capacity, and thus the need for renewable energy generation becomes more urgent. The fact that large amounts of energy from offshore wind will become available, especially near ports at the North Sea and the Baltic Sea, could make it more cost effective to use this energy near the port than to transport it inland. If the industry can benefit from cost savings in the electric infrastructure, this will be a major driver for energy system integration in and near ports. This does however require close cooperation between the electricity sector, especially grid operators; the local industries; port authorities and terminal operators; and regulatory and permitting agencies for the legal possibilities to do so.

The available energy from offshore wind around the North Sea and the Baltic will be immense, assuming most plans will be realized. However, this energy is not always fully available. To utilize this energy will require very flexible applications. But most industrial processes and applications need to run continuously, and so require an alternative energy source to switch to, such as natural gas. The most obvious applications are electric heating/steam generation and electrolysis of water to hydrogen. Both applications use natural gas as an alternative fuel to switch back to during times of low variable electricity generation. Electric heating does not require large investments in equipment, though grid enforcement might be required, depending on the circumstances. There are studies to build multiples of Gigawatts of electrolyser capacity around the North Sea, for example in Eemshaven, the Netherlands.

Most hydrogen applications demand a continuous supply, requiring that hydrogen is buffered, or that production alternates between electrolysis and production from natural gas. This last option can benefit greatly from carbon capture and storage (CCS) infrastructure and carbon dioxide storage in depleted offshore gas fields, making continuous hydrogen production near carbon-free.

A bit speculative and likely on a smaller scale, a similar mechanism may emerge around Mediterranean ports, where LNG from ports might supplement hydrogen production and/or industrial heat from power from nearby inland and (in the far future) possibly floating offshore solar farms.

Hydrogen might eventually be used to produce high value fuels for sectors that are difficult to decarbonize, such as aviation and shipping. With the transition to a carbon neutral energy system, there will still be a need for carbon neutral fuels that can be transported around the world to meet demand and the role ports play in supplying society with energy (whether electricity or alternative fuels) remains.

6.2 ELECTRICITY INFRASTRUCTURE AND OPERATION

The changing supply and demand of electricity in and near ports discussed in the previous paragraph has huge consequences for the electric infrastructure.

Within the port itself, electrification of port-connected activities through cold ironing and electrifying ferries and short-range shipping will have a major impact on the required electric infrastructure. For example, charge poles must be installed and connected in crowded port areas. Inland transport will have a similar impact on the required infrastructure, depending to what extend road transportation will be decarbonized by electrification or by other means, like hydrogen. Most of this additional electricity demand in ports will likely have little flexibility by itself. Benefits often allocated to electrification of road transport, such as peak shaving to avoid extra cabling for which there might be little space, will need to come from additional measures, such as batteries.

The landing of immense quantities of energy from offshore wind farms in the North Sea and the Baltic Sea to shore will also require huge investments. This applies not only for establishing the needed offshore grid and connections but also for the transmission of this energy to the main electricity system.

It may be possible to avoid or reduce costs for investments in the transmission system through flexible solutions that use part of this energy at or near, the port. The most obvious applications are opportunity heating and hydrogen production by electrolysis. A prerequisite however is that this industry can share in the cost savings in the transmission system, making the business case for these flexible solutions viable in ports first. This requires a clearer regulatory framework at EU and national level coupled with the right incentives to allow local demand and generation to support the networks for a representative reward, such as a local flex market where grid operators can buy flexibility to avoid congestion.

For the local electricity infrastructure, this still means a significant strengthening of the infrastructure. It will need to be able to facilitate huge swings in load, and special control and coordination is required as industry switches between electricity and natural gas depending on the availability of electricity from offshore wind. It will require close cooperation between industry and the operation of the different infrastructures for electricity, natural gas, heat, hydrogen and possibly carbon dioxide, as all will be affected. The different infrastructures need to support each other, which leads to implications for the design as well as for operation of the energy system in and around ports.

Concerns over grid reliability are often expressed due to the switch to variable renewable energy ensuring the security of electricity supply. As the system is undergoing a major change and complexity and interaction are increasing, the effect on grid reliability is uncertain. While the redundancy in the greater electricity system could decrease with decarbonization, the redundancy of the energy system for industry around the port may increase. The risks and consequences of these changes could be mitigated by ensuring a smart design of the whole system and intelligent operation and control.

6.3 OPPORTUNITIES AND CHALLENGES FOR THE ELECTRICITY SECTOR

Ports are very interesting places for the electricity sector. In the last few decades several power plants have been built near ports, partly because of logistical advantages for fuel supply and demand for heat at nearby industry or cities, but also for the efficiency due to the availability of reliable cooling water.

Many of the transitions described in this report also are not unique to ports. While it is noteworthy that these transitions will come together in ports, the truly unique feature is that they will come together at a scale that compels all involved stakeholders to seriously commit and cooperate to develop solutions to overcome the challenges. These solutions then will become the blueprint for solutions in other areas and sectors.

All transitions described have their own individual opportunities and challenges. While many of the challenges are connected to the required expansion of the electric infrastructure, opportunities lie in combining the trends and taking a systems approach on energy supply in and near ports creating new synergies and ways to cooperate.

The electricity sector can play an important role in establishing this, if it manages to look beyond electricity. Not only because ports are economically very important, but also because it will require the development of skills and competences that eventually will be required in other industrial areas. Electricity generation and electricity demand will continue to become much more integrated in the operation of industry and other infrastructures and energy vectors.

At the same time, the development of such an integrated ecosystem is challenging. If the electricity sector does not respond to the challenge at the scale or pace demanded by industrial stakeholders, port authorities and shipping companies, these stakeholders can see the electricity system as a hurdle and main bottleneck, rather than an asset for decarbonization. New solutions need to be found for regulated grid companies and standardized energy supply contracts to be compatible with an energy ecosystem in and near ports that requires more flexible and collaborative tools to unleash the potential of a truly integrated ecosystem.

However, if the electricity sector manages to rise to this task it can become an active and responsive participant in creating energy ecosystems around ports. This will strengthen the position of electricity as a universal energy carrier and will have a huge dividend far beyond ports.

7

POLICY RECOMMENDATIONS

POLICY DISCUSSION

This report highlights the important role ports can play as potential front runners in the energy transition. For the EU as well as national and local governments, it is important to recognize ports as such in order to reach the EU goals on sustainability and decarbonization. The vision on Port 2.0 in this report is primarily based on DNV GL's Energy Technology Outlook. The decarbonization targets for 2050 are not reached and thus additional policy measures are necessary. Therefore, this chapter formulates policy recommendations for the EC and national and local governments to enable and support the transformation of ports into decarbonization hubs.

EU sustainability goals interact with other goals, for instance concerning security of energy supply and affordability of energy. This makes policy development a complex balancing act that affects all aspects of society and can only result in effective regulation if it is consistent and stimulates cooperation between all stakeholders and elements. The Green Deal acknowledges this challenge.

The nature of the ten Green Transitions discussed in this report including their consequences, makes this even more complex. The different energy carriers and different uses of energy are increasingly interacting with each other. Successful policy will facilitate energy carriers to complement each other's weaknesses; offer guidance to stakeholders to establish and adapt infrastructures to changing circumstances. Without the active support of all involved stakeholders, the sustainability goals and paths towards them cannot be realized.

This cooperation requires a high degree of consistency in regulation, to prevent undesired incentives and opportunities for exploitation. Not only new regulation has to be checked on consistency with existing regulation, also old regulation, including norms and standards, might turn out to be inconsistent with regulation in other domains. It should be acknowledged that unforeseen inconsistencies might emerge and that a structured and sustained way to manage this is required.

Ports are the places where these Green Transitions come together at scale, involving high stakes for the involved stakeholders, each having their own individual decarbonization goals, and compelling them to show serious commitment to develop solutions to overcome the challenges. This makes ports one of the first places where policy development for the energy transition of the industry becomes urgent.

The necessary actions for transformations of ports and port areas consist usually of costly and lengthy procedures. Hence, to boost investors willingness to intensify their green business decision, a friendly and simple financial regulatory ecosystem should be guaranteed. Following the suggestion to include electric power in the marine fuels category special taxation measures should be incorporated to boost this fuel switch. As ports are meeting points of variety of players, ranging from private to public sectors, design of efficient regulatory environment to ensure sustainable provision of Public Private Partnerships (PPPs) will accelerate the green change.

OUR RECOMMENDATIONS:

Ports are very relevant for policy development, since they are spearheading the energy transition in industry and developments in ports will benefit from decarbonization of other industrial areas. However, the analysis has also shown that additional measures are needed to ensure full compliance with the objectives of the Paris Agreement. In order to achieve full climate neutrality by 2050, an overall political framework with consequent targets for all economic sectors is necessary.

In addition, a number of more specific, detailed policies are needed. The main objectives of the following policy recommendations are to acknowledge and cope with complexity, drive consistency, and facilitate cooperation between various stakeholders, such as port authorities, industries, power generators, infrastructure managers and governmental organizations.

1. Standardization of shore power should be stimulated and barriers to adhere to the standards should be removed:

Some standards for shore power have been established, while more are in process for new technologies. Still these standards are not yet fully accepted. Some suppliers of charging equipment—especially for ferries—do not adhere to it, and instead opt for more automated and tailored solutions to reduce connection time and to save on handling cost. When their facilities are specifically designed for specific individual ferries, this can prevent other ships from using these facilities, possibly limiting the potential of these facilities later.

The use of the existing standards and evolution of new standards should be further promoted. Ports belonging to the Trans European Transport Network (TEN-T) already have to implement shore power facilities by 2025 according to the existing standard for High Voltage. It is recommended to expand this to standards in other domains and promote the use of the standards in other ports.

2. Stimulate further electrification of port-connected activities for early movers:

Electricity is the greenest of energy carriers, hence the biggest and fastest path to decarbonize usually carbon-intensive areas of ports, is through electrification of port-connected activities. The general conclusion of most innovative electrification projects designing, developing and testing installations and vehicles powered by electricity, seems to be that these alternatives are well suited for the assigned tasks but expensive. Follow-up investments are rarely made because of the high investments in charging infrastructure, initial lack of customers that will use it, and the current limited number of suppliers for equipment (comparable to the EV market 5 to 10 years ago). Interventions like funds for the unprofitable top, buy-back arrangements and accelerated depreciation should be considered to compensate first movers to implement existing, or soon to be available standards. Notice that electrification of port-connected activities should be aligned with the extension of the electricity infrastructure.

3. Funding Research, development and innovation:

There is no progress without R&D and innovation. They guarantee development of new products and services, which can then be implemented on a commercial scale to speed up the transition to a green and sustainable Europe. Direct funding for business R&D is therefore essential. Research and innovation in power and fuels as well as business models for cooperation between industry and infrastructure and between energy carriers should be regarded a high priority.

4. Funding environment attracting investments:

The necessary actions for transformations of ports and port areas usually consist of costly and lengthy procedures. To boost investors' willingness to intensify their green business decision, a friendly and simple financial regulatory ecosystem should be guaranteed. Following the suggestion to include electric power in the marine fuels category special taxation measures should be incorporated to boost this fuel switch. As ports are meeting points for variety of players, ranging from private to public sectors, design of efficient regulatory environment to ensure sustainable provision of Public Private Partnerships (PPPs) will accelerate the green transition.

5. European coordination for environmentally friendly incentives and fees for maritime through ports:

Pricing signals prove to be beneficial by rewarding maritime operators opting for more environmentally friendly technologies, preventing marine pollution. Such port dues could reward vessel owners who operate high performing fleets and demonstrate more stringent environmental requirements and show lower emissions and pollution, while at the same time acting as an incentive to stimulate other vessel owners to follow. These can include stimulation of ships to adapt to cold ironing and create a way out of the chicken and egg problem.

Ports have the potential to become front runners in the energy transition. To develop a view of the future transition, the port

6. Facilitate and support stakeholders' dialogue:

Authorities and involved stakeholders (energy producers and industry representatives, system operators, regulators) should develop integrated roadmaps which include future infrastructures, transition pathways, ways of working between the involved parties, governance structures and business models showing how stakeholders will be awarded for supporting and using the energy ecosystem.

7. Enable ports to continue to facilitate the interaction between dispatchable and renewable power generation:

The power mix will change fundamentally towards 2050. The new energy system will be defined by renewable sources of energy which will partner with dispatchable power generation, flexibility and infrastructure (incl. hydrogen). The current mix of dispatchable base, mid and peak power will adapt to a high percentage of variable renewable power capable of handling the volatility in generation and demand. Rules for ancillary services may need to evolve to accommodate this change.
Ports should be allowed to play an important role in this context as they offer many opportunities for power generation, infrastructure and flexibility to interact in the same location.

8. Support the initial investments for hydrogen production through electrolysis at ports:

Hydrogen production using renewable electricity from wind and solar will be an important aspect of the future energy ecosystem. It can be used as a feedstock for synthetic fuels, to decarbonize heat generation in the industry and has the capability to store large amounts of energy for a long time without significant losses. Hydrogen generation from excess renewable electricity competes with opportunity heating (using this electricity to temporarily replace natural gas). Opportunity heating requires much lower investments and can outcompete hydrogen production by electrolysis on the short term*. To avoid opportunity heating creating a financial lock-in in the long term, hydrogen production through electrolysis needs to be initially supported.

9. Implement a fair way to share benefits of avoiding unnecessary grid investments with stakeholders to which this can be attributed:

Opportunity demand, such as opportunity heating (temporary replacing natural gas with electricity) and hydrogen production through electrolysis can avoid unnecessary investments in the transmission system by absorbing a significant part of the local excess of renewable energy. To stimulate this demand, stakeholders in the port should be able to benefit equally from the avoided grid investments, for example though a (permanent) congestion management solution, provided this is the most cost-efficient and optimal solution.

10. Mandate port authorities, in coordination with DSOs, to facilitate the development of a port energy infrastructure across multiple energy carriers:

Energy infrastructures and use of various energy carriers are interacting with each other. This requires cooperation between all involved stakeholders, including DSOs. Port authorities, in coordination with DSOs should be mandated to facilitate the realization of a port (energy) infrastructure including multiple energy carriers and taking into account flexible demand as mentioned in recommendation 9.

Possible examples of this facilitation include: the development of a heat or steam network and centrally generate heat, thus avoiding unnecessary investments in the electricity distribution grid, and still to allow opportunity heating; the mobilization of flexibility to support the local grid, for example using shore power as a source of flexibility; evaluate the requirements for space, investments and digitalization in the electricity grids in cooperation with stakeholders in the port area.

11. Develop and implement a structured way of solving inconsistencies in legislation and tax-regulation:

Inconsistencies in legislation and between legislation and decarbonization goals are gradually becoming clear. Examples are taxing electricity use at times of overproduction which can lead to curtailment of renewable energy instead of use of excess electricity in energy storage or opportunity heating. These discrepancies in tax regimes and rules and regulations, should be identified, debated openly and solved in a structured and consistent way. A concerted action to identify inconsistencies is recommended.

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*Eurelectric believes that electric heat pumps are the most efficient way of providing heat and supports a technologic neutrality approach when different technologies are deployed

8

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DNV GL Core team

Theo Bosma
Marcel Eijgelaar
Rob van Gerwen
Joeri Posma
Jillis Raadschelders
Ben Römgens
Nynke Verhaegh

DNV GL Energy

Lucy Craig
Erik Dugstad
James Leahy
Gunter Lichtenberger
Guido Magneschi
Tim Mennel
Cornelis Plet
Prajeev Rasiah
Mitchell Rosenberg
Andreas Schröter
Maksym Semenyuk
Jennifer States
Bart Stoffer

DNV GL Oil and Gas

Jorg Aarnes
Erik Andreas Hektor
Albert van den Noort
Rob van der Spek

.

DNV GL Maritime

Imran Halimi Bin Ibrahim
Osman Mohd Shahrin
Christos Chryssakis
Kjetil Martinsen
Hans Anton Tvete

DNV GL Group

Bent Erik Bakken
Mats Rinaldo
Onur Ozgun
Thomas Horschig

Eurelectric

Natalia Plaskiewicz, Eurelectric
Gilda Amorosi, Eurelectric
Kristian Blindheim, Energi Norge
Daniel Christiansen, Dansk Energi
François Boisseleau, ENGIE
Antonio Fayad, EDP
Ramses Garrote, Viesgo
Hervé Hamonic, UFE
Bart Hoevenaars, Tesla
Ane Landaluze, Iberdola
Dimitrios Lyridis, NTUA
Ulf Moller, Energi Norge
Jan Pedersen, Agder Energi AS
Sophia Politopoulou, Deddie
John Prousalidis, NTUA
Lorenzo Rambaldi, Enel X
Yago Sanchez Ramos, Viesgo
Mark Reijerkerk, Tesla
Pable Caballero Simon, Edesa
Dimitrios Tsangaris, Public Power Corporation
Stefan van Doorn, Eneco

With input from

DNV GL Netherlands B.V.
Utrechtseweg 310-B50
6812 AR Arnhem, the Netherlands
Tel: +31 26 356 9111
Email: contact.energy@dnvgl.com
www.dnvgl.com