Royal HaskoningDHV
Enhancing Society Together

The new energy landscape

Impact on and implications for European ports

Table of contents

FACTSHEETS
Port

FACTSHEETS
Wider port area

FACTSHEETS
Economy & community

1 Preface

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Chair
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The energy transition is very high on the agenda of Europe's ports. Being at the same time important economic players and mission driven entities, ports want to be a partner in decarbonising both port activities and the supply chain. Beyond that, ports can also contribute positively to a sustainable economy as clean energy hubs. While the core business of Europe's ports remains to connect maritime and hinterland transport for goods and passengers in their function as crucial nodes in the supply chain, ports can play an instrumental role in Europe's new energy landscape. Many ports have already taken concrete steps in that direction. Many others are exploring opportunities. The possibilities are very diverse, so are the ports.

With this study we hope to assist ports in finding their individual pathway. We also consider this study to be a helpful tool for policy makers who want to understand the role of ports in the energy transition, as well as its implications on ports. We would like to thank Royal HaskoningDHV for the valuable work on this study as well as the ESPO-EFIP steering group. We hope this study serves as a basis for further thinking and discussion among ESPO members, with the larger port community, as well as with policy makers.

Antoine Berbain
President
EFIP

In 2019 the European inland ports reaffirmed themselves as "Enablers of Green Logistics". This was a direct response to the societal need to reduce carbon emissions and achieve the energy transition. A fundamental objective here within is ensuring that inland ports can be hubs of renewable and sustainable energy sources.

Inland ports constitute multimodal hinterland hubs which bring together logistics operators, industry and much more. These hubs have the potential to act or support energy centres. They face many known and unknown challenges. This high degree of uncertainty results in investment decisions being postponed and thus delaying the needed energy transition.

This study is an essential part in mapping and identifying the myriad of facets that inland ports will have to address and be aware of. Its conclusions not only cover technical and legislative requirements but also the need for continued cooperation between sea- and inland ports and the various stakeholders involved. This result was possible with the work of Royal HaskoningDHV, ESPO and EFIP and has resulted in an essential guide to achieving the green energy transition.

2 Executive summary

This report is written with the purpose to increase awareness and understanding of the impact of the energy transition on ports for a wide audience of stakeholders. The energy transition is considered a major gamechanger for our economy and society. The changes in energy systems, industrial processes and cargo flows are expected to change the way ports are used and infrastructure they require. For that reason, ESPO and EFIP commissioned Royal HaskoningDHV to identify the impact on port infrastructure and the implications for the role of port authorities.

The basis of this study lies in desk study review of recent literature, complemented with expertise from Royal HaskoningDHV. We have structured the analysis in seventeen factsheets. These are the core of this report, as they explain the specific topics and the drivers behind these developments. Based on the current and expected status of the developments we have identified the potential impact on port infrastructure, the challenges and enablers, and the role of ports and port authorities. The purpose of these factsheets is to inform the reader on the individual topics and to find common denominators for our overall conclusions. We also more specifically highlight the impact and complementarity of sea- and inland ports in this report.

In the study we have assessed the impact of the energy transition topics for ports and port authorities on three layers. The first layer contains the measures aimed at reducing carbon emissions within the port. These include operations under the responsibility of the port authority, but also operations of shipping lines and terminal operators. The second layer is the energy transition in the wider port area. This entails activities aimed at the direct environment of the port: industrial clusters, linkages between the port and nearby urban areas, and connected offshore activities. The third layer considers the significance of ports in the energy transition for the surrounding economy and community.

The factsheets have been developed in the wider context of the energy transition as a continuous long-term process, driven by technological advances and public pressure. In this context we expect systemic shocks that will both hamper and accelerate the transition, as the geopolitical, economic and social reality changes over time. Furthermore, European and national policy frameworks are expected to increasingly push energy transition targets, introducing measures, and stimulating economic and societal change.

In the new energy landscape land-use in ports will be different, requiring more energy orientated long- term plans and integrated spatial planning. As a result of changing energy systems and industrial supply chains, more energy infrastructure is needed in the port. The electrification of systems, cleaner industrial processes, integration of renewables, and use of new energy carriers will require upgraded, integrated and dedicated transport, handling, storage and conversion infrastructure in the port. As a consequence, more energy focused activities will emerge in the port, requiring more operations and maintenance.

The challenges that ports face in the energy transition include securing funding, finding the right expertise, strategic planning of land use, complex operations, collaboration with stakeholders, dealing with technical uncertainty, the societal and political environment and organisation. However, it will also offer opportunities in terms of cost savings, securing market share and attracting new cargo and industries.

Every port has its own profile defining their options, priorities and potential role. Seaports often play a role in connecting multiple flows of cargo and energy, while inland ports are flexible, can adopt some technology more quickly and might develop a specialist role in new supply chains. In general, ports will increasingly need to balance commercial and economic objectives, with port authorities playing a central role as landlord, community builder and potentially developer in the energy transition. They will aim to decarbonise their own footprint but can only stimulate emission reductions of the main emitters. Within the wider port area and for the benefit of the wider economy and community, port authorities can empower their hub function by acting as facilitator, enabler, developer and integrator of renewable energy streams and supply chains. Due to the complex and uncertain nature of the energy transition and diversity in ports, it is recommended for port authorities to identify their own tailored role on how to develop, act, facilitate and stimulate energy transition initiatives in the port.

3 Introduction

The goal of this study is to identify the potential impact of the energy transition and the new energy landscape on European sea and inland ports and present the findings in an accessible way for a wider audience of stakeholders. The European Sea Ports Organisation (ESPO) and the European Federation of Inland Ports (EFIP) commissioned Royal HaskoningDHV (RHDHV) to perform a literature study on this topic, and combine the insight from external literature with its own experience derived from port and energy transition projects in practice.

This introduction highlights the goal and reason of the report, while chapter 4 describes the context in which this report is developed. Chapter 5 contains the factsheets which provide easy access to information on seventeen specific energy transition topics. Chapter 6 provides an overview of the key findings and the conclusions for port authorities.

The goal of this study is twofold: first, to explain the implications of the energy transition on ports by identifying the challenges and enabling factors for key developments and second, to explain what the role of port authorities is in these developments. The study provides insight into how port authorities can proactively take on a suitable role, whilst considering different port profiles and where applicable, distinguishing between sea and inland ports.

The goal of this report is to increase knowledge and awareness of the impact that energy transition has on ports and the role port authorities can play.

*The **reason** for this report is that the energy transition is a gamechanger which will increasingly have a very significant impact on ports and the role of port authorities.*

Climate change is often considered the biggest challenge of mankind to date. The energy system, responsible for roughly 65% of Greenhouse Gas (GHG) emissions (not counting the energy consumption of the transport sector), represents a large part of both the problem and the solution. Besides the decarbonisation of the energy system, the development of a circular economy will also contribute to climate change mitigation, while simultaneously addressing pollution and waste, biodiversity, and shortage of resources. The energy landscape changes, leading to fundamental economic, infrastructural, and process changes over at least the next three decades, will have far-reaching implications for consumers, producers, governments, and consequently also for ports in Europe.

The energy transition is important for port authorities as they, like other economic actors, will need to decarbonise the assets and operations within their remit. Ports are also important energy hubs, as on average 40% of the commodities going through ports are energy-related. Ports are often highly connected to economic activity, as industrial clusters are often located in and near ports. Energy transition will have a fundamental impact on these port industrial clusters in terms of energy use and production processes. Finally, ports are often located in the vicinity of populated areas and port authorities are mostly mission-driven and publicly engaged by means of public ownership, shareholders, and municipal/ regional influence.

Climate and energy policies will stimulate port authorities to act and define targets within their own responsibility and reach, which stimulates the implementation of decarbonisation solutions but also the development of new business strategies. A thorough understanding of the implications, requirements, and opportunities of the energy transition for ports will enhance a successful transition, beneficial to all stakeholders.

CHANGING ENERGY SYSTEMS, INDUSTRIAL PROCESSES AND CARGO FLOWS WILL AFFECT A PORT'S LAND USE, INFRASTRUCTURE AND FACILITIES

The energy transition is expected to change ports through the use of land, the service needs of port clients, and the required port equipment and energy infrastructure. As the energy landscape is changing, new industries and production processes emerge as well, which will have different demands for port services and facilities.

Besides changes in demand, the emergence of on-site renewable production, electrification of processes, and capacity for handling and storing waste and biomass will require different use of land and a change in the energy and infrastructure landscape in the port. As the industry is greening production processes, there is a need to replace the current conventional energy supply with renewable sources. This requires different energy infrastructures to transmit, store, convert, and supply industrial processes, which is expected to have a fundamental impact on spatial planning, system integration, infrastructure, and services within the port.

Energy transition will also directly affect trade flows of energy commodities through ports. The energy mix is changing, as coal is set to slowly phase out while the share of low (e.g., LNG) to zero (e.g., hydrogen) carbon carriers is

Space Land-use trade-off	Facilities Service new energy	Infrastructure Enable new energy	Cargo flows New energy flows & processes	Industry New technology & clusters	Hubs Connectivity and alliances
▪ Land availability ▪ Transition of current lay-out ▪ Modal shift ▪ Spatial planning	▪ Handling equipment ▪ Port transport ▪ New charging and fuel bunker facilities ▪ Onshore power ▪ Energy transport ▪ Floating facilities	▪ Dedicated terminals and quays ▪ New on-/off loading facilities ▪ Power connection ▪ Energy conversion and storage	▪ LNG growth ▪ Renewable power integration ▪ New fuel import and production ▪ Emission flows and storage	▪ Industry energy demand change ▪ Technology and process innovation ▪ Change in players ▪ New industry and local production	▪ Hinterland and multi-modality ▪ Production and storage hubs ▪ Urban area energy connection ▪ Value chain clusters

Figure 3-1: *Areas of change for ports due to energy transition*

expected to increase and facilitate the transition in different stages. This will directly impact the modal split of energy transportation. Upscaling of offshore wind, solar, other new future energy technologies, and (bio)waste will also lead to the transport of different types of cargo (e.g., turbine transport, waste to energy) compared to traditional dry and liquid bulk.

THIS REPORT IDENTIFIES THE IMPACT OF THE ENERGY TRANSITION ON THREE LAYERS

The maritime and inland water transport sector is affected by the energy transition in many different ways. This report structures the analysis of the energy transition in developments. For each of the developments, a factsheet has been produced which examines the impact on ports as a whole, including all parties in the supply chain, and the port managing body in particular. The developments are categorized into three different layers.

The first layer contains the measures aimed at reducing carbon emissions of operations within the port. These include operations under the responsibility of the port authority, but also operations of shipping lines and terminal operators.

The second layer is the energy transition in the wider port area. This layer entails activities aimed at the direct environment of the port: industrial clusters, linkages between the port and nearby urban areas, and offshore activities connected to the port through supply chains. The involvement of the port authority is often required to facilitate these activities, though the degree of involvement may vary greatly depending on factors such as the economic and public interests of the port and the mandate of the port managing body.

The third layer considers the significance of ports in the energy transition for the surrounding economy and community. As ports operate as important logistic hubs, they are often a critical component of the supply chain for new energy carriers and circular models for resources. Port authorities can initiate or may be called upon by stakeholders to get involved in the development of new energy supply chains, circular and bio-based concepts, and the decarbonisation of transport.

THIS REPORT ADDRESSES THE IMPACT AND COMPLEMENTARITY OF SEA- AND INLAND PORTS

The expected changes in ports and the changing role of port authorities are to some extent port specific. An important distinction highlighted in this report is the different impacts on sea and inland ports. While there are similarities in terms of technical developments such as renewable energy, electrification of port operations, and alternative fuel bunkering, there is merit in examining the differences where they occur. The differences are discussed more in detail for each development in the factsheets, but some general observations can be made.

Inland ports often play a different role in energy supply chains than seaports. For example, inland ports can more easily adopt technologies for transport electrification and onshore power supply, as the ship sizes, and the shorter inland journeys are better suited for testing, implementation and adaptation. On the other hand, inland ports tend to be smaller and more decentralised. They often face the challenge of finding the right scale for bundling initiatives to make the required changes economically attractive and effective.

In the energy transition, seaports and inland ports will play a complementary role in connecting and strengthening future energy supply chains. Cooperation and interaction between inland and seaports will be important to facilitate both procurement and supply of renewable energy in both directions. This is an important step to further develop environmentally friendly hinterland and inland connections and serve industry, manufacturing, and consumer markets sustainably.

THE BASIS OF THIS STUDY LIES IN A REVIEW OF RELEVANT LITERATURE

This study is based on collecting insights from existing studies and literature on the energy transition in general, and its impact on ports in particular. An initial list was provided by ESPO and EFIP, which was further extended through desk research. Given the limited availability of studies combining a comprehensive review of the energy transition with an assessment of its impact on port infrastructure, there was a need to complement the literature review with expertise gathered in projects by Royal HaskoningDHV, ESPO, EFIP and its community.

FOR THE PURPOSE OF THIS STUDY, SEVENTEEN DEVELOPMENTS WITHIN THE ENERGY TRANSITION HAVE BEEN IDENTIFIED

Based on the decarbonisation efforts in various economic sectors, an initial list was made of developments in the energy transition that could be of relevance to ports. These developments were assigned to the three layers mentioned above. This provided the framework for the analysis of the impact of the energy transition on ports and port managing bodies. Throughout the study developments were reorganised, resulting in a final list of seventeen developments.

For each development, a factsheet was produced to explain the development and its implications for ports and port managing bodies. These factsheets describe the impact of the developments by discussing the current status and future expectations of a development and identifying its main drivers, and by examining the impact on port infrastructure, enabling factors, challenges, differences in terms of port profiles, the role of the port in general and the role of port authorities in particular. These findings are used to draw generic conclusions on what ports and port authorities can expect and how they can act in the energy transition. Figure 3-2 provides an overview of all factsheets.

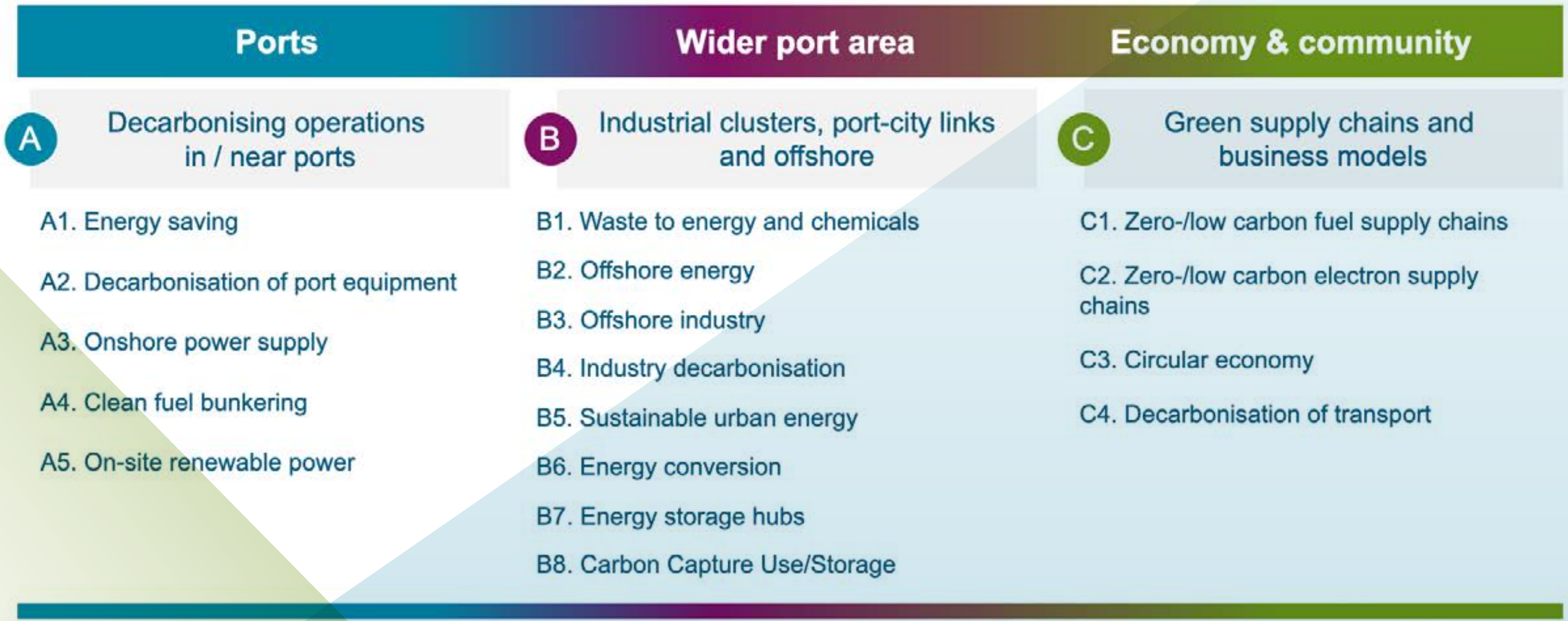


Figure 3-2: *The selected energy transition factsheet topics*

4 Context

THE ENERGY TRANSITION IS A CONTINUOUS LONG-TERM PROCESS, DRIVEN BY TECHNOLOGICAL ADVANCES AND PUBLIC PRESSURE

The energy transition is a pathway toward a complete transformation of the global energy sector from fossil dependent to a zero-emission energy mix. This is driven by increasing urgency signalled by recent scientific research and climate change reports, resulting in the emission reduction targets in multilateral agreements such as the Paris Agreement and the EU Green Deal. To limit the harmful impact of climate change, the transition will need to accelerate. In the end, we will benefit from cleaner and more circular use of energy and resources globally.

This transition will change the way we produce, transport, and consume our energy completely. The efficiency of energy consumption will need to increase across all sectors. A radical increase in the implementation of renewable energy for buildings, mobility, and industry is imperative. Any remaining energy from fossil sources will need to be as low carbon as possible, then offset or mitigated through technology such as carbon capture and storage (CCS). These steps combined mean that our energy system will change drastically as new energy solutions are developed and an increasingly diverse mix of sources, carriers and technology emerges on a global scale.

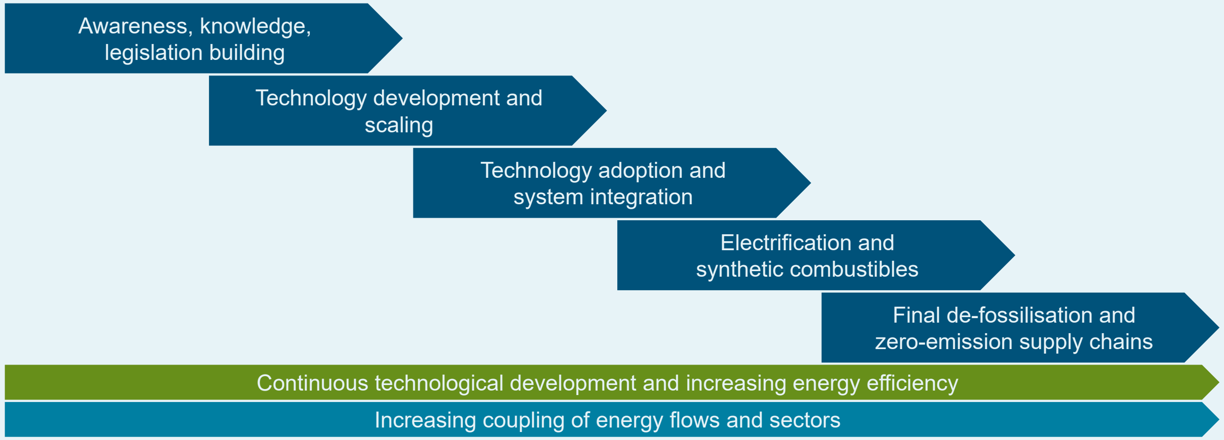


Figure 4-1: *Expected phases in the energy transition (Source: World Economic Forum)*

In the coming decades the further development of technologies is expected with the further upscaling of already competitive technologies (such as solar PV and wind energy), and the progression of currently immature technologies and energy carriers (such as green hydrogen and ammonia). This will require a new phase of adaptation and systematic integration of new energy sources and carriers in the energy mix.

In the next stage, the development of new synthetic combustibles is expected, based on large scale electrolysis and the creation of synthetic fuels for transport and industry.

This will pave the way for long-term decarbonisation by abolishing fossil sources and creating renewable supply chains and export/import streams central to our energy system.

The ultimate goal is complete decarbonisation of our energy and resources system as a result of this phased transition, supported by continuous technological development, increasingly efficient use of energy and resources, and increased coupling of energy flows and sectors.

Energy is a quintessential component of all economic sectors. Different perspectives can be examined, as illustrated in Figure 4-2. Each perspective brings different solutions for the transition, driven by specific needs and challenges. **From these different perspectives, we have derived the relevant factsheets topics in this report, covering the full energy transition perspective in different stages of transition**.

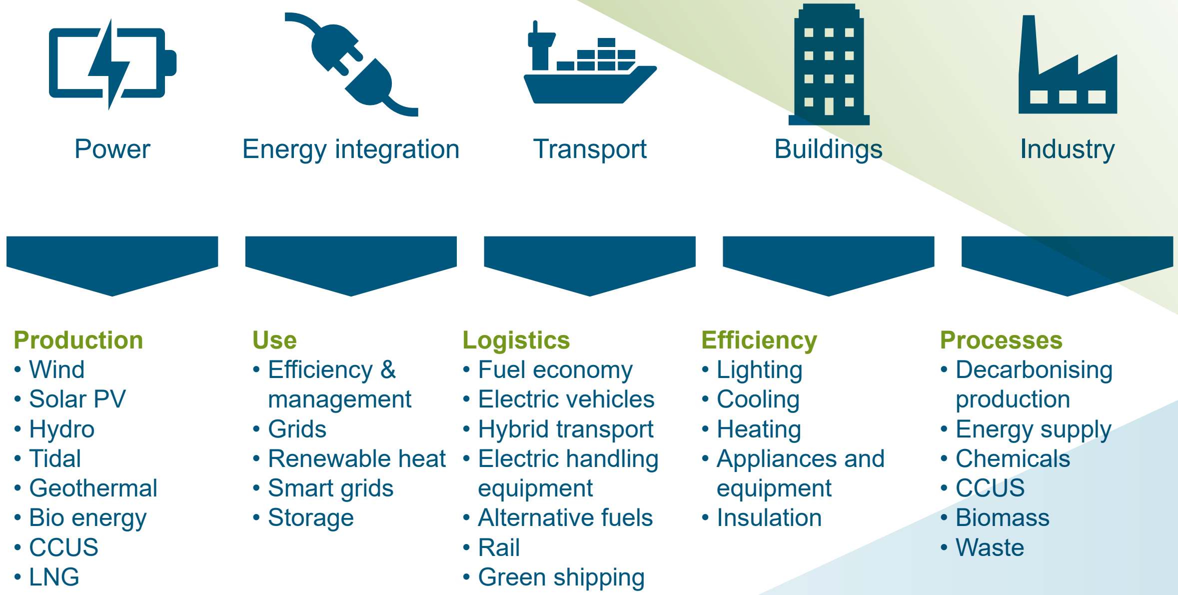


Figure 4-2: *Energy perspectives (Source: IEA 2018)*

SYSTEMIC SHOCKS CAN BOTH HAMPER AND ACCELERATE THE ENERGY TRANSITION AS THE GEOPOLITICAL, ECONOMIC AND SOCIAL REALITY CHANGES

The energy transition is a long-term process, with a gradual pathway toward a carbon-neutral society. As with most long-term goals the actual path towards this goal is not a straight linear line towards the end, but rather a path of acceleration and delay with uncertainty on achieving the goals and ambitions. Over the past decade, the world has seen a financial debt crisis, large incoming migration flows in Europe from conflicts in North Africa, temporary supply chain disruptions, an oil and gas crisis, a trade war between the US and China, and the COVID-19 pandemic. All these systemic shocks have a major impact on the geopolitical, economic, and social climate and decision-making, which translates directly and indirectly into implications for the energy transition and related investments.

The current war in Ukraine and the possibility of a long-term conflict with Russia is a clear example of a crisis that can both have a detrimental and stimulating impact on the energy transition. It exposes the current dependence of the European energy system on imported fossil fuels. The long-term impact is hard to predict but in the short run, the security of supply and inflation is a direct concern for European countries. In a search for alternative sources and the desire to keep energy affordable, countries will try to secure alternative supplies (not necessarily renewable options) and reduce taxation or even subsidise energy for (groups of) consumers. Due to the current conflict, public budgets need to be revised, as governments feel the need to strengthen defence budgets and deal with inflation, potentially at the cost of public support for energy transition and climate action. Lead times and costs of investment projects to create more sustainable supply chains for energy are affected by the current crisis as well.

Conversely, the need to secure supply and high prices for oil and gas make renewables more attractive as well, which can accelerate renewable energy projects and electrification efforts. The REPowerEU plan of the European Commission is a direct result of the war in Ukraine and aims to remove Europe's dependence on Russian fossil fuels well before 2030 and increase the overall resilience of the European energy system.

The shocks witnessed in the past decade, the current geopolitical climate, the ongoing economic power shift from West to East, and the increasingly hazardous impact of climate change, indicate that systemic shocks will continue to disrupt and change the state of play. This creates uncertainty and challenging situations for all economic operators throughout the energy transition. This is the landscape in which port managing bodies need to plan ahead and invest for the long term.

> **POLICY FRAMEWORKS ARE INCREASINGLY PUSHING ENERGY TRANSITION TARGETS, INTRODUCING MEASURES, AND STIMULATING ECONOMIC AND SOCIETAL CHANGE**

The sense of urgency and broad global consensus on the need for climate action has accelerated significantly since the Paris Agreement in 2015. Although specific emission and energy-related targets and policy frameworks were already increasingly directed by the EU, the Fit-for-55 package is seen as a key component for the transition of the EU economy, which will have an enormous impact on Europe's transport, industry, economy and society.

With the European Green Deal, the European Union has formulated plans that should lead to a zero-carbon economy by 2050. In this Green Deal, transformation paths have been formulated for sectors with high emissions. The original objective was to achieve a 50% reduction in emissions by 2030 compared to 1990 levels. At the same time, the European Green Deal should stimulate competitiveness in the European economy.

One key sector is the maritime sector, which, according to the legislation, would need to be "drastically less polluting" to meet its current guidelines for achieving sustainable development goals. The main responsibility lies with the shipping indsutry to become 'green'. In the context of the European Green Deal, port managing bodies and other actors in maritime supply chains will have to implement sustainability strategies aimed at, for example, smart Information and Communication Technology (ICT) for mobility, alternative fuels, and modal shift to rail and inland shipping.

In July 2021 the European Commission proposed an additional package of legislative proposals, called the Fit-for-55 package, to deliver the European Green Deal, with the aim to reduce emissions by 55% by 2030. Relevant initiatives for ports in this package include:

- **The Alternative Fuel Infrastructure Regulation (AFIR)** aims at the timely deployment of zero-emission infrastructure and is foreseen to contain requirements to supply onshore power supply (OPS) to ships at berth, and to provide infrastructure for Liquefied Natural Gas (LNG).
- **Fuel EU Maritime (FEUM)** requires ships carrying EU trade to progressively switch to sustainable fuels and use onshore power supply when available.
- **The European Emission Trading System (ETS)** has been in effect since 2005, but in 2023 the shipping industry will be gradually added to the scheme. This affects ships within the EU as well as ships calling at a port in the EU.
- **Carbon Border Adjustment Mechanism (CBAM)** will require EU importers to buy carbon certificates to the carbon price that would have been paid, had the goods been produced under the EU's carbon pricing rules.
- **The EU Taxonomy** aims to redirect money towards sustainable project by creating a common classification system for sustainable economic activity. The Taxonomy regulation was first published in June 2020 and went into force in July 2020. Supplemental delegated acts have been added to further specify the content, methodology and presentation of information to be disclosed on the proportion of environmentally sustainable economic activities in investments or lending activities. The latest delegated act from February 2022 contained the approval for specific nuclear and gas energy activities in the list of economic activities under strict conditions.
- **The EU's Energy Taxation directive**, last updated in 2003, is being revised in July 2021 as part of the Green Deal. This directive aims to use taxation as an instrument to reach climate and environmental objectives by encouraging the switch to cleaner energy and greener industry. This entails harmonising taxation rates, setting out rules and minimal taxation duties for energy products. As a result, fossil fuels used for intra-EU maritime transport should no longer be fully exempt from energy taxation in the EU.

In 2020 the European Commission launched the **NextGenerationEU (NGEU)**, a recovery plan for Europe to emerge stronger from the pandemic by transforming economies and creating new opportunities. It is the largest stimulus package ever financed in Europe and it is strongly linked with other European initiatives to fight climate change, such as those incorporated in the European Green Deal and the Fit-for-55 package. These initiatives will impact ports throughout Europe. The impact of NGEU and the Recovery and Resilience package will vary greatly between the Member States, as it depends on dedicated funding in national plans and budgets. Crucial is the availability of additional funding, which is needed to deploy alternative fuels infrastructure in ports in Europe.

Considering the geopolitical situation, the European Commission has recently proposed the **REPowerEU** plan to make Europe independent from Russian fossil fuels well before 2030 and increase the overall resilience of the European energy system. This can be achieved to some extent by improving energy efficiency, diversifying gas supplies and increasing the imports of LNG. A large contribution to this goal is expected from green hydrogen, requiring large scale production and import as well as new hydrogen corridors for transportation across Europe.

Large volumes of biofuels and the increase of renewable energy and electrification in industry are all measures that will be needed to build a more robust energy system. Many of these measures will affect European ports as they are natural gateways for energy flows to Europe's homes and industries.

Besides the directly climate-driven policies, there are also specific EU strategies that have a clear connection with energy transition targets and the port sector. The most relevant examples are the **EU Transport Strategy and NAIADES plans for inland ports**. The European Commission presented its Sustainable and Smart Mobility Strategy and Action plan in December 2020. This strategy lays the foundation for how the EU transport system can achieve its green and digital transformation. It is translated into clear ambitions for all transport modules in 2030, 2035 and 2050 and ten key areas for action. Examples of such action plans related to the port sector are the creation of zero-emission ports and the greening of freight transport.

The NAIADES III action plan was tabled by the European Commission in June 2021 and provides a 35-point action plan to boost the role of inland waterway transport in mobility and logistics systems. Like the previous NAIADES frameworks, it is focused on the promotion and future-proofing of the inland waterway transport in the EU. The core objectives are to shift more cargo to Europe's rivers and canals and facilitate the transition to zero-emission barges by 2050, in line with the European Green Deal and the Sustainable and Smart Mobility Strategy of the EU. This new action plan will put in place the conditions for the inland waterway transport sector to better seize the opportunities linked to the shift towards a zero-emission and digital economy.

5 Factsheets

This chapter contains 17 factsheets on specific energy transition topics, divided into three sections corresponding to the layers mentioned in chapter 3.

STRUCTURE AND CONTENT

The structure of the sections and factsheets is as follows:

A. PORT

- A1. Energy saving
- A2. Decarbonisation of port equipment
- A3. Onshore power supply
- A4. Clean fuel bunkering
- A5. On-site renewable power

B. WIDER PORT AREA

- B1. Waste to energy and chemicals
- B2. Offshore energy
- B3. Offshore industry
- B4. Industry decarbonisation
- B5. Sustainable urban energy
- B6. Energy conversion
- B7. Energy storage hubs
- B8. Carbon Capture Use/Storage

C. ECONOMY AND COMMUNITY

- C1. Zero-/low carbon fuel supply chains
- C2. Zero-/low carbon electron supply chains
- C3. Circular economy
- C4. Decarbonisation of transport

The factsheets:

- explain the topic, developments, relevance, and its drivers;
- describe the role of the port and the port authorities;
- identify the impact on infrastructure;
- pin-point key enablers and challenges;
- formulate port profiles relevant to the topic;
- specify the impact more in-depth by giving examples and key impact figures.

PURPOSE

The purpose of these factsheets is to inform the reader on the individual topics and show the impact, enablers, challenges and role of ports for a wide variety of energy transition topics. Consequently, the overall conclusions in chapter 6 are drawn from the observations in these factsheets.

SOURCES

Every factsheet is based on existing literature and research, complemented by the experience of Royal HaskoningDHV, ESPO and EFIP secretariats and the wider community of European ports. The factsheets provide reference to the key sources used, chapter 7 lists all sources used in this report.

A1. Energy saving

INTRODUCTION

Energy saving measures or energy efficiency measures, when properly implemented, enable energy savings through a reduction in energy consumption. These measures are important for ports as they can potentially facilitate the meeting of carbon reduction targets and/or enable wider operating expenditures (OPEX) savings and thus increasing competitiveness.

These measures cover a broad range of interventions within a port context, predominantly including lighting, energy storage/recovery systems, smart energy management technologies, energy efficiency improvements in buildings (such as upgrading insulation), and electrification of mobile equipment (Factsheet A2). Specific technologies for energy efficiency such as LED lighting or energy recovery systems are highly mature, though with varied uptake by ports. Energy-saving interventions focus either on the port as a whole, managing overall energy usage holistically, or target single areas or particular functions of a port, though with the potential for port-wide rollout.

A clear example is lighting, benefiting from energy efficiency measures, through the adoption of more efficient lighting and the use of smart lighting measures to automatically dim or deactivate lighting when not required which can result in energy-savings up to 15%. Energy storage systems implemented for port machinery or equipment (e.g., reach stacker, crane, harbour vessel etc.) can enable the capturing of energy otherwise lost as heat during processes such as lowering of containers, enabling peak-shaving and lowering peak energy demand. Smart energy management software such as digital twins can utilise complex modelling to provide insights into energy demand, enabling testing of future scenarios, optimal siting of energy infrastructure to reduce transmission losses, and applicability of power transfer within the port estate during periods of peak demand.

Energy efficiency improvements for port buildings (following eco-building standards, advanced insulation, heat recuperation techniques, etc.) can also greatly reduce operational energy consumption. Variable speed switch and control for motors/equipment can be used to optimise use and reduce energy wastage. All these interventions produce the same outcome, a reduction in overall energy demand.

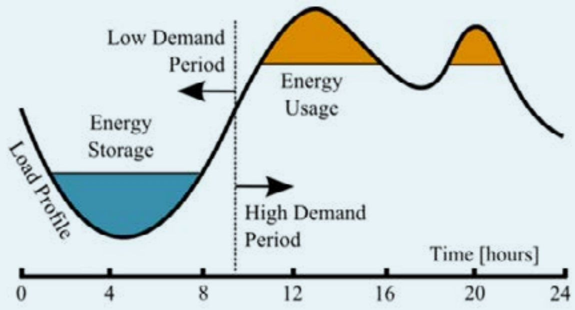


Figure: *Alasali et al (2017)*

Photo: *Eurogate (2017)*

DRIVER/BENEFITS

Legislation

- The EU has specific targets for improving energy efficiency under the Energy Efficiency Directive. There is a target of 32.5% reduction in energy consumption by 2030, though with a new target of 39% proposed, and even greater targets being discussed currently to facilitate independence from Russian energy imports.

Energy-saving upside

- Energy efficiency interventions would (to varying degrees) reduce energy consumption, enabling reduced Scope 2 emissions[1].
- Improves public perception of the port as being technologically advanced and efficient.
- Port machinery and equipment: reduction of fuel consumption resulting in fewer air emissions if powered by fossil-fuels.
- Power demand modelling can enable the testing of future energy demand scenarios such as shore power and assess if future infrastructure is necessary, providing savings on infrastructure when spare capacity can be transferred within the port, alleviating the need for additional infrastructure.

Technical upside

Additional benefits from energy efficiency measures can materialise, such as:

- Energy-efficient lights are typically brighter than conventional lighting requiring fewer bulbs to cover the same area. They have longer lifespans and reduced maintenance needs, thus lowering OPEX costs. Efficient lighting also enables improved health and safety outcomes from better visibility and faster warm-up times, as well as facilitates ecological benefits from more targeted lighting.

ROLE OF PORTS

General role of ports

Energy-saving technologies can be directly adopted within the port by retrofitting existing systems and equipment with more efficient technologies or ensuring that new purchases utilise these technologies. With digital twins seeing increasing adoption amongst ports, when implemented, ports can ensure these solutions include energy system modelling.

Where there are links with terminal operating systems (TOS) existing lighting within the port can be replaced by energy-efficient alternatives if conventional lighting is currently used, with automated lighting able to be integrated into TOS.

Port managing body

Port authorities want to efficiently manage energy demand and consumption in their own and broader port activities and may be encouraged through regulations, ambitions to become more energy-efficient, and potential cost savings, to implement these technologies. With these technologies almost always integrated within the port footprint, ports have an important role in the adoption of these technologies.

Though port authorities have limited influence over the specific implementation of technologies within terminals, they can act as coordinating bodies for this and/or set requirements for terminal operators to meet. A second role is linked to the potential for capital expenditures (CAPEX) cost savings when purchasing physical infrastructure such as LED bulbs in bulk, with port authorities well placed to facilitate this between terminals.

IMPACT ON PORT INFRASTRUCTURE

Energy efficiency technologies typically have little impact on the spatial footprint of port infrastructure. In fact, benefits for infrastructure may arise:

- Efficient lighting has the potential to benefit cargo handling from improved visibility. White light allows colour recognition, and the lux level can be 10% lower for the same perception, compared to the monochromous light of Sodium type lamps.
- Energy modelling can facilitate a more holistic approach to energy management, potentially eliminating the need for future additional infrastructure/spatial needs by optimising current energy infrastructure.

[1] Scope 2 emissions are defined as indirect GHG emissions associated with the purchase of electricity, steam, heat, or cooling

ENABLING FACTORS

- Technical advancement and availability are the key enablers to making progress on energy-saving and the attractiveness to replace or purchase systems.
- The availability of funding is another enabler for the adoption of these technologies as the CAPEX can be large. With the energy price levels influencing the estimated payback period.
- Cooperation between the solution provider and the port is required for energy modelling systems, particularly on data for current system configuration.

MAIN CHALLENGES

- The upfront CAPEX requirement and payback period for purchase and installation is a significant barrier to the implementation of these technologies.
- Ensuring continuous building functionality and work done by staff during the installation of energy efficiency measures in port buildings can be a challenge during port operating hours; either phased implementation of these measures is required, or temporary relocation of staff/equipment to other buildings during installation works.
- Installation of efficiency measures affects the ports' operational process. This is often the showstopper. Therefore, energy efficiency measures must be considered in the case of a new construction or large-scale renovations. At a later stage, it is often considered unfeasible for operational and economic reasons.
- Disruption during the construction phase: where existing port buildings are retrofitted/modernised, this is likely to render the building inoperable during the works with alternative planning required to ensure the activity conducted within the building can continue throughout the duration of the works.

PORT PROFILE

With a wide variety of options available for energy efficiency measures, there is not one 'optimal implementation' of these measures. The measures are in general applicable for both inland ports and seaports.

- With all ports requiring lighting to some degree, the use of energy-efficient lighting applies to all ports. Most significant savings can be realised for ports when replacement or new purchase is done at the time that ageing lighting systems/equipment is nearing the end of their lifespan. Intelligent or automated lighting may be most applicable for ports that are already technologically advanced.
- Energy-efficient port buildings apply to all ports, with existing buildings able to be retrofitted, modernised or rebuilt. Equally, port expansions should ensure new builds are constructed in line with energy efficiency guidelines.
- Energy storage systems are most applicable to container terminals, with the majority of readily available, off-the-shelf systems based on container handling equipment. This often comes as an add-on for new purchases, retrofits are possible but difficult.
- Variable speed motors apply to all ports with relevancy to all plants utilising motors such as within dry bulk ports in conveyor belts.
- Power demand modelling applies to all ports, though with the greatest gains seen for ports with substantive energy infrastructure to enable optimisation of energy consumption to reduce the future need for additional infrastructure, or those planning significant changes to their power systems to enable modelling of future scenarios.

SOURCES

15, 50, 66, 68, 75

A2. Decarbonisation of port equipment

Electrification through retrofitting or replacement of existing diesel port equipment with electric drives is a cost-effective and energy-efficient measure to reduce emissions of port and cargo handling operations. This applies to diesel-powered port-owned equipment such as port authorities' own vehicles and vessel fleets, such as tugboats, barges, and support vessels, as well as to land-side terminal or cargo handling equipment including terminal tractors, forklifts, rubber-tired gantry cranes (RTGs) and mobile harbour cranes (MHC).

Most types of mobile terminal equipment operate internally with electrical drives, with this power generated onboard by a diesel generator. This type of equipment is very suitable for electrification, with drives being directly or indirectly powered by this onboard electrical power grid.

Fully-electric equipment is considered zero-emission at the point of use (accounting for the electricity source, energy should be generated by renewables; see Factsheet A5 on on-site renewable energy generation). Equipment that cannot be fully electrified, can still have their emissions reduced with hybrid diesel-electric units. Though not a zero-emission solution, hybrid drive systems can result in significantly fewer emissions than equipment purely running on diesel fuel only.

The use of alternative energy carriers, such as ammonia or methanol, may be a solution, but are currently a less proven technology for application in port and terminal equipment, with lower technological maturity. It is noted that dual-fuel engines for trucks and tugs are amongst existing examples (large scale operating on diesel and LNG, operating on low-to-zero carbon fuels on a smaller scale). In the future, complementary to batteries, low-to-zero carbon fuels such as hydrogen (combined with a fuel cell or engine) could be deployed on a larger scale for heavy-duty equipment and/or equipment that have longer periods of operation.

In Factsheet A4 there is more information on low-to-zero carbon fuels for marine transport, while Factsheet B8 contains more storage information.

Photo: *Electrified-RTG*

DRIVER/BENEFITS

Drivers for decarbonisation of port and terminal equipment are:

Policy and regulation

- Compliance in meeting carbon emission reduction targets set in policy or legislation.

Port performance and efficiency

- Aim to improve the environmental performance of the port, and lower the impact of the port or terminals on nearby residential areas, through reduction of noise and local air quality improvements.
- Improving operational efficiency through replacement of diesel power in mobile equipment with more efficient centralised power generation by a (green) electricity grid.

Potential negative externalities

- Cargo owners and consumers focus on the environmental and emission footprint of goods and services and negative externalities of the transport supply chain.

Benefits of electrically powered equipment and fleet

- Reduction of local emissions and noise.
- Improvement of the working environment for port and terminal staff.
- Reduction of the impact of port and terminal operations on the surrounding community and environment.
- Reduction in energy use and cost.

ROLE OF PORTS

Port authorities can invest directly in electrifying their own diesel-powered port equipment and fleet.

Responsibility for port equipment lies with the terminal operators. Port authorities, which are most often landlord ports, can encourage, incentivise or enforce private terminal operators to migrate to decarbonised equipment options, depending on port governance and regulatory powers. Some port authorities may actively stimulate or enforce decarbonisation measures for terminal equipment through legislation or concession agreements (if both parties agree). Some port authorities may also choose to facilitate implementation financially through investment of required retrofitting or purchase of new electric equipment for terminals.

IMPACT ON PORT INFRASTRUCTURE

Hybrid-diesel electric

Use of hybrid drive systems is easier than full electrification of equipment, while having no significant impacts to existing port infrastructure.

Electrification of diesel equipment

Electrification of (mobile) equipment comes with new and additional requirements on the power grid, both within the port as well as on the public grid quality.

Impact on electrical power network

Direct electrification requires a physical connection between the equipment and the grid. Most common methods to do so are onboard cable reels and bus bar systems linked to power infrastructure. Indirect electrification requires the presence of an energy storage device such as batteries onboard the mobile equipment which allows storage and reuse of braking energy.

Electrification requires power supply and/or charging infrastructure. This needs to fit in the available space and grid capacity needs to be available:

- Upgrade of internal power infrastructure to accommodate increased power demand and higher peak values.
- Additional grid power capacity required which may create further investment in HV/MV structures beyond the port.
- Reliability of electrical power supply can be more critical requiring a robust and reliable power grid.
- Direct connection options for grid connected electrification:
  - Cable reel which requires minimum additional infrastructure, but has limited flexibility in movement.
  - Busbar system equipment can move without assistance, but the infrastructure requires space and is costly.
- Indirect connection options for battery-powered equipment:
  - Parking space and charging infrastruc-

ture for plug-in charging (or battery-swap facility).
  - Due to charging time, additional equipment may be needed to support operations.

Impact on port terminal layout, including spatial requirements:

- Additional space required for busbar, charging facilities, and cable trenches.
- Civil works for connection pits (to be covered) for charging infrastructure and underground cable routing.
- Space for battery-swap storage facility.
- Provision for local substations within port and beyond.

Training of staff on new electrical equipment use, or maintenance thereof, will be required.

ENABLING FACTORS

The following enablers are key for successful decarbonisation of port equipment:

- Economic benefits of lower cost electricity make the business case easier.
- Equipment already having diesel electric drives makes electrification upgrades easier, compared to normal diesel operated equipment for which full replacement may be needed.

Figure: *Cable reel and busbar electrification of RTG cranes (Source: Royal HaskoningDHV)*

- Timing or equipment replacement: The most economic or cost-effective way of electrification is when equipment fleets are to be replaced (e.g., nearing end-of-life) and/or terminal zones are being upgraded.
- Free space available for electricity infrastructure.
- Supportive investment funding or legislative direction to decarbonise with the medium-term lifespan of port equipment (10+ years).
- Component and electricity demand fit will determine feasibility and pace of electrification, and if it is manageable in the local context of the port.
- Large enough cargo revenue volumes to amortise the investment in electrification process and equipment.
- Technological developments are relatively fast and well developed, stimulating standardisation of decarbonisation methods and the infrastructure need for port or terminal electrification.

MAIN CHALLENGES

Challenges to ensure electrification of port and terminal equipment include:

- Resilience of the electrical grid; operational downtime may result if there is no electricity supply (e.g., due to bad weather) if there is also no backup electricity generation.
- Civil works required for power connection points at existing terminals and lead time to implement electrification solutions will disrupt ongoing operations.
- Use and storage of batteries have safety issues that are to be accounted for, such as a fire hazard.

PORT PROFILE

Location and size

- Proximity of city residents can drive electrification, with demand for improved air quality and noise pollution arising from diesel operations.
- Higher capital investment for infrastructure and equipment may not be commercially viable for small or remote ports and terminals without external funding.
- Ports in smaller cities, or remote locations or islands may be less suited to electrification due to potential lack of regional electricity generation capacity.
- Regions with less stable grid reliability may need on-port back-up generation to maintain operational equipment (e.g., containerized battery solutions or hydrogen-based OPS-systems, rather than large diesel generators).

Type of port

- Electrification is generally more feasible for ports or terminals (both maritime and inland) where the space is compact, and equipment is used for short durations at a time and over short distances.
- Mobility and flexibility of port equipment can be reduced by electrification infrastructure, therefore smaller, multi-purpose ports with wide-ranging cargo needs (and limited fleet size) may be less adaptable.
- For ports or terminals with low capacity, but high equipment use and for long periods, hybrid drive systems may be more suitable than full electrification.
- Where automation of equipment is implemented in ports, this can further boost decarbonisation by ensuring more efficient moves which in turn reduce emissions; majority of automated container and bulk handling equipment is electrified.

SOURCES

51, 52, 58, 67, 68, 77, 80

A. Sustainable transport in/ near port

LEVEL A - PORT

A3. Onshore power supply (OPS)

Ships require power while berthed for on-board activities and during overnight stay. Usually, this power is generated by the ship's on-board generators. An alternative is to provide onshore power supply (OPS), sometimes referred to as shore-side electricity (SSE) or cold ironing so that the ship can be (partially) supplied with electricity from shore. In the future, also batteries on board ships could be powered with OPS.

Most shore power systems are grid-connected but there are also mobile configurations. For these mobile systems, battery system, fuel cell and LNG engine concepts are available although not deployed on a large scale yet.

DRIVER/BENEFITS

- Environmental benefits: Not having to run ship engines or generators implies important benefits by avoidance of pollution, improved local air quality and noise mitigation, especially in urban areas.
- Emission reduction: Regardless of whether green electricity is used to supply OPS, OPS is a solution to reduce GHG emissions from berthed ships. However, when OPS is completely supplied by green electricity, which can sometimes be generated in the vicinity of the port, the GHG emissions reduction is the highest (100%). OPS results in the highest reductions of GHG emission for ships that are staying longer in ports, mainly smaller vessels, or those with high on-board power requirements such as cruise ships or container vessels carrying reefers.
- Battery charging: As electrification of certain types of ships is expected, OPS can be potentially used to charge batteries on board of vessels. Initially focused on smaller vessels making shorter trips.
- Taxation: A limited number of EU Member States have been provided a temporary permit by the EU to apply a reduced rate of taxation to shore-side electricity for ships. The proposal for a revised Energy Taxation Directive could also make it easier to exempt electricity provided to ships at berth (via OPS) from taxation.
- Legislation: The Fit-For-55 (FF55) package requires TEN-T (Trans-European Transport Network) ports to offer OPS facilities to shipping and obligates certain ships to use OPS.

ROLE OF PORTS

The role of the port will be to ensure that OPS facilities are available, though this does not necessarily mean that the port managing body will take on the role of building and/or operating the facilities. The specific role of the port managing body depends also on its governance structure and the national framework.

Shore power can be sourced out partially or completely to a concessionaire who is responsible for operations, maintenance and eventually also construction and financing.

IMPACT ON PORT INFRASTRUCTURE

Ports that want to accommodate OPS require investments in physical infrastructure:

- OPS systems require space on quays for plugs, cables, and converter stations, they can both be fixed (grid-connected) and mobile.
- Stand-alone mobile configurations require an energy storage system, for example a battery module, the mobile configurations could be in the form of a power barge.
- In its current form, the FF55 proposals determine the criteria for OPS at port level rather than terminal level. Terminals should be part of development of OPS facilities.
- Electricity grid capacity may require upgrading, this can cause delays in the realisation of OPS systems and requires collaboration with Distribution System Operators (DSOs). DSOs are required to increase the electricity grid capacity, which is associated with high costs. Therefore, the estimated electricity demand is of great importance.

- Low voltage OPS installations for inland vessels will need to be accommodated in both maritime and inland ports.
- OPS could enable "industrial/commercial" activities in locations where they otherwise would not have been allowed due to environmental legislation (e.g., the relocation of a passenger terminal to a location close to residential area).

ENABLING FACTORS

The following aspects are relevant for ports to play the role that is desired/required:

- The business case for OPS is often not commercially viable, due to a high investment and high electricity prices, without public funding support and/or fiscal stimulation, especially for maritime vessels and locations where OPS is not mandated. This could stay in place if the use of OPS is not obligated.
- Reduced taxation for electricity intended for ships at berth and carbon tax on ship emissions.
- The amount of time in the port and frequency of berthing will be impacted using OPS compared to use of diesel generators. Improving supply efficiency and access will limit time spent and improve the attractiveness of the solution.
- Alternative fuels are not expected to hinder the use of OPS, since the cost of OPS is expected to be below that of electricity generated on board with alternative fuels.
- International rules are necessary to prevent the deteriorating competitive position of ports that are leading in the implementation of OPS.
- Technical standards for connectivity are required, e.g., to ensure compatibility of OPS for international ships. Not all types of ships have already a standard in place. A lack of standards could lead to the need for tailored OPS installations.
- The commitment of shipping companies is required to ensure a large-scale role out. The urge to renew the fleet due to an aging inland shipping fleet might create an enabling momentum.
- Shore power for inland navigation is widely used in Europe, but effort is required to harmonise electricity payment systems.
- A reduction of peak demand for OPS could reduce investments in upgrading the grid.

MAIN CHALLENGES

- A challenge is the fast development of chargers and battery systems compared to the long lifetime of OPS.
- The cost of OPS versus the gains in GHG emission reduction.
- The electrification of industry and other electrical power demand (e.g., port equipment) lead to a large increase in power need, peak demand, and a reliable grid in port areas.
- Reliability of electricity grid, for ports whose electricity must come from the public grid regardless of availability of onshore generation.
- Impact of OPS on handling operations, especially on short quays as OPS infrastructure requires space on the quay.
- Operator acceptability of OPS (space required, OPS capital and operational costs, and participation in investments).
- OPS electricity price competitiveness against cost of electricity generated onboard.
- Standards for cruise and container vessels have been established, however, not for other types of vessels.

PORT PROFILE

- The impact of OPS, the costs and achieved GHG emission reduction on ports differs mainly according to the number of calls for specific vessel types, e.g. ports receiving ships with typical a higher number of reefers will require higher capacities.
- The location (i.e., island vs. mainland) and available electricity infrastructure affects the implementation of OPS (e.g., mobile versus grid-connected configurations).
- OPS benefits noise and pollution reduction depend on the location of a port, nearby urban centres or sensitive natural areas. These benefits are clearly more pronounced than for a port in a remote location.

SOURCES

4, 12, 60

LEVEL A - PORT

A4. Clean fuel bunkering

Increasing demand for international cargo transport combined with growing ambitions to reach climate targets make alternative fuels a key enabler for carbon neutrality. While the adoption of specific alternative fuels is largely driven by shipping lines and their future plans for retrofitting and purchasing vessels, ports can act as facilitator by using, servicing, and promoting alternative fuels. Besides carbon emission reductions, alternative fuel bunkering can also prevent air emissions and improve local air quality.

However, the shipping sector and ports face high uncertainty in the adoption of net-zero fuels or battery-powered ships. With many fuels put forward as the future for marine vessels (e.g. hydrogen, methanol, ammonia, synthetic fuels), there is no clear answer which fuel, or combination of fuels, will be most prevalent. There is also a variety of bunkering options. Cryogenic fuels, with low boiling temperatures like liquid hydrogen (LH_2) or LNG, require highly insulated containers with cryogenic hoses for bunkering. While fuels like ammonia are corrosive and toxic and need specialised equipment to eliminate any potential for leakage. Non-traditional bunkering solutions, such as containerised fuel tanks for compressed hydrogen (CH_2), enable simplified bunkering and can initiate the use of hydrogen in inland shipping in the foreseeable future, but are likely to lengthen port calls of larger shipping vessels. Battery-electric propulsion is of greater viability for inland vessels or port support vessels.

Regardless of which fuel, or combination of fuels, is chosen, ports must plan now. This should be done in order to timely provide the right fuels, maintain market share, meet emission targets, and deal with the various and complex safety and handling requirements of these fuels. LNG, LH_2, CH_2, Ammonia, and Methanol, are currently foreseen as most likely maritime fuels, and lessons learned on drivers, impact, and challenges, will also apply to other future liquid bulk bunker fuels.

Figure: *LNG bunkering of cruise liner from LNG bunker vessel, Tenerife, Canary Islands*

DRIVER/BENEFITS

The key driver behind adoption of alternative zero or low carbon fuels is the need for the maritime sector to become carbon neutral. With the burning of fossil fuels by vessels being the greatest source of carbon emissions in the sector, all those involved are under increasing pressure acceleration emissions reduction.

Legislation drivers

- The initial targets by the IMO are set to reduce carbon intensity of international shipping by 40% by 2030, and 70% by 2050 (compared to 2008). Moreover, the total annual GHG emissions need to be reduced by 50% compared to 2008 across international shipping.
- The "IMO 2020" rule limits the sulphur content in fuel oil and resulting in ships needing to use very low sulphur fuel oil (VLSFO) to comply to the new limit.
- The "Fit-for-55" package has a target to reduce transport emissions by approximately 90%.
- EMSA LNG Bunkering Guidance outlines necessary advice and reference for port managing bodies.
- There are also country- or port-specific targets to reduce, and ultimately eliminate, fossil-based fuels.

Global supply and demand dynamics

Overall, increased availability, technology and price developments, and standardisation will make alternative fuels will stimulate vessel investment decisions.

- If more ports provide supply bunkering infrastructure, this will secure supply and availability, and stimulate demand for shipping lines bunkering with alternative fuels.
- Some shipping lines have already shared their plans to reach IMO's targets, some examples:
  - Maersk wants to have their first carbon neutral vessel by 2023.
  - MSC has a deal with Total to bunker their vessels with LNG.
  - Ammonia ready vessels are being built by several companies.
  - Carnival has a deal with Shell to bunker their LNG cruises in Barcelona and Canary Islands.
  - Baleária has LNG-retrofitted six of their vessels.

Industry synergies

Ports with a significant bunkering supply chain for alternative fuels might be able to synergise by-products with local industries, such as the generation of biofuels from nearby waste including waste from vessels (in accordance with MARPOL), waste heat networks from refrigeration infrastructure or oxygen generated from electrolysis to be used in other industries such as pharmaceuticals.

ROLE OF PORTS

General role of ports

The first port role is a user role, as ports want to take action to decarbonise their own fleet. The second role is a facilitator role, by supplying and enabling commercial bunkering of alternative fuels. This requires insights on associated safety and handling risks of alternative fuels, the earmarking of land and infrastructure for alternative fuel, and to enable future adoption once a decision has been made at on which alternative fuels will be used. Furthermore, ports need to gain clarity, push progress and direction of alternative fuel use and adoption in cooperation with stakeholders. The third role is a promoter role, where ports can raise awareness within the port community and wider public.

The role of the port managing body

The port managing body can produce regulatory frameworks and guidance, and tender requirements for port works to enable the bunkering of alternative fuels in their ports. Port managing body may need to alter specific by-laws or regulations to allow the bunkering of alternative fuels or to allow alternative-fuelled vessels to enter the port. Equally, it may, in coordination with other bodies like the Society for Gas as a Marine Fuel (SGMF), produce guidance for bunkering of alternative fuels.

The establishment of green (maritime) corridors; an ecosystem of port managing bodies, terminal operators, shipping lines, and cargo handlers to create a transport zero-emission chains between ports will drive supply and demand dynamics. Many ports are starting to work within this framework in order to promote/facilitate the introduction of zero carbon fuels.

IMPACT ON PORT INFRASTRUCTURE

General provision and spatial requirements

- Ports will likely need a storage and import terminal or production facility, from where bunker vessels can pick up alternative fuels and supply it to the vessels in need of bunker (Factsheet B8). For small port-based vessels, bunkering from a fixed barge or onshore storage could be considered.
- An adequate dedicated area for product handling and safe storage is required. For example, ammonia is expected to need substantially larger safety distances than LNG, applying both to onshore storage facilities, and the safety zones around locations where ship-to-ship bunkering takes place.
- For smaller boats, separate bunkering infrastructure may be necessary, as they have different physical compatibility and flow rates compared to bigger vessels e.g., container vessels.
- Synthetic (bio)fuels such as biokerosene or biodiesel are not covered in depth as the production and transportationg costs render these fuels commercially unviable. Also, the infrastructure requirements would be similar to those for fossil fuels.

Bunkering

- Shore-to-ship bunkering: Vessels are bunkered directly from onshore tank or vessel fuel station, connected with a hose or marine loading arm (MLA).
- Ship-to-ship (STS) bunkering: Bunkering from locations at sea, along the quay, or at anchor. This is the most popular method for seagoing vessels as the bunker vessel can be moored alongside the vessel while the vessel undergoes simultaneous cargo handling (simops). After bunkering is done, the bunker vessel comes back to the port and needs to be berthed, requiring dedicated quay locations.
- Truck-to-ship (TTS) bunkering: A truck carrying fuel, which is connected to the vessel with a hose, is more suitable for smaller vessels as volumes are small and the flow rate is limited. Port facilities need to a have a well-connected road network, and develop facilities where truck to ship bunkering will not obstruct other activities when bunkering.
- Bunkering with compressed hydrogen (CH_2) in swappable containers: No additional investments are needed at existing inland container terminals which already handle dangerous goods; swapping containers fits well with existing logistics operations

of inland shipping organisations handling containers. Safety requirements are necessary on site and licenses needed. Logistical planning will be significantly affected as H_2 containers must be delivered in time.

ENABLING FACTORS

Legislation and governance

- Governance needs to be established between port owners, terminal operators, alternative fuel storage owners, fuel/bunker production company, and shipping lines.
- Government guidance is necessary for safety and regulation of fuel quality, to ensure legality in use of the alternative fuel as a marine fuel, and potential funding for large-scale pilot projects.
- Public support and legislation such as subsidies for use of alternative fuels by shipping lines, stricter emission limits, or CO_2 emission/carbon taxes will help the transition to zero carbon fuels.
- Support funding to finance the transition to alternative fuels as significant investment is required to provide bunkering infrastructure including new technologies.
- Guarantee of origin schemes; third party assurance that the fuel used is from the correct production pathway, preventing for example that blue hydrogen is sold as green hydrogen to create extra revenue and false decarbonisation claims.
- Establishment of safety standards and regulations for licensing and authorizing bunkering infrastructure, operating procedures, emergency response and related activities.

Technology and supply chain

- Ongoing research and innovation breakthroughs to further improve the safety in handling and bunkering alternative fuels as well as (marine) engines running on alternative fuels.
- Port planning with dedicated loading berths for bunker vessels and/or for shore-ship bunkering required. For ports that have a liquid storage hub (Factsheet B8), fuel could come directly from the storage hub and therefore does not need to rely on separate imports. Production outside the port and logistics up to storage should be planned to ensure a smooth supply bunkering chain.

MAIN CHALLENGES

Technical

- Even though LNG produces less carbon dioxide than fuel oil, it is still not carbon neutral.

- Ammonia is currently banned for use as a fuel by the International Code of Safety for Ships using Gases or other Low-flash-point Fuels (IGF Code) due to it being a toxic substance, though will likely be allowed in future.
- Safety aspects for design in terms of distance and handling alternative fuels is a challenge due to a lack of expertise and established criteria. Furthermore, there is still a lack of guides, international standards and codes for the use of H_2, ammonia, and methanol as marine fuels.
- Energy density of low/zero-carbon fuels are substantially less per volume than business-as-usual fuels thus requiring more space, on top of the additional space needed to adhere to safety distances.
- There are ongoing difficulties in measuring the number of alternative fuels (metrology).
- The lack of alternative fuel bunker vessels and future choice of the 'preferred' fuel creates difficulties as it Is likely that several fuels will be in use in years to come. Which will strain ports that already face land scarcity, as separate barges for different fuels require more and different berthing points.

Financial

- Alternative bunkering infrastructure needs significant investments but there is currently uncertainty in demand and optimum alternative fuel, with technological drawbacks for each. This is while also flexibility is needed to adapt to expected market circumstances.

PORT PROFILE

With ports aiming to achieve net zero operations to meet the Paris climate goals, all will need to ensure some level of access to an alternative fuel bunkering supply chain.

- Ports relying on bunkering of conventional fuels may wish to ensure future income, maintain market share, and access diversification opportunities. Capitalising early-on can provide a competitive advantage in enabling more stable supply chains.
- Due to the spatial impacts of alternative fuels, smaller or inland ports in proximity to larger ports or alternative fuel providers, could circumvent their own bunkering of alternative fuels by entering into an agreement with the larger entity to provide bunkering services, or specialise in specific alternatives that can also service the partnering port.
- If a port wishes to provide alternative fuel bunkering, significant land may be needed for the required infrastructure, in addition to safety zone requirements and/or key health and safety considerations.
- As alternative fuel bunkering will become the standard, all ports need to consider how best to provide alternative fuel bunkering, or how to secure third-party bunkering services at their port.
- Handling of CH_2 is preferred for inland shipping with swapping of H_2 containers at container terminals within inland waterway networks rather than deep sea container terminals focusing on maritime shipping. Battery-electric propulsion is also seen as more applicable for inland vessels than seagoing vessels and would require a network of charging stations.

SOURCES

3, 5, 13, 38, 40, 53, 54, 67, 76

A5. On-site renewable power

Localised energy generation from renewable sources such as solar or wind are being increasingly implemented within port areas to reduce carbon emissions in support of decarbonisation efforts and achieve independence from the grid by decentralised energy generation. Adoption of solar and onshore wind energy is relatively widespread, has gained acceptance as viable and principle renewable energy sources and has comparatively high technological maturity. Wave and tidal power generation offers future potential as renewable energy sources for ports. However, these sources are not widely available, with the technology still emerging.

Local renewable power generation can typically be used to power port office buildings, sheds, workshops and surrounding buildings, charge electric port equipment and vehicles, and in some cases shows potential of generating enough power to provide onshore power in the future. If linked with Energy Storage Systems (ESS), on site renewables can mitigate peak rate tariffs and provide ports with significant cost savings. Port authorities, and all players within the port, can individually and jointly develop and use renewable generated power by optimally utilising available space in the port.

DRIVER/BENEFITS

For many years climate change mitigation has been a primary reason to support renewable energy development. With fast development and improvements in solar and wind energy technologies, these renewables are in many cases now cost-competitive and lead to energy cost savings over time. Key drivers for ports to invest and install local renewable energy generation are listed below:

Business opportunity and growth

- Commercial business case with earning potential via cost savings on energy costs and green taxes, and/or sale of surplus energy to third parties or tenants.
- Guarantees of Origin (GO) of locally produced renewable energy can attract new industries.
- Employment opportunities via positioning the port as innovative renewable energy hub.

Policy and regulation

- Compliance with (international) climate change mitigation agreements.
- EU-regulations and regional legislation (e.g., RES Directive, Renewable Energy Sources) on promoting use of energy from renewable sources to meet greenhouse gas (GHG) emission reduction targets and future carbon neutral goals.

Sustainability image for competitiveness

- Adoption of renewables can aid in achieving a port's internal goals and clean port strategies for carbon emission reduction, improvement of the port's environmental performance, and contibute towards corporate social responsibility initiatives.

Photo: *port of Helsinki (2020)*

Autonomy and security of energy supply

- Enable independence from the public electricity grid and peak demand times or during emergencies.
- Faster expansion of renewables given the current energy crisis and Europe's dependence on Russian fossil fuels.
- Improve system reliability with additional capacity and security of electricity supply.
- Minimise use of existing diesel generators.

ROLE OF PORTS

- Port authorities, and all players within the port, can individually and jointly develop and use renewable generated power by optimally utilising available space in the port.

The role of the port managing body

- Ports are responsible for future-proofing their port to accommodate renewables. For example, making sure new structures are adequate to accommodate future rooftop solar photo voltaic (PV) installation.
- Ports authorities can initiate, and drive implementation of renewable energy generation sited within the port boundary. Their role can be to fund construction of renewable generation and take responsibility for operations thereof. The port can also enter

into agreements to (partially) outsource to an expert concessionaire, who is responsible for day-to-day operations and maintenance.
- The port can also act as facilitator for renewable energy generation by (commercial) actors in the port. For example, by utilising residual land or appoint dedicated areas.
- Planning, installation and operation of renewable energy generation on site involves coordination between the port and multiple partners or external parties, e.g., owner, beneficiary, developer, contractor, operator and suppliers of technology and equipment components.

IMPACT ON PORT INFRASTRUCTURE

Application of renewable energy generation on site (within port owned land) can in general be incorporated into the design of a new port, expansion of a port or the modernisation of an existing port. Major benefits for the port include saving on annual energy costs and enabling a reduction in CO_2 emissions. A number of factors are to be accounted for and may affect the port:

Spatial requirement

- Solar PV can be applied on a very flexible scale with varying spatial requirements, e.g., from one solar panel up to large sites of several km^2.
- Installation of solar panels requires space, preferably free or open areas which are unsuitable for other utilisation, i.e., rooftops of offices, warehouses, car and truck sheds, and obsolete land that cannot be otherwise used for port activities. This is to minimise taking up large areas of economically valuable space in the port.
- Wind turbines are cost-effective from a minimum scale of approximately 2-3 MW which leads to significant spatial requirements.
- Installation of wind turbines bring safety risks and inconvenience issues for surroundings. Standard onshore wind turbines require an exclusion radius related to physical size of the wind turbines or to the noise levels.

Use of space to its maximum

- Structural investigation of building rooftops is required to assess the impact on buildings and suitability of surfaces, including roof strength, orientation of panels, safety, accessibility of the roof, etc.
- Open land-based locations in the port also requires assessment of orientation and inclined plane of the surface.

Site preparation

- Levelling, laying of foundations and civil aspects are required to prepare locations for installation.

Electrical power infrastructure

- Electrical connection to facilitate the integration of the new renewable energy sources into the power transmission and distribution system, i.e., substation and space for a local electrical equipment room.

Grid adjustments in the port

- The internal electrical power network, grid configuration and bottlenecks in capacity should be checked. Extension and upgrade of existing medium voltage power network may be required.

Energy storage and space

- Inconsistency of supply as generated power from renewable energy sources is intermittent, unpredictable and uncontrollable. Balancing of load is required due to fluctuations of voltage and grid being unacceptable.
- This requires installation of energy storage systems to optimise consumption and generation of energy. Battery-storage technology can be deployed to enable storage of renewable energy to be used at peaks of energy demand, or in the future alternative the utilisation of energy carrier's storage, such as hydrogen and ammonia.
- This requires substantial additional space and capital investments.

Operations and Maintenance

- Solar power generation leads to increased maintenance requirements of solar panels due to issues linked to high concentration of dust particles and overheating. Periodic cleaning of panels is required to avoid reduction of generating capacity.

- Installation of on-site wind turbines will also result in increasing efforts on operations and maintenance, and may for example result in navigation interferences and aviation restrictions.

ENABLING FACTORS

The following factors play a role in the easier uptake and successful implementation of localised renewable energy generation:

- Integration of renewable energy generation into a port's spatial design and construction of port (if new).
- Access to and availability of large open spaces and suitable surfaces within the port where renewable energy generation installation may be feasible, such as free land area unsuitable for other utilisation, or rooftops of large warehouses and buildings for solar panel installation.
- Physical weather patterns in the locality of the port, i.e., high yearly solar irradiation and/or high average wind speed. Hydro or tidal power may not be realistic alternatives depending on location of the port and operational processes.
- A connection to the public grid that can be used for balancing of the renewable energy. The grid operator should allow for power flow in both directions, i.e., allow feedback of power into the grid. This is generally the least expensive solution.
- Installation of an energy storage system is required if balancing via the grid connection is not possible and/or capacity is limited, installation of an energy storage system is required. The ESS can be used for buffering the output of the renewable power generation system, e.g., energy from solar generation stored during the day and used at night or when the sun is not shining.
- System modification, upgrade, and extension of existing power networks over time will accommodate integration and expansion of new energy sources.
- Efficient permitting procedures can help to stimulate project development and processes for owners and beneficiaries.

Solar PV:

- Easily scalable and implementable; having suitable roof structures on buildings can allow smaller scale implementation of solar power despite port land constraints.
- To save land space or where landside space is limited, floating solar power plants provide an alternative solution, though are at a low level of technological maturity. Suitable wind, wave and surface conditions are also required, with salinity potentially impacting the durability of panel components.

Wind energy:

- Average wind speed needs to be high enough to allow efficient load operation of the wind turbines. Low utilisation of a wind turbine cannot be operated economically and would not be considered feasible.

Tidal and/or wave energy:

- Currently only considered if wind and solar are not possible.
- Comparatively immature as a technology and requires large investment, though funding for new technologies is available.
- Tidal energy is predictable unlike solar and wind energy.
- Tidal energy is only relevant for very specific geographical conditions, with sufficient wave resources.

MAIN CHALLENGES

Main challenges are related to space and funding:

- Available land area for installation of wind turbines and/or solar PV on land is a constraint.
- Funding support for commercial scale renewable technologies (such as wind and solar) is limited. The financial support landscape for wave and tidal energy is more attractive, however, there are fewer examples of successful deployment case studies.
- Landscape integration and ecology pose a challenge when developing wind power on land and onshore, having to sufficiently avoid/mitigation issues such as noise, safety, and biodiversity.

PORT PROFILE

There is no single solution that applies to all ports, as the potential to generate power from renewable sources varies per location. Undertaking an assessment of the potential for generation from the different alternative sources and evaluating the local feasibility is essential to identify the optimal energy profile of the port. Climatological data can be analysed to identify the potential of each form of renewable power generation that is applicable for the port location, e.g., yearly solar power generation potential (kWh/kWhpeak) is based on solar irradiation of the area measured in kWh per m^2 per year; average wind speed in m/sec.

This will determine which renewable strategy is applicable and fits within a port authority's energy strategy and how it will be incorporated into the port masterplan, in turn informing investment decisions.

Large-scale opportunities are not feasible for many ports due to spatial constraints and cost barriers. Small ports may also require energy storage facilities.

SOURCES

24, 52, 55, 58

B1. Waste to energy and chemicals

Waste (biomass[2], food, industrial waste, plastics, etc.) is increasingly being viewed as a high value resource, as (re)use can turn waste into economic value. Urbanisation is driving growth of municipal waste significantly, with a large share being biogenic. Sources include municipal waste, such as wastewater, solid waste, animal manure, outdated foods and feeds, used cooking oils, and other sources like woody biomass and crop residues, that are expected to play a larger role.

Incineration, the combustion of waste with energy recovery (electricity, heat), is currently the largest waste-to-energy implementation.

The transformation of wastes into fuels (waste-to-fuels, and other high-value chemicals (waste-to-chemicals) is becoming an increasing field of green chemistry. With fossil fuels as the key feedstock at the moment for many industries, there is the need to switch from fossil fuels to biomass as one of the main feedstocks. There is however high uncertainty in the share of sustainable biomass for fuels/chemicals production compared to for example synthetic technologies. Dry streams are typically processed via thermal routes (to produce electricity and heat), wet streams via fermentation (to produce e.g., biogas).

There are several new and emerging technologies that can produce energy from waste without direct combustion. Some are suitable to convert the energy into liquid/gaseous fuels. Here, a distinction can be made between thermal treatment technologies (e.g., gasification, pyrolysis) and non-thermal technologies (e.g., anaerobic digestion, fermentation).

Ports are already hosting plants that use biomass to produce electricity and heat (e.g., biomass can be co-fired in coal-fired power plants) and are increasingly hosting waste-based energy or (bio-)waste-fuel production plants. The integration in the wider port area can

Figure: *Waste-to-energy plant (Dublin, source: geograph.ie/photo/5816269)*

[2] Organic material both aboveground and belowground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. Biomass includes the pool definition for above - and below - ground biomass. Note: This definition by the IPCC sets out a division between above-ground and below-ground. Other definitions exist, that e.g. make a distinction between wet and dry biomass. Biomass needs to be produced in a sustainable way to be effective at reducing GHG emissions.

lead to environmental and economic benefits, e.g., re-using waste from cities and the connection with waste streams from industrial clusters.

DRIVER/BENEFITS

- The EU Fit-for-55 package, national and regional climate legislation require reduction of greenhouse gas emissions. The focus of ongoing policymaking is on addressing methane emissions from agriculture, waste facilities, and the oil and gas sector.
- Circular economies support the ambition of becoming carbon neutral/net zero. By eliminating waste and pollution, emissions associated with production of materials are reduced.
- Targets for the admixing of biofuels for transportation lead to an increase in the production of these fuels from waste.
- To maintain economic value these new bio-based production plants need to partly replace the fossil-based economy that will slowly be phased out. This applies for both the production facilities in the ports themselves as well as the new feedstock streams towards production locations in their hinterland.

ROLE OF PORTS

General role of ports

- Ports could contribute to air and environmental quality improvement with waste handling and recycling facilities.
- As ports act as an interface between large-scale industrial activities and logistic flows come, ports are well established to turn waste into energy/fuels/chemicals.
- Ports could import waste streams to produce refuse-derived fuels, considering EU requirements for waste hierarchy and the objectives of the circular economy.
- Ports could become biomass-hubs connecting receiving large quantities of raw biomass and forwarding these in smaller quantities to hinterland other sectors.
- Processing (bio-based) waste streams provides an opportunity for ports to produce high-quality products, e.g., replace the production of fossil fertilizers and chemicals.
- Ports near urban areas could play a role in the generation of heat and/or electricity from municipal and/or industrial waste.

The role of the port managing body

- Ports can play an active role in forming clusters to achieve synergies between companies to process large volumes of waste to produce energy/fuels/chemicals.
- Ports can provide land to produce energy/fuels/chemicals from waste streams.
- For waste-to-energy, increasingly CHPs (Combined Head and Power) are used. Ports can facilitate and stimulate the collaboration between power and heat producers and off takers to ensure efficient production and transport within the port.
- Ports can integrate land power cables from offshore wind parks to ensure enough renewable power is available to feed new businesses.

IMPACT ON PORT INFRASTRUCTURE

The main impacts of the waste to energy, fuels and chemicals activities on port infrastructure are:

- On the short term, focus is on waste-to-energy (incinerators, sewage treatment plants, installations for the combustion of waste wood, biomass and co-firing of biomass in coal-fired power plants) and waste-to-fuels activities (e.g., the production of biodiesel/HVO (Hydrotreated Vegetable Oil) and methanol).
- On the longer term, a growing demand for bio-based chemicals will require facilities for waste-to-chemicals processes and potentially the production of bio-kerosene.
- The need for (bio-based) waste terminals.
- Reinforcement and adaptation of infrastructure to transport electricity, heat and waste streams.
- Facilities to import biomass and transport to the hinterland, as not all biomasses may be used in the port itself.
- The ability of current installations in ports that were built to produce electricity being able to be adapted to produce heat as well (e.g., from waste wood, wood chips and manure).
- The transhipment and storage activities will partly shift from fossil based to bio-based commodities such as wood pellets and

chips, pyrolysis oil and bio-coal.
- Storage facilities for biogas. Biogas is produced from crops, manure, solid waste and wastewater and is a mixture of (among others) methane and CO_2. Unless the biogas is converted to biomethane, the biogas can be used locally to produce electricity or heat.
- To produce (bio-)fuels, storage and transportation facilities are required. Biomethane may be transported through (existing) gas pipelines. Other fuels, such as bio-LNG, bio-LPG and methanol require transport through road/rail/water.
- For bio-production facilities, CCS (Carbon Capture and Storage) infrastructure may be required.

ENABLING FACTORS

The following factors enable ports to attract waste to energy, fuels and chemicals activities:

Technical

- Prioritise areas to ensure the transition is enabled
- Facilitate waste cluster forming to maximise carbon efficiency.
- The need to invest in adequate waste reception (collection and treatment) facilities and waste-to-chemicals initiatives, among others.
- Interrelations between the development of waste to energy/fuels/chemistry and the development of fossil-based and power-based industries.

- Large scale import of biomass is necessary to make the transition from fossil-based to bio-based energy, fuels and chemicals. The sustainability of the biomass and food-security need to be preserved.
- Facilitate suitable power grid developments as decarbonised production has an increased power need compared with fossil production methods. Depending on the port location and available area, renewable power production in the port could also be an enabler.
- Facilitate hydrogen import or production facilities as waste to chemical or fuel (like HVO or bio-kerosene) production often requires substantial amounts of hydrogen.
- Innovations remain necessary and have to be linked directly to market perspective and policy to achieve large-scale applications.

Commercial/economic

- The need to invest in adequate waste reception (collection and treatment) facilities.
- The long-term demand for biomass is largely determined by the use of electricity for mobility and industry.
- The transition to bio-derived products is largely determined by carbon pricing

schemes and government policy.
- An optimal exchange of streams (materials and energy) leads to a profitable cluster. Therefore, the optimal use of waste, energy, fuels and feedstocks needs to be promoted (e.g. lower ground prices for matching facilities).

Society
- Need to ensure compliance with regulations for air and water quality, management of waste, treatment and handling of chemicals and mitigation of any negative environmental impacts.
- The distinction between waste and raw materials needs to be abolished to stimulate the (re)use of waste as a resource (no-waste status).
- Sustainability criteria for the use/sourcing of e.g., woody biomass for heat and electricity, transportation fuels and the chemical industry need to be clearly defined. Potentially, these criteria could be coupled to land sale/lease agreements.
- Certification of waste/sustainable biomass streams to ensure these streams fulfil sustainability criteria.
- Logisitics chain integration is required to ensure security of supply, control of price, quality and sustainability in every link in the chain.

MAIN CHALLENGES

The main challenges for the port to attract waste to energy, fuels and chemicals activities are:
- Growing fossil businesses may limit sustainable developments.
- The expansion of the recycling industry might face a future ban on (intercontinental) imports of waste.
- The immature technology for waste-to-chemicals activities is challenging to achieve large-scale implementation on the short term.
- Lack of affordable renewable power and hydrogen.
- Circular economy efforts could reduce waste volumes through waste reduction, reuse, recycling and waste management.
- Sustainable biogas/biomethane production requires a reduced role for (and/or ban on) direct crop use, because of the competition with food.
- Spatial planning due to the potential increase of demand for terminals for the biomass and bio-based raw materials. Bio-based materials require significant land use for storage, due to the low energy density (e.g., wood).

PORT PROFILE

The following distinction can be made between the role of different ports in the development of waste to energy, fuels and chemicals activities:
- Seaports could get involved in offshore aquatic biomass activities, but this will heavily depend on the decline in the cost curve.
- Ports that are well positioned amongst industrial clusters and logistics could form part of waste to energy, fuels and chemicals activities.
- Ports near large cities could play a role in the processing of municipal waste into energy, fuels and chemicals.
- Ports with facilities to import biomass and with connections to the hinterland could act as a hub in the supply chain for the use of biomass to produce, energy, fuels and/or chemicals.
- Ports that are located near incinerators could benefit from the adaptation to circular waste processes.
- Inland ports may play a role in the transportation of waste through inland waterways to incinerators. Incinerators are often located near waterways due to their waste logistics as well as cooling water requirements.

SOURCES

11, 12, 17, 20, 30, 33, 60

B2. Offshore energy

Offshore wind energy is projected to become one of the fastest-growing renewable energy markets by capacity. The energy generated offshore is to typically integrated into onshore power systems (via electricity grid or gas).

Electricity can be transmitted directly to public grids by having an onshore substation that connects the subsea cables to land. Technologically, this can be done using high voltage AC (HVAC) or high voltage DC (HVDC) systems.

The integration of energy generated by OWFs comes with two main challenges: (1) Distribution: expansion or upgrade of the current onshore networks will be required to facilitate the integration; and (2) Storage: land-side energy storage facilities will be required to balance the fluctuating supply and demand and connection between offshore and onshore infrastructure. Wind energy is intermittent; one option is to use the temporary energy surplus to power electrolysis and store the energy in the form of energy carriers such as hydrogen. For short-term storage, batteries are more efficient to deal with surplus renewable energy production. However, for long-term storage hydrogen might be a relevant medium to store surplus RES, as such, it could be more scalable given its potential growing applications outside the power sector.

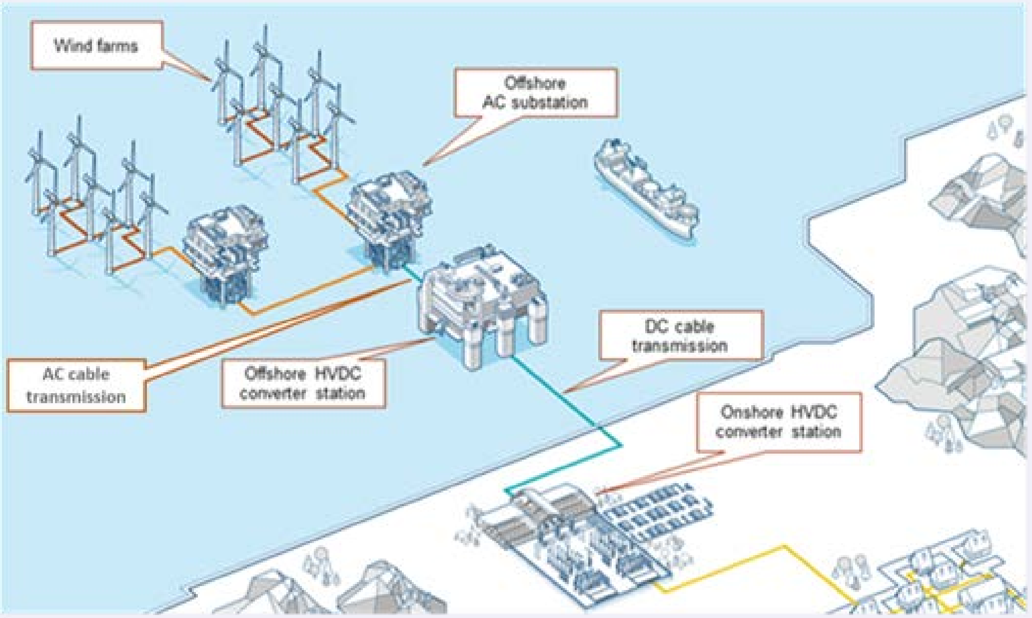


Figure: *Integration of offshore wind farms (OWF) using HVDC transmission system (source: ABB).*

Due to the increase of OWF capacity over the years, it is expected that the existing grid will not be able to handle the transmission of electricity generated offshore due to overcapacity. There is an urgent need to address this issue to ensure integration of offshore wind energy into the energy system. Conversion of electricity to hydrogen could be an alternative means to transport the power to land. In this case, ports can play a part in the conversion process and the distribution of hydrogen itself. Although using hydrogen as a means of transporting renewable energy seems promising, this concept is still emerging and has not been widely implemented yet, although pilot projects are running.

This factsheet presents integration of energy generated offshore to onshore by 1) submarine power cables for transport of electricity and 2) in the form of hydrogen via hydrogen pipelines or vessels.

DRIVER/BENEFITS

Offshore wind farms refer to wind farms located in the ocean, both in shallow waters near the coast and further out to sea, ranging from tens to approximately a hundred kilometres from the shore, depending on suitable depth of the seabed. Typically, conventional fixed foundation turbines are installed at 15 m to 25 m water depth (maximum depth therefore is 40 m to 50 m) and 15 km to 40 km coastal distance but can be further which is also the case for floating offshore wind. OWFs produce a higher quantity of energy compared to onshore due to the faster wind speeds than on land. Another reason for OWFs being generally favoured over onshore farms is nuisance to local surroundings and environment (noise and visual impact) leading to public resistance for onshore wind turbines in addition to a general a lack of space in very densely populated countries.
In November 2020, the EU Strategy on Offshore Renewable Energy was presented, which sets a target of 300 GW offshore wind capacity by 2050.

ROLE OF PORTS

General role of ports
Ports that are located near OWF could be key players to facilitate the energy transition process for industrial clusters.

- Ports can play an important role in facilitating the installation, operations and management (O&M), and storage of the necessary equipment for OWF (Factsheet B3).
- Ports are envisaged to be a part of the offshore energy system, acting as an interface between sea and land for offshore renewables, thereby distributing the energy that is generated at sea, through the port and to the end user. The onshore substation of OWF can be placed in a port, although it does not need to be. In some countries such as the Netherlands, electricity from renewable sources first needs to be injected into the public grid, instead of being directly supplied to the end users. With the growing demand of OWF generation, generated energy could exceed the capacity of the public grid. Currently, some transmission system operators are looking into directly connecting renewables to the industrial clusters in port areas, therefore bypassing the public or centralized grid. This may also serve as attraction for consumers to be (re) located into the vicinity of the port area to utilize direct connection to energy generated by offshore wind. Ports are often home to clusters of energy-intensive industries that would make the deployment of local hydrogen networks worthwhile.

It is also expected that a significant portion of the generated energy from OWF, especially from the more remote OWFs, will be produced, imported (e.g., via pipelines), and exported (e.g., via vessel or pipelines) in the form of hydrogen or hydrogen-derived fuels such as ammonia. Ports could also participate in facilitating storage infrastructure (Factsheet B8). Thus, it can be expected that the electrolysers will be placed in the port areas. The ports will play the role of hub and distributor of hydrogen.

The role of port managing body
The port authorities will be expected to participate and engage with stakeholders in order to facilitate integration plans and remain involved in discussion surrounding subsequent effects such as relocation of industries in and around the port area and the port's connections to the grids (electricity and others, like hydrogen pipeline networks).

IMPACT ON PORT INFRASTRUCTURE

- The port managing body with transmission system operator (TSO) needs to accommodate for the cables and pipelines coming in from offshore/onshore substations (cable trenches in nearby structures can affect the structure).
- Terminal operators need to accommodate for hydrogen pipelines and facilitate storage and distribution facilities.
- Terminal operators need to accommodate for a terminal dedicated for conversion of hydrogen and electrolysers (power to gas

infrastructure).

- Port managing body needs to provide provision to derive hydrogen from its carrier and vice versa.
- New policies need to be established by government and port managing body to ensure safety standards for design and operation of related hydrogen infrastructure in ports.

ENABLING FACTORS

Enabling factors

- Governance for direct connection of OWF: close cooperation is needed between port operators, industries, distribution, and transmission system operators (DSOs and TSOs).
- Governance for hydrogen transport: close cooperation between port operators, shipping lines, and DSO/TSO as well as end users at ports.

- The European Union has made a policy focusing on linking energy infrastructure of its member states, known as the Trans-European Networks for Energy (TEN-E).
- There are currently many pipes for oil and gas (O&G) offshore. The plan is to transport hydrogen using these pipes, with technical modifications, operational testing, as well as adherence to safety standards which are in development.
- Ports often part of the country's energy supply masterplan and are therefore supported in the regional role they intend to play.
- Established policy and trading platform of the handling of hydrogen.

Opportunities

- Current climate agreements and EU policy on achieving net zero carbon could help in securing funds and getting investors involved in realising the infrastructure in the port.
- Involving hydrogen in port planning could trigger the interests for wide-scale hydrogen production and could identify market opportunities.
- Integration of hydrogen into the port can encourage new entrants to support renewable energy related activities, this can also result in improved synergies between port authorities and energy operators.
- Having direct electricity connection to the port could bring additional revenues to port

managing body, because it could encourage new entrants to be located on the port-owned land area so port managing body will get additional income from leasing their land.

Main challenges

- As hydrogen technology is still emerging, supply chain requirements and realization thereof could potentially affect or delay the construction of associated hydrogen infrastructure.
- Moving large electricity consumers to the port area requires a huge amount of space as well as incentive and/or government assistance, potentially including funding.
- Business case for locally producing hydrogen is still uncertain as there is still uncertainty in the optimal low-cost solution (local production versus import) too.
- With the world slowly turning away from fossil fuels, it could be that in the coming years oil and gas pipelines are planned to be made redundant. Hydrogen transport via pipelines should start before the pipes are decommissioned. Although using hydrogen as a means of transporting renewables seems promising, the development is still emerging and has not been widely implemented yet (therefore publicly available literature/knowledge is limited).
- Hydrogen production including electrolysis will take place at large production facilities to maximise its efficiency. Consequently, the safety and land challenges associated with producing hydrogen will have a large effect on the port. Most ports will not be able to accommodate the conversion process due to the lack of capacity.

PORT PROFILE

Location

- Integration of OWF, be it in the form of electricity or hydrogen, mainly interests maritime ports located closest to the wind farms.
- Direct connection to the port area will support the already-energy-intensive industries and could encourage new entrants to invite local industries to move towards a closer vicinity of the port.
- The concept of energy islands is becoming prominent. Currently there are plans to have them built in some EU countries. Synergies between ports and these islands are expected, however, again these will mainly benefit the ports closest to them.

SOURCES

32, 45, 78, 79

B3. Offshore industry

The development of offshore wind farms (OWF) is one of the major contributors to the increase of renewable power supply in Europe. Currently, Europe has a total installed capacity of 25 GW, while the latest EU Offshore Renewable Energy Strategy sets targets to reach at least 60 GW by 2030, and 300 GW by 2050. Meaning more than a ten-fold of current capacity is needed, driving growth opportunities and development.

The development process includes the component production, a stable supply chain, logistics, and supporting infrastructure for the installation, operation and maintenance (O&M) and decommissioning of offshore wind farms.

Next to the supply chain development in port areas, the transformation of (excess) wind power to hydrogen may lead to additional energy infrastructure in ports, for example electrolysers converting power to hydrogen in the port, and pipelines bringing hydrogen produced offshore to the port and further inland.

The decommissioning of offshore oil and gas (O&G) platforms is required since many of the fields approach the end of their economic life in the coming decades. Some of the platforms may be re-used, e.g., for hydrogen production from wind power or storage of CO_2.

This will lead to a transformation of current O&G focused offshore service clusters, active in ports, needing to develop capabilities to successfully and replace conventional energy activities by a financially attractive position in offshore wind.

DRIVER/BENEFITS

Offshore wind has a positive momentum and is a renewable technology winner in NW-Europe, driven by successful cost price reduction efforts, scalability, and an investment and development push from energy companies and other value chain players. Developments are further driven by:

- European energy security: The aim to secure resources, diversify supply, and especially reduce import dependence has grown significantly since the EU Energy Security Strategy in 2014. Scaling up renewable production like OWF is seen as an opportunity to become energy independent, while the war in Ukraine further accelerates the need to remove dependency on Russian gas.
- Policy push and targets: Climate change and energy transition legislation, driven by European and national ambitions and targets, demand decarbonisation of electricity production. National initiatives set targets for the development of offshore wind farms. Support mechanisms and the reduction of production costs of offshore wind farms have driven the development and will continue to improve the business case of offshore wind power. Especially when a more widespread carbon tax system is introduced.
- Favours over onshore: Onshore production of renewable energy can be complex to realise at large scale due to local resistance. While offshore wind is able reach a much higher level of full load hours, and can attractively be scaled and developed.
- Cost reduction push: The need to achieve cost reductions will lead to increasingly larger wind farms and turbines. While the conversion of wind power to hydrogen could contribute to cost reduction of the landing of wind power from OWF.
- Conventional players moving to renewables: Energy companies, O&G majors, and Offshore companies are divesting their interest in fossil fuels and try to make a successful move to renewables. Giving an impulse to market dynamics, investments and professionalism and skills moving to the market.
- Re-use: The re-use of offshore oil and gas platforms could reduce decommissioning costs and accelerate the energy transition.
- Multi-use: OWFs deliver the opportunity to combine platforms with under water cultivation, eco-scour, and other mature and immature renewable technology.

ROLE OF PORTS

Ports that are located near offshore wind farms and/or facilitate cable landfall and power transmission, can play a role in the development process of OWF. Several port roles can be identified, and combined within one port, with regards to offshore wind:

- Operations and maintenance port (small draft, limited area requirements).
- Marshalling / assembly port (Larger area requirements, and heavy load quay).
- Fabrication port (production of one or more components for OW farms).
- Facilitator of the logistic operation for decommissioning and re-use of platforms.
- Energy landing, storage, and service port.

The port authorities can play a facilitating and stimulating role:

- Developing clusters by setting up OWF networks and actively attract companies to the port area by offering an attractive proposition for land use and port synergies.
- Co-investment: Like co-investments in onshore wind farms, offshore wind farms could also provide investment opportunities. These can can potentially be a strategic way to secure renewable energy for industrial clusters in ports. Project pipeline / investment security, governance structure, business model and financial position of a port determines the ability to pursue.

IMPACT ON PORT INFRASTRUCTURE

Ports that want to accommodate offshore wind throughout the project cycle often must invest in physical infrastructure:

- Dredging for sufficient water depth to accommodate vessels for the construction, O&M and decommissioning of offshore wind farms.
- Reinforcement of quays and/or realisation of heavy load platforms.
- Realisation of (temporary) terminals for the

storage of wind turbine components during construction and/or operational phases.
- Facilitate space for component producers and suppliers in the port, or create hinterland connections to wind turbine component suppliers.
- Built (temporary) storage space and recycling facilities for platform or turbine components, and decommissioning of offshore platforms and foundations.
- If OWF electricity lands in the port area or will be connected to port industrial users, reinforcement of the electricity grid is required to deal with and integrate incoming power and channel offshore wind energy to energy intensive users. Giving potential need to develop power-to-power and power-to-gas infrastructure.

ENABLING FACTORS

Ports want to adapt to the long-term expected port area requirements, infrastructure for cargo transport and utilities, transport of cargo and modal split, driven by the increasing share of offshore produced energy and development of near port industry clusters. To enable the scale up of offshore wind, investments are needed to facilitate generated power, developing storage and conversion infrastructure, standardisation of industry methods, and stimulating legislation.

- Transmission infrastructure: Close cooperation with TSOs and DSOs and private network-owners is needed to facilitate and optimise energy infrastructure within the port area and connections to the transmission and distribution system. This can also have implications for the required skills and competences of port staff.
- Legislation: Legal adaptations are required to allow blending of hydrogen in and the re-use of existing natural gas networks and the connection of electricity cables to electrolyser infrastructure.
- Port infrastructure: Required port infrastructure to facilitate the offshore wind power and potentially the conversion to hydrogen will need to be integrated into the planning and funding of (inter)national offshore wind programs.
- Investment climate: The investment climate of offshore wind farms (e.g. logistics costs and the price of raw materials such as steel) may affect the timing of offshore wind farm construction and thereby the planning for required port infrastructure.
- Power-to-gas: For the development of power-to-gas infrastructure in port areas, clarification is needed on the environmental, safety and spatial planning laws.

MAIN CHALLENGES

Despite technological headway made and current growth projections, the development of the offshore wind supply chain and scaling capacity is still in early stages.

- Technology and industry profitability: In scaling wind farms and turbines, in new environments, with innovative solutions, will lead to higher risk and lower profitability for developers, contractors, and suppliers. Leading to potential investment risks for ports in infrastructure and facilities.
- Supply chain development: Creating an efficient and healthy supply chain to produce, install, and service the European and global offshore wind market is still in early stages, and can create offshore wind project development risks.
- Spatial planning: Increasing size of turbines and farms in crowded waters, with shipping lanes, ecological areas, and fishing zones all posing a challenge.
- End-use uncertainty: Dealing with offshore wind power generation peaks, demand-supply imbalance, and future attractiveness and demand for power-to-gas, creates uncertainty for a port to invest and develop transmission, storage, and convergence facilities.

PORT PROFILE

The integration of offshore wind power reinforces existing energy intensive ports and provides opportunities for new entrants to develop energy intensive industries.

- OWF proximity: Offshore wind power developments are directly relevant for ports that are located close to the wind farms, having the ability to support component production and supply, offshore installation and O&M services, and logistics.
- Industrial base: European regions with a strong industrial base can position as supplier of key components such as turbine blades, monopiles, and cables, and act as marshalling ports, as growth of offshore wind will require sourcing from multiple locations to secure supply and service parallel construction processes.
- Logistic hubs: Ports from all over Europe can play a role in the logistic puzzle of OWFs. With components coming from different manufacturers and the need for efficient value chains, ports with good (deep water) facilities with relatively low transport and labour cost can play a role to supply.
- Shipbuilding, maintnance and repair: Installing, operating and maintaining OWFs in line with the expected scale up, requires a large fleet of installation and service vessel. For the next generation turbines, a lot of these installation vessels still must be built. Requiring significant shipyard, quayside, and service facilities.
- Decommissioning and re-use of offshore platforms, foundations, and materials, is relevant for ports located in proximity and provides opportunities for industrial companies near ports to re-use or recycle components and materials. Also, ports in locations further away can play a role in terms of transport cost, when they have the right infrastructure, low labour cost, sufficient storage or a recycling industry.
- Floating wind is expected to mature beyond 2028, but could in the long run provide opportunities for deeper waters. Facilitating floating wind farms require much more space in the port, wet storage can be a solution for ports with limited land area.
- Co-owner/developer: The ownership structure and public aspects of new energy infrastructure could affect the revenue model of ports.

SOURCE

42, 43, 46, 78

B4. Industry decarbonisation

Due to the European emissions trading system (ETS), national policies on emissions, pressure from investors and market incentives the energy intensive industries must adjust their processes in order to reduce greenhouse gas emissions.

Energy intensive industries like refineries, steam crackers, hydrogen and ammonia producers, chemical and plastics industry, iron, steel and cement industry will go through an impactful transition as they currently use a large amount of energy, while they have to make significant long-term investments in production facilities to adjust their processes.

The industry has multiple decarbonisation options, such as electrification, improved heat integration, using renewable or bio-based fuels and feedstocks, make use of residual heat and/or adding Carbon Capture and Storage (CCS) to clean the process. And may even use Carbon Capture and Utilisation (CCU) to reuse captured CO_2 as a feedstock to produce synthetic fuels, chemicals and building materials.

In the long run, industries must reform completely, as traditional oil refineries and fossil-fuelled power plants have to convert into zero/low carbon fuels and electrical power plants. While recycling practices and circular solutions lead to a complete reorganisation of value chains. Ports can facilitate the industry transition by providing affordable renewable energy and connect infrastructure. New activities that emerge in the port and wider port area concentrate on the production, import and/or storage of renewable, synthetic and bio-based fuels and chemicals. Furthermore, industries require room to adjust to sustainable processes, ports may facilitate the required space and related infrastructure.

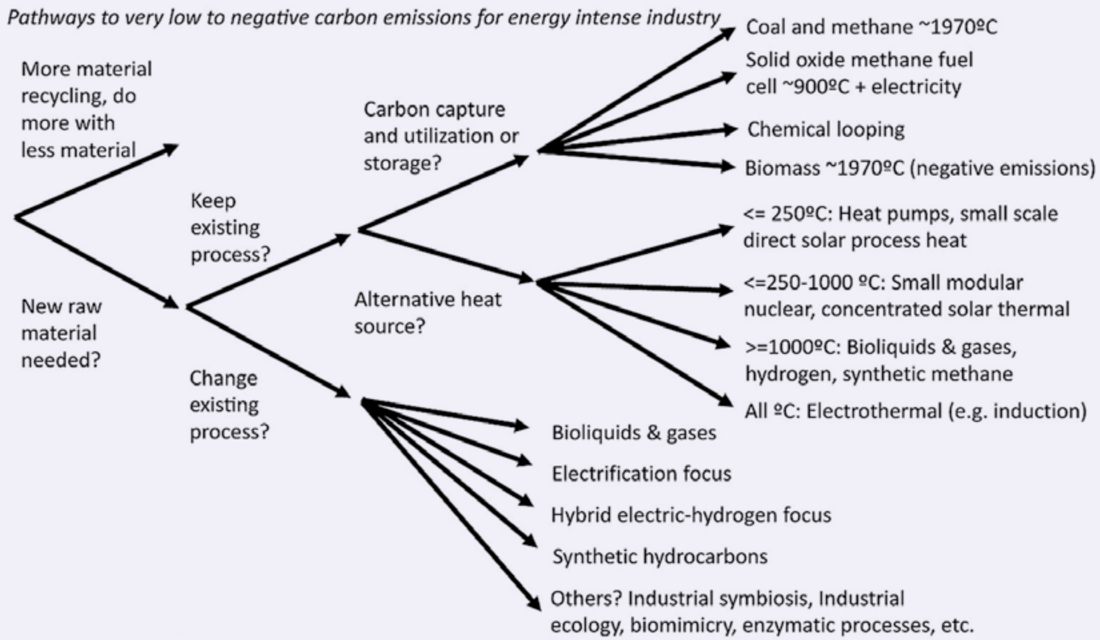


Figure: *Pathways to zero-/low- carbon emissions for energy intense industries, (source: Bataille et al (2018), A review of technology and policy deep decarbonization pathway options for making energy-intensive industry production consistent with the Paris Agreement).*

DRIVER/BENEFITS

Climate change mitigation is the main driver behind decarbonisation of industries. Currently, being pushed by the following climate mitigation drivers:

- ETS: The EU ETS CO_2 pricing negatively affects the fossil-based business cases.
- Legislation: EU Fit-for-55 package, national and regional climate legislation and strategies, and subsidies for decarbonisation options and legislation on emissions.
- Sustainable finance/ESG: Due to societal pressure, green investment obligations, and the growing financial streams associated with sustainable investments, investors and industry stakeholders are increasingly pushing management to implement low-carbon solutions.

ROLE OF PORTS

Decarbonisation leads to a long-term decrease of conventional energy trade flows. Yet the amount of cargo of circular and bio-based materials is expected to increase. This will have impact on terminals and industry in the port area. Ports can play an active role in the decarbonisation of industries.

General role of ports

- Facilitate industrial cooperation to enable industries to lower primary energy demand further and to efficiently execute decarbonisation steps. Ports can engage traditionally separate industries in a collective approach to increase competitive advantage in transition. Involving physical exchange of materials, energy, water and/or by-product. For instance, the utilisation of heat as a by-product of an electrolyser by an energy intensive industry.
- Provide affordable renewable energy and resource feedstocks to industries in transition.
- Grow bio-refinery clusters in circular/bio-based hubs, with the port as natural partner, initiator and facilitator.
- Expand the recycling industry. High recycling rates of for examples plastic and composite based products and components will lead to an expanding recycling industry in Europe, with ports being excellent candidates for recycling hubs.

The role of port managing body

Ports will have to deal with new industries and might need to reinvent their roles.

- Ports can play an active role in bringing stakeholders together and aligning decarbonisation strategies to create industrial symbiosis. This could include helping industries in regulatory aspects through involving government relations.
- Providing land for industry transition, new industrial clusters and renewable energy production, based on a transition vision and masterplan (e.g., by making land area available for the development of an import terminal for fuels).
- Improving local energy grid with grid operators and enable low carbon utility services by ensuring an infrastructure for hydrogen, biogas and/or CO_2. Ensuring the preconditions for decarbonisation of industries near the port are optimal. A port can play an active role as investor in and operator of new infrastructure.
- Ports can actively stimulate market consortia for zero/low carbon fuels or sustainable resources for bio-based or recycling clusters. Ports can facilitate matchmaking between suppliers and off takers to ensure import/export through the port.

IMPACT ON PORT INFRASTRUCTURE

The main impacts of the decarbonisation and transition to new industries on port infrastructure are:

- Hydrogen will increasingly replace fossil fuels as feedstock and energy source in industrial processes. Industry focused on producing and storing hydrogen carriers might emerge in bunkering ports.
- Dry bulk terminals are most likely being replaced by bio and waste terminals, due to the growing demand for biomass to produce bio-based products. A substantial share of biomass or bio-based raw materials is expected to be imported.
- The phase-out and transition of fossil fuel import facilities, power plants, and energy intensive industries require a different or new purpose of available land space. Such as the import or export of renewable energy carriers or the production of synthetic fuels, or maybe relocation to urban areas as production becomes cleaner.
- Sea ports might need to provide the necessary infrastructure for transporting by vessel or pipeline of CO_2 to empty gas fields (CCS).
- Hinterland connections need to be adjusted from fossil to renewable energy carriers or CO_2 pipelines. For example, hydrogen needs to be compressed for road transport and pipeline transportation requires new valves and compressors and could require retrofit of pipelines.
- An expansion of the electricity grid to distribute the additional electricity to the industries is needed. Furthermore, new infrastructure for transporting hydrogen (to end users in the hinterland) or CO_2 (to storage or re-use facilities) might be required.
- The coal supply chain is on the short-term going to shift to an LNG supply chain. Coal-fired power plants will be replaced by natural gas fired power plants. This requires a shift in the logistical supply chain for power plants.

ENABLING FACTORS

The following factors enable industries to decarbonise and thereby attract more energy intensive industries:

Technical

- Land availability is important especially for new emerging industries such as synthetic fuels producers, hydrogen carrier conversion/hydrogen producers and renewable electricity producers require land.
- Adequate and cost competitive renewable energy infrastructure and low carbon utilities such as a reliable electricity grid and hydrogen or CO_2 infrastructure, enable industries to undergo their transition and limit the risk of industries reallocating.
- Symbiosis of inputs/outputs in an industrial cluster allows for a more competitive and faster transition of industries.
- Availability of empty gas fields allows industries to opt for CCS as decarbonisation measure.

Commercial / economic

- Subsidy programs and carbon pricing

schemes for the decarbonisation options of the industries, so that industries can make a cost competitive transition from fossil to renewable based production.
- Contracts and co-operation between partners, suppliers and off-takers, grid owners, etc, between industrial clusters and ports allow for a more competitive and faster transition of industries.
- Availability of human resources such as skilled workers to develop, install, and operate low carbon industrial assets and the related required infrastructure.

Society
- Ties with the governments and public players at all levels to speed up decarbonisation permit applications.
- Social acceptance for decarbonisation options as CCS, biomass and renewable energy technologies such as wind turbines.
- Environmental regulations to ensure the safe use/transportation of e.g., hydrogen, CO_2 in industries in port areas.

MAIN CHALLENGES
- The decarbonisation of industry is a complex process that will take decades to complete. These are the main challenges:
- Immature technology: Immature appliances and value chains for some technologies create challenges like the lack of reliable large-scale processing technologies for bio-based or recycled sources. Many low carbon industrial processes are not yet flexible enough to deal with the intermittent nature of renewable electricity, so hybrid solutions must be facilitated.
- Competitiveness: Industrial processes must be retrofitted to hydrogen or electrified, resulting in high investment costs. Low cost of primary raw materials, fossil-based feedstock and fossil fuels make it difficult to create a business case for products based on renewable energy, bio-based feedstock or recycled materials.
- Safety: New energy carriers are accompanied with risks such as toxicity and explosivity, which require strict handling and regulations that need to be adapted to the new situation.
- Spatial issues: In the transition both new activities evolving from decarbonisation and conventional activities will take place in parallel, this leads to a (temporary) increase of land use.
- Energy density: The existing fossil fuel transport infrastructure must be replaced with a hydrogen or biomass infrastructure. This will have volume impact (larger storage area, more transport volume) as the energy density of biomass and hydrogen carriers is lower than that of fossil fuels. On the long term the total quantities in volume will be influenced by to efficiency improvements and circularity.
- Long term reduction of demand for new products: Additive manufacturing, such as 3D and 4D printing, and circular practices to extend product life span might lead to decreasing material import and export of components, machinery and products.
- Uncertain whether sufficient biogenic CO_2 (from the combustion/decomposition of organic material), biomass and biogas will be available in the future at the scale of widespread production of for instance hydrogen-based synthetic hydrocarbon fuels.
- International trade dynamics: Depending on market developments with respect to raw materials/unfinished products or finished product cargo trade, the type of industries that are required will be impacted. As contracts of port authorities with industrial companies are usually for a period of 20 to 30 years this complicates decision making.

PORT PROFILE
Ports with industrial clusters
- Ports with industrial clusters might attract new industries because they are able to facilitate industrial symbiosis.
- Ports that are not able to provide cheap renewable energy to the industries in their industrial cluster risk the relocation of these industries to countries with good renewable energy conditions.
- Ports with a large crude-oil/chemical industry cluster will be affected by the decarbonisation of industries as fossil-based activities will be phased out. These ports need to start the transition to new energies and circular

resources in time by actively participating in collaboration with new energies/circular industries.

Ports with connection to renewable energy

- Ports with a large potential for connecting to renewable energy such as offshore wind may find new opportunities in attracting industries or the export of energy.
- Ports in remote locations could benefit from the vicinity to renewable energy generation.
- A port that can cost-effectively import renewable energy carries enables industries to decarbonise and therefore might attract more energy intensive industries.

Ports with industrial activities in densely built areas

- Ports in densely built areas may encounter difficulties in expanding the electricity grid/ building new pipelines and required area for the handling of renewable energy carriers and biomass.
- A further expansion of the electricity network to distribute the additional electricity is expensive in densely populated areas with large industrial clusters.
- Sea ports with offshore oil and gas producers might need to provide the necessary infrastructure for shipping/transporting by pipeline CO_2 to empty gas fields (CCS).

Inland ports near and with industrial clusters

- Inland ports might play a large role in shipping renewable energy carriers or CO_2 to and from the industrial clusters in the hinterland, allowing industries to gradually undergo the decarbonisation transition while in some cases pipeline infrastructure is put in place for higher transport efficiencies.
- Inland ports may play a role in decarbonizing industrial clusters, e.g., the development of recycling facilities to reduce GHG emissions of incinerators.

SOURCE

6, 12, 26, 59, 72

B5. Sustainable urban energy

Ports and urban areas are connected in many ways. Currently, ports are a logistic platform for the transit of energy sources to urban areas, such as fossil fuels (such as LNG, coal, oil and petroleum). In the shift to renewable energy this logistic platform can change into a renewable energy hub for the distribution of:

- Renewable electricity (wind and solar, see Factsheet: B2)
- Renewable fuels (e.g., hydrogen, bio-based fuels, see Factsheet C1)
- Renewable and/or residual heat and cooling

Some of the new energy can be distributed by current infrastructures, but there will be a need for adapted and new infrastructure for the future energy supply. Capacities and the way the infrastructure is used, including storage, will change over time.

Furthermore, ports and cities can be connected in an integrated community energy system (ICES). The growing availability of green energy and demand calls for system integration and smart grids. This poses an opportunity for smart clusters around ports and urban areas capable of storing and converting energy sources. In doing so urban energy needs are fulfilled in a sustainable, reliable and flexible way and industry can benefit too.

Figure: *Port and urban area (source: RHDHV media bank)*

DRIVER/BENEFITS

Ports can be part of the solution for renewable energy supply of cities but are not the main solution. The port itself has a high energy demand which needs to be fulfilled. Surpluses can be exported, and the port can be a part of a larger energy system, because this will benefit both the port and the urban areas.

A driver behind this development is the demand for sustainable energy from urban areas. The European Green Deal calls for system integration and connected energy infrastructures. One of the main points in the Green Deal for decarbonising the energy system is to encourage the use of residual heat from industry and data centres. Of all heat sources, residual heat is often the cheapest.

ROLE OF PORTS

Role of ports

Ports as an industrial cluster can become energy hubs and smart clusters interacting with surrounding urban areas. The role of the port (area) would be to function as:

- An area for electricity generation.
- The location where offshore energy is collected and redistributed.
- A battery for the region.
- Production site for renewable fuels.
- A hub and source for distributing heat and cooling.

ROLE OF PORT AUTHORITIES

The priority of the authorities of ports is to fulfil the energy need of the port itself. Beside that the port authorities can co-invest in infrastructure or facilitate and stimulate the development of regional energy exchange. Port authorities can collaborate with energy grid operators and relevant stakeholders (e.g., industrial clusters, cities) to integrate the energy infrastructure in the port. This could help optimise spatial planning, investments in energy infrastructure and operation. For the distribution of (residual) heat and cooling the port authority can be the initiator and even exploiter of the heat distribution network. This will be a more natural role for bigger ports owned by public authorities. As a park service the authority can develop the infrastructure, collect residual heat from industries and redistribute this amongst consumers. This network can also be built and operated by a private initiative or a collaboration between port and private parties.

IMPACT ON PORT INFRASTRUCTURE

Regional energy systems can take up many forms. For all those forms adaption of infrastructure will be biggest impact on port infrastructure. A few examples:

- Energy storage facilities (batteries, underground heat storage).
- Conversion stations.
- Smart electricity grid.
- District heating network or a large heat connection between port and urban area.

ENABLING FACTORS

- A regulatory framework that allows the companies that make up the port community to integrate as traders in the energy market.
- Energy transition roadmap covering both port, industry and close by residential areas.
- Residual heat regulation enforcing use by third parties.
- Large scale heat demand at temperature below 80 °C in port proximity.
- Well organized entity capable of setting up district heating.
- Clear (public-private) coordination of activities.

MAIN CHALLENGES

An integrated renewable energy system will be very complex. This is a new system with different types of energy and multiple suppliers. Therefore, there are a lot of stakeholders involved. Bringing these together will be challenging.

Furthermore, there are other challenges:

- Matching the supply and demand with respect to seasonal and weekly differences.
- Getting long term commitment and security of supply from industries. Therefore, there is need for a fall-back system.
- Innovation and more energy-efficiency of industrial processes will decrease the amount of residual heat/cooling on the long term.
- The investment in infrastructure is high.

Normally there is a distance between the industries of a port and residential areas, this makes energy exchange more challenging and expensive.

PORT PROFILE

This topic is mostly related to the connection between urban areas and the industries located at ports. To form an integrated energy system the port needs to be in proximity of an urban area.

Bigger ports offer more opportunities for investments in large integrated energy networks. However, with smaller ports the connection to nearby urban areas might be closer. This can be an opportunity if the industries are connected, synergise with nearby communities and are therefore keener to make long term commitments and investments.

SOURCES

11, 19, 42, 64

B6. Energy conversion

The future energy system contains zero/low carbon electricity and fuels. The conversion between electrons and fuels, through power-to-gas and gas-to-power technologies is an important element in a reliable and flexible energy system and to provide carbon neutral fuels and feedstock. The increase of renewable power will lead to volatility which can be (partially) balanced through power-to-gas and gas-to-power technologies.

Figure: *Artist impression of a GigaWatt scale electrolyser (RHDHV, 2022, source)*

Power-to-gas
Power-to-gas (e.g., converting power to hydrogen by electrolysis) enables the storage of large amounts of renewable energy, reduces curtailment of renewable power (e.g., a wind turbine that needs to be shut down to mitigate issues with export to the grid) and improves energy system flexibility by shifting energy demand from the power grids to the gas network.

The three main electrolyser technologies are alkaline (mature and commercial technology), PEM (Proton Exchange Membrane, more suitable for flexible operation and hydrogen production at higher pressures, less widely deployed) and SOEC (Solid Oxide Electrolyser Cell, not yet commercialised, operates at high temperatures, could be used in reverse mode as a fuel cell).

Gas-to-power
Gas-to-power (e.g., the conversion of hydrogen to power by a gas turbine or fuel cell) could help to decarbonise dispatchable power. Stored hydrogen can be used as a fuel for power production, e.g., to level a mismatch in the electricity balance between seasons.

In the EU, the priority use of hydrogen will focus on industry (to decarbonise feedstock and/or to provide high temperature heat), followed by heavy transport, shipping and provide power flexibility, while applications for cars and building sector are identified as limited.

Hydrogen-based fuels and carriers
The conversion of hydrogen to zero/low carbon fuels also lead to the deployment of energy conversion infrastructure. Various conversion

options are possible, e.g., from hydrogen to ammonia, methanol and vice versa. Also, for hydrogen transport over long distances, conversion to hydrogen carriers (liquid hydrogen, LOHC (Liquid Organic Hydrogen Carrier) may be required.

Ports will play an important role in power-to-gas, gas-to-power and hydrogen-based fuels and carriers conversion technologies, due to activities such as the import/export of fuels, the vicinity to industrial clusters, new vessel bunkering, and landing of offshore produced power.

DRIVER/BENEFITS

The REPowerEU plan is a main impetus for the hydrogen economy. This plan estimates that an additional 15 million tons (of which 10 imported and 5 produced in Europe) of renewable hydrogen is required to replace imported Russian gas. The 5 million tons of hydrogen produced in Europe is additional to the 5 million tons already planned in Fit-for-55.

The EU Green Deal identifies hydrogen as one of the priorities in the energy transition. In the hydrogen strategy (2020) the EU aims to increase the hydrogen market in 2030 by 80 GW of electrolysis production capacity (half of which being outside the EU.

An important driver is the decarbonisation of industry, for which hydrogen is identified as an important feedstock and high temperature heat source. The RED2 directive sets targets for the use of renewable energy in transport fuels, requiring investments in green hydrogen-based fuels.

A surplus of renewable electricity generated at lower cost could be a low-cost hydrogen source. This could provide the opportunity to more attractively convert hydrogen into hydrogen-based fuels or feedstocks (such as synthetic hydrocarbons and ammonia).

The production of power from green hydrogen could contribute to the decarbonisation of the power sector, although predictions of the amount of hydrogen required vary widely. More focus in the next decade will be on the use of hydrogen as an industrial feedstock and the decarbonisation of high-temperature heat.

ROLE OF PORTS

General role of ports

- Ports may offer a suitable location for hydrogen production through electrolysis, e.g., produced from onshore wind/solar power. The hydrogen end use could be nearby industries or, through transportation through the port, to end users in the hinterland.
- The development of offshore wind farms could lead to the increase of electrolyser capacity to bring part of the energy ashore.
- (Existing) infrastructure for chemically processing the produced hydrogen further into low/zero carbon fuels/feedstocks could occur in the port.
- The port could play a role in diversifying applications for hydrogen by sharing hydrogen refuelling infrastructure for port equipment, road transport and inland vessels.
- Ports could act as an import/export hub for hydrogen (see also factsheet C1).

Role of the port managing body

- The port managing body could facilitate or actively participate in business consortia to stimulate the development of power-to-gas, gas-to-power and hydrogen-based fuels or carriers conversion infrastructure

IMPACT ON PORT INFRASTRUCTURE

Power-to-gas and gas-to-power infrastructure could have the following impact on infrastructure in the port:

- Ports could provide parts for the construction and or maintenance of power-to-gas and gas-to-power facilities.
- Terminals to store parts/equipment for power-to-gas and gas-to-power facilities.
- Space for road, access, maintenance and pipe and cable routing.
- Storage of hydrogen nearby the electrolyser to accommodate base load demand from end users.
- The electricity grid to connect power-to-gas or gas-to-power infrastructure. Additionally, a connection to a district heating network may be required if residual heat from electrolysers is used elsewhere.

- Hinterland connections to transport produced hydrogen (water/road/rail/pipelines).
- Land area is required for electrolysers and related equipment such as transformers, rectifiers, water supply, cooling water towers, separators, dryers and compressors.

For the import of hydrogen carriers (including ammonia), conversion could have the following impact on infrastructure in the port:

- Jetties to import the carriers into the port from vessels.
- Conversion infrastructure for liquid hydrogen, ammonia, LOHCs.
- Energy supply (electricity and heat) for the cracking of ammonia (conversion to hydrogen) and the recovery of hydrogen from LOHCs.
- Storage space for hydrogen carriers at the conversion sites.
- Compressor stations to compress hydrogen to the pressure required for injection in the pipeline.

ENABLING FACTORS

The following factors could facilitate the development of energy conversion infrastructure in and near port areas:

- Support for the initial investment for hydrogen production through electrolysis.
- Rules for ancillary services need to evolve to accommodate the new mix of variable renewable power and volatility in power generation and demand.

- The production of hydrogen through electrolysis can avoid unnecessary investments in electricity grids. Stakeholders in the port should benefit equally from the avoided investments.
- The extended role of ports in power-to-gas, gas-to-power and other energy conversion activities should be compatible with existing and future regulatory frameworks to enable port managing bodies to deploy these activities.

MAIN CHALLENGES

In general, the main challenges related to energy conversion infrastructure are:

- The uncertainty in regulation, safety standards, certification and subsidies.
- The limited availability of land in already densely populated ports.
- Uncertainty in the import/export value chain for hydrogen, the preferred hydrogen carrier and the impact on local production of hydrogen in/near ports.
- Safety issues with the use of certain fuels, such as the use of ammonia nearby urban

clusters. These need to be addressed in environmental regulations.

The main challenges related to power-to-hydrogen are:

- The availability of low-cost renewable power to ensure that electrolysers operate at high full load hours and to reduce the impact of the investment on the levelized cost of hydrogen.
- Cost reduction of the electrode catalysts and membranes of PEM electrolysers.
- Degradation of materials of SOEC electrolysers, resulting from the high operating temperatures.
- Fresh water access for electrolysis can be an issue in water-stressed areas.

PORT PROFILE

- Seaports located near offshore wind farms and nearby landing points for wind power may benefit from production of hydrogen (and transport to the hinterland).
- Ports near other offshore produced energy (e.g., floating solar) could also benefit from production of hydrogen (and transport to the hinterland).
- Ports near production locations of hydrogen-based fuels or feedstocks could play a role in producing the hydrogen through electrolysis. Possibly, the production of these hydrogen-based fuels could take place in the port as well.
- Ports located near industrial clusters that use these fuels/feedstocks or gas-fired power plants that blend hydrogen.
- Ports located near facilities for producing grey hydrogen could play a role to build electrolysers nearby. Combined, these conventional installations can be converted into hybrid hydrogen production sites. This allows switching between electricity and natural gas, depending on commodity prices.
- Inland ports could provide hydrogen bunkering infrastructure for inland vessels and inland water transport could be used in the logistics of hydrogen transport.
- Ports with availability of green hydrogen could play a role to provide back-up power to critical infrastructure in the port area or wider area around the port (infrastructure in the urban agglomeration) through fuel cells.

SOURCE

9, 12, 21, 25, 27, 36, 47

B7. Energy storage hubs

Decarbonisation plays a vital role in reducing global carbon emissions to net-zero. With the need to significantly reduce and ultimately eliminate usage of fossil-based fuels, zero to low carbon alternative sources are sought. Not only is fuel supply and distribution infrastructure affected by the substitution of conventional fuels, but also (liquid) storage will play a key role in the energy transition. Potentially benefiting light-duty road transport, shipping, and aviation.

Despite liquefied natural gas (LNG) not being carbon neutral (excluding technically bio-LNG), it does produce 40% less carbon dioxide per GJ than coal, and 25% less than fuel oil, when burnt and is at present a suitable low-carbon energy carrier. It is thus considered a suitable fuel to support the energy transition and requires a global storage build-up in the upcoming decade.

Photo: *Liquid (grey) hydrogen storage at NASA (source: NASA).*

Hydrogen is a zero-carbon energy carrier, if produced from renewable sources. It is seen as an important piece of the zero-carbon strategy since during COP26, 32 countries and the EU have agreed to accelerate the deployment of green hydrogen. Transportation of hydrogen will have implications on storage infrastructure. In its pure form as gas, it is mainly transported in pipelines, but in ships it could be transported as liquefied hydrogen (LH_2) and in liquid organic hydrogen carrier (LOHC) form, whereby the hydrogen is bound to specific organic compounds. In its derived form, e.g., conversion to methanol or ammonia, it can also be transported in ships. Converting hydrogen into a derived form is currently twice less expensive than producing LH_2, as it is still in its infancy and may or may not mature. While ammonia is regularly transported in large ships for the fertiliser industry and methanol is globally transported and traded as well.

Hydrogen and natural gas can be stored and transported by ship in gaseous form, however, it is generally done in a liquid form, as transporting pressurised gas requires strong steel containers and is not done at any scale today. Energy density per volume is higher in liquid form so longer-distance marine transport is more attractive than using pipelines.

This factsheet reflects on fuels that may be transported in ships and impact ports: LNG, Hydrogen in pure form (GH_2 and LH_2), Hydrogen carried in other liquids (LOHC), and in derived forms (Ammonia and Methanol). Synthetic (bio)fuels like biokerosene or biodiesel are not covered as current cost are too high and storage practices are similar to fossil fuels.

DRIVER/BENEFITS

Legislation

- REPowerEU – EU to increase the diversity of energy supply by producing and importing green hydrogen
- EU Green Deal – EU to become the first carbon neutral continent by 2050

Energy autonomy and diversification in energy sources for energy security

Not only does climate change mitigation result in the need for low to zero carbon energy carriers and storage hubs but given the current energy crisis related to Russia's war on Ukraine, the need for energy autonomy and a shift from reliance on Russian gas is stressed. The European Commission has developed a plan for the European Union (EU) to be completely independent from Russia when it comes to energy supply, and specifically gas.. At time of writing, there are already 24 operational large-scale LNG import terminals in the EU. Some EU countries have shared their plans regarding building LNG terminals such as Germany, further increasing the total number of import LNG terminals. Government and researchers also foresee that the LNG terminals, with modifications, could be compatible with and converted into hydrogen import terminals.

Hydrogen relation with (offshore) renewable energy

The total capacity of (offshore) renewable electricity generation will increase significantly in the coming years and is likely to exceed the grid capacity and local demand. Hydrogen can be produced with this 'excess' energy and stored as buffer for local use in time of low wind and sun or for onwards global transport to locations with high energy demand but low local production possibility. Hydrogen is expected to play a key part in the wider energy transition picture, and deployment of its infrastructure should not be pursued in isolation. A lot of ongoing research is being done in the field of hydrogen and technologies required for safe storage and transportation.

ROLE OF PORTS

General role of ports

Ports host industrial facilities (refineries, chemical plants, etc) and waterborne import and export of feedstock and products. This will also be the main role regarding low/zero-carbon energy carrier liquids.

The role of port managing body

Port authorities will play a key role in engaging with various stakeholders to facilitate the implementation of low/zero-carbon liquid production, storage import and export facility/hubs. The port should act as landlord and 'master planner' and ensure allocation and clustering of various industries and terminal operators in a way that is safe and efficient. Port authorities also have the task to implement safety measures established on these liquids and to ensure that terminal operators adhere to the measures.
Zero/low energy carriers should not be seen as a commodity, but as a pipeline. Port authorities could also consider changing their role and move more to a 'utility' type (energy) company role, as such they could play a more active role in managing the energy flows within the port area themselves. Alternatively, they could lease their land to an energy supplying company to manage the energy flow within the port area.

IMPACT ON PORT INFRASTRUCTURE

- Additional liquid terminals and storage areas are required, keeping in mind that the zero-carbon energy carriers have less energy density than fossil fuels, thus for the same amount of energy stored, compared to diesel, LH_2 needs 4 times the volume, ammonia 3 times and LNG 2 times.

- LOHCs have even larger storage requirements compared to the other hydrogen carriers. It needs large amount of storage, due to the volume of the carrier material.
- Additional liquid bulk berths/(off)loading facilities required to augment and over time replace the fossil fuel ex/imports.
- Built (temporary) storage space and recycling facilities for platform or turbine components, and decommissioning of offshore platforms and foundations
- Hydrogen production and conversion facilities require large areas for the related plants/facilities, not just storage.
- Big electricity consumers/energy intensive industries could be encouraged to relocate near the ports to minimise long-range transport of energy carriers.
- Increase in traffic congestion via different modes of liquid bulk transport need to be accounted for, as liquid can be imported and exported via rail, road, or sea.
- Storage is assumed to be done in large volume tanks (tens to hundreds of thousands cubic metres order of magnitude), noting that LNG and LH_2 require cryogenic insulated tanks, ammonia needs refrigerated insulated tanks and methanol and LOHC are liquid under ambient conditions.
- On top of the lower energy densities compared to fossil fuels, significant space is required to adhere to the safety distance obligation, due to the characteristics of the liquids (e.g., ammonia is toxic, and hydrogen is flammable).
- Product handling and storage safety should always be kept in mind – large scale ammonia storage and handling requires double the safety distances currently required and implemented for LNG.
- Alternatively, relocating the energy users close to the energy source could be considered. This would decrease the need for shipping large volumes of energy carriers and only the product made with the energy needs transport.

ENABLING FACTORS

Legislation and public acceptance

- The EU and other governmental organisations have plans to phase out their overdependence on Russian gas.
- Public and government interest in achieving a carbon neutral future will help to secure funds. The EU has given subsidies on implementing "Green" projects in ports.
- Ports are often included in a country's masterplan; this supports the regional role ports intend to play.
- CO_2 emission/carbon taxes will help the transition to zero carbon fuels.

Energy security and supply chain

- Building low and zero-carbon (import) terminals will diversify energy supply and thus increase energy security.
- Complete value chains: from the energy producer, via a converter (if needed) and storage, then shipping and the importer, onwards transporter and the end-user must be in place for the port and facility infrastructure to be effectively developed in a port.

Financial

- By making the port an energy importing/producing storage hub, this may change the business model of the port, and it may bring additional revenues to port operators if ports anticipate on this.

MAIN CHALLENGES

Technical

- Acceptance of LNG and the consequent EU/government support might pose a problem as it is not carbon neutral.
- Technological challenges remain with LH_2 on liquefaction (requires much energy), storage (-253°C, deep cryogenic, requiring high quality expensive materials and insulation; gas-to-liquid (ortho-para isomer) conversion issues with large boil-off generation); atmospheric large tanks and seagoing ships still require development, etc.
- Ammonia is a very toxic substance; the International Code for the Construction and Equipment of Ships Carrying Liquefied

Gases in Bulk (IGC Code) currently bans the use of ammonia as fuel.

- Safety and land challenges associated with producing and cracking ammonia. Provision for water treatment/desalination facility with required volume for hydrogen production is also necessary.
- Ammonia burnt as fuel in power generation or in vehicles causes environmental damage (N/NH3/NOx-deposition) and increases greenhouse gas emissions (N_2O). Additional flue gas cleaning using DeNOx technology is required
- Converting ammonia back to hydrogen requires additional facilities and energy.
- Energy density of low/zero-carbon energy carriers is substantially less per volume than that of e.g., fossil fuel.

Physical

- Port area availability will be challenging from the large areas required for production and storage perspective, especially during the transition when also the 'old' fuels are still needed.

Financial

- LOHC requires transport of the 'hydrogen-stripped' component back to hydrogen source, adding transport cost.

PORT PROFILE

Locally generated zero/low-energy carriers may be feasible in smaller liquid bulk volumes, but for large import/export, large ships and thus large ports are likely the most economical. This means that large-area ports within proximity to deep water are the best placed to be zero to low carbon energy storage hubs. Onward inland transport of zero-carbon gas or liquids is most cost-effective via pipelines. Inland Waterway Transport (IWT) is probably only economically useful/possible for energy transport to remote users or for use as (bunker) transport fuel.

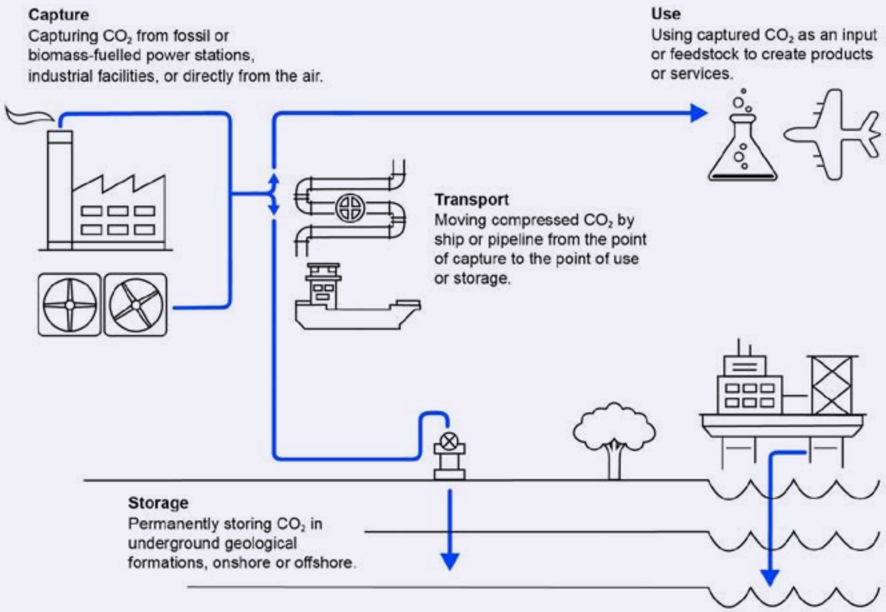
SOURCES

1, 16, 35, 39, 41, 56, 69, 70

B8. Carbon Capture, Utilisation and Storage (CCUS)

Carbon capture, utilisation and storage technologies, or CCUS, is used to capture carbon dioxide (CO_2) for use or for storage underground. To reduce and/or permanently remove CO_2 emissions originating from industrial activity, CCUS involves the process of:

- Capturing CO_2 that is produced during energy generation and industrial processes. This includes hydrogen production from natural gas, the so-called blue hydrogen.
- Transport of the captured CO_2:
  - The captured CO_2 can be compressed and chilled to a liquid and transported for application or to an offshore storage site.
  - Transport is predominantly by pipelines and/or ships, but for smaller volumes by rail or truck is also a possibility.
- Either its re-use or permanent storage.
  - Carbon capture and utilisation (CCU) technologies allow the captured CO_2 to be reused in other production cycles which reduces its concentrations in the atmosphere. It can be used by actors on-site within the port area and its hinterland in greenhouses or for industrial purposes including as sustainable feedstock to produce synthetic fuels, chemicals and building materials.
  - To achieve carbon removal, permanent storage of CO_2 is done underground in deep geological formations, either in aquifers[3] or depleted oil and gas fields, like in the North Sea which has great potential to store CO_2.



Schematic of CCUS (Source: *IEA, 2020)*

CCUS is currently one of few solutions available to tackle emissions from heavy or energy-intensive industries, the so-called hard-to-abate-sectors, including those typically within or surrounding port areas. For the start-up phase of large-scale hydrogen, it is expected that blue hydrogen combined with CCS will play a major part. CCUS is therefore expected to play an important role in the energy transition with carbon capture and storage (CCS) and CCUS

[3] Saline aquifers are geological formations consisting of water permeable rocks that are saturated with salt water.

needed at scale to achieve net zero targets. Ports show interest in CCUS to decarbonise industries in the wider port area or industrial cluster.

Although the concept of CCUS is not new and despite technology development in the last 50 years, CCUS remains in its early stages and is considered as emerging. Deployment had stalled in earlier years, and it is only relatively recently that a surge in planned CCUS projects has been seen for development towards realising commercial projects, in Europe and elsewhere (so far it has mainly been used for enhanced oil and gas recovery, by increasing pressure in the oil and gas reservoirs).

As these projects are mostly new in development stages (generally in feasibility stage and some in a form of design and construction), it is noted there is still a lack of publicly available scientific literature and technical guidance for design and successful implementation of CCUS and implications thereof on existing infrastructure and logistics, not necessarily of the components but for the full CCUS value chain.

DRIVER/BENEFITS

The Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) are amongst the organisations and institutions that argue that without carbon removals, it is difficult to keep temperature levels indicated in the Paris Agreement.

Regional and local policy also regards carbon capture and storage as an essential contributing part in tackling climate change mitigation to meet CO_2 emission reduction targets for industry. The EU supports the development of more CCUS projects, for example:

- EU Green Deal: CCS (and CCUS) will be needed at scale to decarbonise energy-intensive industries. Deployment in climate technologies, including CCS and CCUS is encouraged via increased funding through the EU Innovation Fund.
- Fit-for-55 package proposed introduction of CCU into the EU carbon market policy framework.
- Trans-European Networks for Energy (TEN-E) Regulation: includes CO_2 storage and CO_2 transport modalities other than pipelines, such as shipping, rail or truck transport.
- Policy, related to meeting (ambitious) net zero targets, is therefore considered the main driver for development of CCUS technologies and implementation.

ROLE OF PORTS

General role of ports

Ports are well positioned to play a role as logistics hub and onshore terminal for the collection, transport and temporary storage of CO_2 after capture.

Ports can have a primary facilitating role within the CCUS chain for the industry in their immediate or nearby area, providing necessary infrastructure components or facilities as part of the transport or distribution network for CO_2, e.g., connection to capturing and collection of CO_2, compressor stations, storage tanks, vessel access and infrastructure for shipping the captured CO_2 to storage locations or pipelines that run through the port area.

Port managing body

Infrastructure investments for CCUS networks can be substantial and are often done in partnership with other private or public entities. Cooperation with other ports is theoretically possible, although it is not seen yet.

The role of the port managing body can also increase further if they choose to actively participate in the partnership organisation coordinating and responsible for governance of the CCUS projects and supply chain.

Ports can have a guiding role in sharing knowledge with other ports, particularly on safety aspects of CCUS in ports.

Other

Shipyards within port areas may also play an active role in retrofitting or building vessels as CO_2 carriers with onboard CCUS systems for transport of captured carbon.

IMPACT ON PORT INFRASTRUCTURE

CO_2 transport pipeline

Ports can support the existing or future industry by providing a CO_2 transport pipeline, as part of newly developed energy infrastructure. A central pipeline could facilitate multiple industries and connect them to a central facility where CO_2 is prepared for transport.

Central facility

Spatial requirements:

- Suitable location and space are required to accommodate a compressor station in the port. Here the CO_2 is pressurized in order to transport and inject the gas into the offshore underground wells.
- Temporary storage tanks may also take up considerable space.
- Additional requirements related to the compressor station specifically include:
  - Electricity connection.
  - Heat waste that is produced and reuse options thereof.

Onloading and offloading facilities

For transport by ship to and from the central facility, additional jetties may be required.

As CCUS technology develops, new or adapted port facilities may be required to handle liquified carbon. Future developments may also include blue hydrogen and direct air capture (DAC) which involves extraction of CO_2 directly from the atmosphere. The technology between CCUS and DAC are different, however DAC can use the transportation and CO_2 storing infrastructures that CCUS has.

ENABLING FACTORS

The following factors could facilitate development of CCUS with ports playing a logistics role or hub within the transport network for CO_2 distribution:

- A stimulating policy environment for CCU application is established by policymakers and a guaranteed market for CCU products.
- Close to source of CO_2 emissions, i.e., proximity to or within energy and chemical cluster (heavy industry from which CO_2 can be directly captured and more easily transported), e.g., fossil fuel production plants, waste incineration plants.
- Viable offshore geological storage site available; country has suitable subsurface for storage of capture CO_2.
- Cooperation between ports, industry partners from chemical and energy sectors and governments (public private partnerships); this makes development of CCUS more attractive.
- Hub and cluster approach to trigger new investments.
- EU funding or subsidies available for CCU and CCUS demonstration projects and scale-up and connecting infrastructure.
- International and regional cross-border partnerships to facilitate development of cross-border CO_2 transport infrastructure networks and agreements for exchange of CO_2 sources.

MAIN CHALLENGES

Main challenges related to CCUS development are of economic and regulatory nature:

- Costs is considered a significant barrier to wide-scale deployment.
- Risk of project delays (or cancellations) is in general relatively high for CCUS projects at early stages of development, or in regions where use of CO_2 is still limited and where expansions require significant capital injections for infrastructure. There is also a risk of delay due to supply chain, among others the availability and transportation of materials.
- Insufficient government subsidies and incentives to develop a market for circular use of CO_2 as feedstock. Without public funding, building CCUS infrastructure is deemed financially very challenging.
- Cooperation between partners and organisation thereof.
- The EU supports the transportation of CO_2 across borders. However, before the policy is established, they need the approval of their member states. There is a lack of ratification or consent to allow legal cross-border transportation.
- Political and public acceptance of spending public money for an end-of-pipe industry solution.

- Governance on the integrated CCUS system, by an industry or by a governmental organisation.
- A potential obstacle for growth in terms of business development of CCUS is the current lack in number of large-scale CCUS facilities that are already operational for several years; this limits the number of CCUS developments that can be used to showcase CCUS as proven technology.
- Technical complexities that are critical to design include:
  - Continuous flow assurance throughout the entire CCUS chain of activities.
  - Suitable pressure and temperature of captured CO_2 that is collected at a central facility.

PORT PROFILE

Maritime vs. inland ports

Major seaports can serve as a main hub for transport of captured CO_2, and further facilitate via shipping services the transport of CO_2 to permanent storage deep offshore. Seaports are also important in the scale-up of CCUS.

Smaller or inland ports can play a flexible role on a smaller scale, providing tailor made facilities to suit particular industries nearest to them or act as carbon collector.

SOURCES

7, 11, 22, 28, 29, 31, 37, 44, 57, 65, 81

C1. Zero-/low carbon fuel supply chains

Fossil fuels (oil, natural gas, grey hydrogen, etc.) currently play a dominant role in the energy system but lead to high GHG emissions and the acceleration of climate change. The use of zero/low carbon fuels (combustible energy sources) mitigate GHG emissions of carbon-based fuels in various sectors. These fuels can be used amongst others in industry as a feed-stock or fuel, as a fuel for transportation, or as a heat source for the built environment. The most frequently mentioned fuels are green hydrogen, green ammonia, green methanol and biofuels. The production process, optimal way of trans-port/storage, conversion technologies and end use differ per fuel. Therefore, the supply chain of each fuel differs. The supply chain covers the whole chain from the production of green elec-tricity towards the end use of the fuel. Green ammonia and green methanol are typically seen as liquid energy carriers for hydrogen. They can be converted back to hydrogen using cracking (ammonia) or reforming (methanol). Biofuels already have an established infrastructure due to the use in multiple sectors. Fossil fuels in combi-nation with Carbon Capture and Storage (CCS) could also play an important role in the transition to the abovementioned zero-carbon fuels. Blue hydrogen, blue ammonia and blue methanol are produced from fossil fuels in combination with CCS.

Photo: *Liquid hydrogen tank*

Ports can play a role in the import of such zero and low carbon fuels when there is not suffi-cient energy available from renewable sources to produce these fuels locally (in the port area). Ports can also play a role in the export of fuels when the imported/locally produced fuels are not (fully) used in the port area and need to be transported to the hinterland. Finally, ports play a prominent role in the production, conversion, transport, storage, import and export of fossil fuels and are expected to play a significant role in these aspects for zero/low carbon fuels too. This thus includes both zero carbon fuels and low carbon fuels (in combination with CCS).

DRIVER/BENEFITS

Most recently, the REPowerEU plan from the EU aims to become more self-sustaining through diversifying energy supply by increasing production of biomethane and production and import of green hydrogen.

The EU has set goals to reduce carbon emissions and to mitigate climate change. These address all modes of transport and includes renewable fuels such as biofuels and low carbon synthetic gaseous and liquid fuels and renewable fuels of non-biological origins.

The Fit-for-55 packages also includes targets for increasing renewably energy in the total EU consumption (amongst others renewable fuels as a feedstock or energy carrier) and reducing carbon emissions for the industry and built environment. The Renewable Energy Directive includes binding targets for the use of renewable fuels.

The large-scale increase of renewable electricity (from wind and solar power) enables a reduction of the cost of the production of green hydrogen and to become competitive with blue/grey hydrogen. Green hydrogen can be used as a feedstock/energy carrier for industry or building block for other zero/low carbon fuels such as ammonia and methanol.

ROLE OF PORTS

Ports already play a significant role in the supply chain of fossil fuels. The deployment of zero-low- carbon fuels offer possibilities to re-use some of the existing infrastructure (e.g., pipelines, bunkering infrastructure) and to build new infrastructure in ports.

The fuels could be used for shipping, other transportation sectors, industry in the port area or the wider economy.

General role of ports

- Ports could play an active role in relation to market consortia for zero/low carbon fuels (e.g., by hosting a bulk terminal), or be a facilitator (e.g., by making land area available for the development of an import terminal for fuels, CO_2 infrastructure for the transport of CO_2 to storage sites).
- Ports have a role in the import, bunkering, export or transit of zero/low carbon fuels or a combination of these activities.
- Port also have an important role in the storage of fuels, e.g., the energy carriers for hydrogen including the conversion back to hydrogen and vice versa.
- The production of the fuels could also take place in the port, e.g., when (new) users of these fuels are located near the port. However, a port with a current role as fuel producer could also become mainly a transit port for zero/low carbon fuels to the hinterland.
- Ports could play a role as a hub for carbon capture of fossil fuels and/or blue hydrogen.

Role of the port managing body

- For the import of fuels, the port may facilitate international cooperation.
- Ports could merge activities with neighbouring ports to create synergies and improve their competitive position (e.g., sharing pipeline infrastructure, storage of fuels, etc.).
- Ports could co-invest in infrastructure for the deployment of zero/low carbon fuels.

IMPACT ON PORT INFRASTRUCTURE

The development of zero/low carbon fuels affect the infrastructure in ports:

Import/export of fuels

- A jetty and loading arm is required to transfer the fuels from/to the ship.
- Depending on the ship type, waterways need to be adapted to accommodate.
- Maritime and inland water transport will be affected, ship types and the frequency of bunkering. This involves ships importing fuels, as well as (inland) shipping transport to export fuels from the port.

Infrastructure in ports

- Pipelines need to retrofitted or new pipelines may need to be implemented to transit the fuels to/from the port.
- Facilities may be required for the local production, conversion of fuels (e.g., production of ammonia from hydrogen) or the liquefaction or regassification of fuels (e.g., from LH_2 to CH_2 or vice versa).

- Bunkering facilities need to be built and/or adapted for the use of fuels. Bunkering facilities for oil could be retrofitted to store methanol. For other fuels, new facilities are required.
- For hydrogen, a refuelling station may be installed to store hydrogen and distribute hydrogen for road transport.
- Significant land area is needed for storing hydrogen/hydrogen carriers. It takes 2 cubic meters of ammonia or 3 cubic meters of hydrogen to match the energy output of 1 cubic meter of LNG.
- The conversion of hydrogen carries/LH_2 to CH_2 require conversion facilities in the port (conversion site, compressors, etc.).
- The conversion activities for LOHCs (Liquid Organic Hydrogen Carriers) and ammonia to CH_2 require significant amounts of electricity and thermal energy. These need to be supplied using existing or new infrastructure (cables, pipelines, etc.).

Hinterland

Hinterland connections to transit the fuels to the end users or to the port. The modality is an important aspect:

- For hydrogen also the method of transport is of importance. Some of the important options are ammonia, LOHC (liquid organic hydrogen carrier), LH_2 (liquid hydrogen) or CH_2 (compressed hydrogen). LOHCs are suitable for transporting using oil infrastructure (tankers, barges, tank storages and pipelines).
- There is still uncertainty if imported LH_2 is converted to CH_2 in ports, or partly transported in liquid form. Also, the cost of transportation of LH_2 is a significant challenge.
- For, methanol the transit to the hinterland could be through inland waterway transport (to inland ports) or rail (provided the port is connected to the rail network). Trucks are a flexible option for smaller ports lacking multimodal hinterland connections.

ENABLING FACTORS

Factors that enable the deployment of zero-low/carbon fuels are:

- The roll-out of alternative fuels infrastructure is required to increase the share of these fuels.
- The safety regulations and standardisation for bunkering on the quay need further elaboration to achieve a European level playing field.
- For the import, the use and the transit of fuels such as hydrogen through e.g., pipeline or by train safety and permitting laws need to be established.
- Investments are needed to accommodate the import, export, bunkering and transit of zero/low carbon fuels in ports.
- Flexibility is required from ports to deal with the uncertainty in the future market share of the various zero/low carbon fuels.
- There is a need for supply/demand coordination to establish new production and end uses for fuels in parallel. Also, to scale up the low carbon hydrogen economy the 'first mover disadvantage' and other barriers need to be addressed.
- The deployment of green hydrogen requires integration with carbon capture, utilisation (and storage), gas and electricity networks.
- The rise of fossil fuel prices (among others through the geopolitical environment) could enable a faster transition to zero/low carbon fuels.
- Ports could play a role in supply/demand coordination for various zero/low carbon fuels to accelerate the deployment of these fuels.

MAIN CHALLENGES

- The uncertainty in the development of various zero-carbon fuels and the immaturity of the supply chain for these fuels.
- For vessel propulsion, fuels must compete with electric propulsion but also a combination of hydrogen and batteries is possible.
- Certain fuels (e.g., ammonia, due to toxicity) near urban areas may pose restrictions on the use due to safety issues/environmental regulations.

PORT PROFILE

The activities in the port area may differ, depending amongst others on the vicinity and the possible connections (water/road/rail) to the hinterland industry and/or other large consumers (e.g., the aviation sector)/ producers of fuels.

- A port could be importing fuels and transiting a large share to the hinterland or nearby industrial sites.
- Some ports already contain liquid bulk terminals to import/export fossil fuels, s
- ome of this infrastructure may be retrofitted and knowledge of handling bulk liquids could be used for zero/low carbon fuels.
- If a port is located nearby a hydrogen production site, the port could play a role in the distribution of hydrogen and/or the production of fuels that use hydrogen as one of the feedstocks.
- A port could also serve as a hub for green maritime and/or inland water transport fuels that are produced/imported in the port.
- Ports that are located along the TEN-T and/or TEN-E network may have an increased role in the supply chain of zero/low carbon fuels due to the accelerated deployment of infrastructure such as pipelines and refuelling stations.

SOURCE

6, 18, 23, 34, 48, 73, 74

C2. Zero-/low carbon electron supply chains

The power sector faces significant changes. An increase in electricity demand should be balanced with an increase in electricity supply. Coal fired power plants will be replaced with cleaner types like natural gas (possibly with Carbon Capture and Storage, CCS) or be dismantled. Renewable power generation, mainly by means of solar and wind, is growing rapidly but it requires the availability of a back-up system of conventional power plants. In Europe, variable renewable energy sources (wind, solar, etc.) will generate a significant amount of the total future electricity demand. Seasonal energy storage in the form of hydrogen could help to decarbonise dispatchable power (power that can be dispatched on demand by the power grid operator) through gas turbines or fuel cells. Electrification of industry and the phase out of fossil fuel power plants impact ports, since they are location sites for both. For example, coal transport takes place through the ports.

Photo: *High voltage electrical power transmission lines (RHDHV)*

DRIVER/BENEFITS

- New legislation (EU, national and local) leads to increasing electrical power demand.
- Also, environmental requirements lead to additional electrical power demand (e.g., onshore power supply).
- EU's Clean Power for Transport initiative requires the deployment of alternative fuels produced with zero/low carbon electrons (electrons generated with zero-/low carbon emissions).

ROLE OF PORTS

Power demand of ports

In port areas, power demand comes mainly from cargo handling, cooling and (in the near future) from onshore power supply. Charging battery of vessels could also be an energy demanding activity, as well as electrification of road transport and port equipment.

Electrification of industry near ports

Industrial clusters will replace their fossil-based boilers and furnaces by electrically powered alternatives. Moreover, increase of heat integration and the use of heat pumps is expected. The latter leads to an increase in electricity demand. Ports will supply less fossil cargo from/to industrial clusters, but an increase in transport capacity of electricity will be required.

Import/export of electricity through ports

Ports could transport zero/low carbon electrical power to/from the hinterland. The landing of offshore generated power (e.g., from wind farms) could take place through the port.

General role of ports

- Variable renewable power will increase and the volatility in power production and demand need to be handled. Ports could play a role as they offer possibilities for power generation and electricity infrastructure (for example High Voltage DC converter stations for wind power generated offshore).
- Providing land for renewable power generation facilities (solar, wind) and hydrogen production (through electrolysis) to transport to industries and/or to export.
- Import facilities for energy carriers produced from renewable sources elsewhere in the world.
- Improving and extending the local power grid (with DSOs and TSOs).

Port authority

- Facilitate industrial symbiosis to enable industry in port areas to lower energy demand.
- Collaborate with energy grid operators and relevant stakeholders (e.g., industrial clusters, cities) to integrate the energy infrastructure in the port, including production/demand, electricity and fuels (since they could interact, e.g., through electrolysis). This could help optimise spatial planning, investments in energy infrastructure and operation.

IMPACT ON PORT INFRASTRUCTURE

Fossil fuelled power plants

- The retrofit of a fossil fuelled power plant to a natural gas/hydrogen/biomass fired plant could be possible. In that case, the fuel supply chain changes from coal to natural gas, hydrogen or biomass respectively.
- The energy density of biomass and hydrogen is lower compared to coal and natural gas. Therefore, more storage area and transport volumes are required.
- Transportation equipment (pipelines, compressors, etc.) for CO_2 is required if CCS is applied to natural gas power plants, to transport CO_2 to (offshore) storage sites.
- Hydrogen (production and) transport infrastructure is required if the power plant is converted to a hydrogen-based plant.
- If not feasible to retrofit, phasing out coal fired power plants creates space for other purposes, e.g., hydrogen production.

Renewable power production and demand, electrification of industry and the hinterland

- Land could be required for renewable power production (wind, solar) and/or the landing of offshore produced wind power (power cables, power stations).
- Electrical infrastructure could be required for power demand in ports, e.g., for onshore power supply, charging battery powered vessels.
- The electrical power grid capacity may be increased to transport zero/low carbon elec-

tricity through the port to nearby industrial clusters/cities or to/from the hinterland.

ENABLING FACTORS

- To balance the power system and to respond to seasonal and hour-to-hour variations of renewable power production, demand side response (e.g., electric vehicles), storage and flexible production/demand of power is required (e.g., the production of fuels from zero/low carbon electricity).
- Active involvement of society, e.g., through demand response, and increased social acceptance for renewable power production and new transmission lines is required.
- Synergies with other sectors, e.g., through power-to-gas helps enable decarbonisation of other sectors and provides power system balancing options.
- Decentralised solar PV and wind power production leads to an increased importance of adequate planning/organisation to prevent local grid congestion and to guarantee security of supply.
- Ports require power management systems to ensure that power is needed only when it is needed and to ensure power is switched off where it is not required.

MAIN CHALLENGES

- Significant investments are needed in electricity port infrastructure, e.g., cables and power stations.
- Skilled workers are required to build, install, operate and maintain the new electrical appliances and infrastructure.
- The cost of storage of electricity (to balance supply/demand of power) is high compared with storage of fossil fuels and the storage capacity is limited.
- The process of permitting, planning and implementation of zero/low carbon power infrastructure should be shortened (currently up to ten years in some countries).

PORT PROFILE

- A port with an industrial cluster could play a role in the electrification of industries, e.g., by transporting electricity through the port.
- The availability of coal fired power plants in the port area could provide an opportunity to facilitate the retrofit to a zero/low carbon power plant, or the use of land for other purposes in the case these power plants are phased out.
- A port with a connection to (offshore) generated zero/low carbon power could play a role to import/export the power to industrial clusters/cities/the hinterland.
- For inland ports and ports with short-sea shipping, fast charging electricity facilities and docking stations will be required for electrically powered vessels.
- Ports with a surplus of imported zero/low carbon electricity could act as a hub to integrate energy production for other sectors, e.g., through the production of hydrogen and/or synthetic fuels.

SOURCES

12, 62

C3. Circular economy

As per the definition used by the European Parliament, the circular economy is a 'model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible'. This model will enable extension of the life cycle of products. Raw material use and energy use are decreased, and therefore GHG emissions are reduced.

In a full circular economy materials and resources will be used in closed loop systems which can still range over multiple countries. Bio-based materials such as wood and bioplastics and plant-based products will be increasingly used. Bio-based materials could be used as a fuel, feedstock or material. They could be fed in to existing (industrial) processes, also new bio-based industries could emerge.

A circular and bio-based economy creates opportunities for new business models. New products are required that enhance the feasibility for recycling, as well as innovation for chemical recycling.

Ports could play a role in the production, storage and handling of circular materials, products and resources and facilitating circular systems.

DRIVER/BENEFITS

The key drivers for the update of circular economy model are:

- Societal awareness at organisations and consumers driven by the widely supported need to increase sustainability of the economy.
- Legislation, as part of the EU Green Deal, a more ambitious circular economy action plan is created. The plan includes legislation and policies to reduce waste, to make sustainable products the norm and to improve circularity.
- Shortage or risk of shortage of critical materials in the production processes.
- Enhancing independency in (international) supply chains.

ROLE OF PORTS

General role of ports

- Ports could support the development of logistics linked to the creation of circular systems and could thus have a transport and processing hub function (be a hub for importing/exporting materials, products and/or resources for circular economy).
- Ports could act as a re- and upcycling hub when recycling rates increase (e.g., post-consumer goods and waste flows) and import/export of products materials are to be recycled. Ports can support with logistical support and expertise for the creation of circular industrial ecosystems and can thus have an important transport and processing hub function.
- Circular hubs or clusters could be developed in ports, transforming wasted material produced in (decommissioning of) ships and maritime related processes to valuable products for other sectors.
- Ports could be active in clean water production (especially for islands), e.g., from renewable energy sources or to use ship facilities for desalination and purification.

Role of the port authority

- The port authority could take an active role by developing a circular economy vision/ roadmap, serve as a matchmaker between producing and recycling industries, and play a role as a partner, initiator or facilitator for circular economy businesses.

IMPACT ON PORT INFRASTRUCTURE

The development of the circular and bio-based economy may affect the infrastructure in ports:

- The reduction of demand for raw materials and the extended product life span of machinery and consumer products due to circular economy practises could reduce transported volumes and limit or change the need for port infrastructure.
- Transported volumes of recyclable/recycled/bio-based materials could increase and result in additional port handling activities, require relevant hinterland and maritime connections (rail/water/road) to transit the materials.
- Potential increase of demand for space for terminals for the import of biomass and bio-based raw materials. A significant share is expected to be imported from other continents to Europe. Bio-based materials require significant land use for storage, due to the low energy density (e.g., wood). The perishable nature of bio-based materials needs to be dealt with in terms of storage facilities.
- Potential change in vessel patterns: biomass streams may have a smaller size and different logistic characteristics than the current fossil fuel streams. This impacts the type and frequency of vessels in the port.
- Potential increase of demand for space for industrial sites within the ports: the sites need ample space for recycling activities or facilities for decommissioning (e.g., wind turbines).

ENABLING FACTORS

The following factors could enable the transition to a circular and bio-based economy:

Technical

- More large-scale sites for bio-based and recycled sources are needed.
- Increased certainty is required in technology developments for bio-based feedstock and products and recycled materials.
- More data-driven logistics when perishable and interconnected streams (e.g., biomass) are developing.
- Enough suitable spaces for hubs for recycled materials and production hubs that also deal

with smell, noise, dangers (fire, leakage of substances to water, toxicity), etc.

Commercial

- Ensure that environmental damage is factored into the process of products and services.
- Need for large scale availability of the supply chain for bio-based materials and recycled materials.
- More information for producers/consumers on the product specs, ecological footprint and life cycle analysis.
- Development and facilitation of new industrial clusters that use recycled and bio-based resources.
- New financial arrangements, risk management and business models are needed.
- The proximity of urban agglomerations could accelerate the development of circular activities.

Legislation

- Set quality standards for circular products to increase the trust of buyers.
- Improvement of regulation for the trade of bio-based materials in the EU, clear sustainability criteria need to be determined.

Main challenges

- The main challenges for accelerating a circular and bio-based economy are:
- The cost of raw materials needs to increase to improve the business case for recycled products.
- Circular systems are often not yet available at an industrial scale.
- A lack of information makes it difficult to assess the investment costs for e.g., increasing the plastic cycling rate.

PORT PROFILE

Ports could play a role in various aspects of circular and bio-based economy. Either circular economy activities could be developed in the port area or ports could play a role in providing logistics in the port with relevant stakeholders (circular/bio-based industries, cities).

- An (inland) port could play a role in the recycling logistics. The proximity to cities and industries could provide access to waste streams (e.g., biowaste) to be supplied to recycling sites. Ship waste could be recycled as well – for example convert this waste into energy (e.g., using a biogas plant).
- A port could play a role in importing bio streams (e.g., biomass); it thus not necessarily has to be located close to the source.
- A port that is located near a renewable energy source could provide an opportunity for energy intensive recycling activities, such as the conversion of plastics to virgin materials or alternative fuels.
- Inland ports that are located near incinerators play a role in the logistics and could service inland circular activities that could emerge.
- Ports with (the potential for) industrial clusters could extend or transform their activities with waste-to-energy or waste-to-chemicals projects (more information on this topic can be found in factsheet B1). New businesses can emerge, also near ports that currently do not have (linear) industrial clusters.
- New opportunities for ports near biomass or recycling streams could open. In bio-based chemistry proximity to the source is more important than proximity to the market.

SOURCE

2, 8, 12, 14, 30, 49, 61

C4. Decarbonisation of transport

Transport is responsible for around a quarter of the EU's CO_2-emissions (in 2018[4]). Therefore, there is need to decarbonise transport to achieve the climate goals. In this transition there are three important developments:

- **Electrification**: This is relevant for both road transport and trains. For this there is a need for new vehicles, as well as charging infrastructure.
- **Zero/low carbon fuels**: Most promising are bio-based and synthetic fuels (including hydrogen). At this moment these fuels are a scarcity and not cost-effective yet. Also, transport will have to compete with industrial processes and maritime transport for these fuels. For aviation, zero/low carbon fuels could play an important role.
- **Modal shift**: As can be seen in the graph, CO_2 emissions per km are smallest for water- and rail transport. A shift away from air and road transport towards water and rail will reduce emissions.

Furthermore, digital innovation is an interesting development for optimising logistics. This will not decarbonise transport but can facilitate transition and lead to a reduction in emissions.Ports play an important role in the transhipment of cargo and people, the connection to urban areas, industrial clusters and the hinterland. Ports handle various mixes of transport and host the connection to (inter)national transport through road, rail and aviation. Important trends that also affect transport of people in port areas are shared mobility (e.g., ride sharing, car sharing) and the shift from private vehicle to public transport and other modes, such as bicycles.

[4] Emissions from fuel combustion of domestic and international aviation, road transport, railways and domestic navigation

DRIVER/BENEFITS

The European Green Deal calls for a 90% reduction in transport emissions by 2050. This is stimulated by investment in infrastructure and rules for zero/low- emission vehicles. In addition, from 2026 on, road transport will be covered by emission trading, putting a price on pollution, stimulating cleaner fuel use, and re-investing in clean technologies.

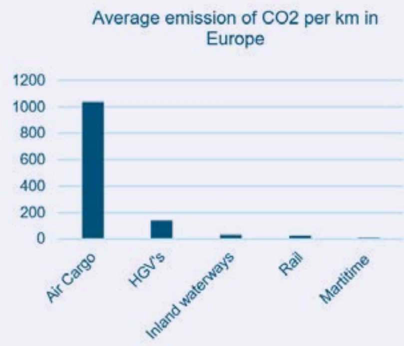


Photo: *Cargo freight by rail (source: RHDHV)*

Transporting companies need to make the sustainable choices. They will be influenced and stimulated on one side through availability of alternatives, and on the other side by discouragement of fossil fuel usage.
These are two sides of the same coin, because discouragement would hamper transport if alternatives were not sufficiently available. These alternatives can only develop and grow if there is demand.

- Consumers and regulators demand more action from transport companies to reduce GHG emissions, e.g., through corporate social responsibility.

ROLE OF PORTS

General role of ports

Ports are a hotspot of industries, sectors, innovation and transport and are therefore a logical place to boost innovation, sector coupling and energy system integration. Ports could host charging infrastructure, fuel stations and transfer terminals. There are many parties involved in the transition to zero emission transport: transport companies, fuel suppliers, port authorities, policy makers. Their combined effort will be needed for a fast and successful transition.

Port authorities themselves do not emit much GHG emissions compared with the transportation stakeholders in the port area. For a modal shift, the port needs to have the facilities and connections for transfer to train and barges. The connection of ports with the hinterland is has an important strategic aspect. Cross-boundary collaboration is key, since a large part of the decision making is not within the ports influence.

Port authority

The role of port managing bodies can take three forms:

- Enabling and facilitating creating the conditions and facilities for transition.
- Regulating: for example, by pricing or spatial measures.
- Managing and incentivising: by bringing stakeholders together and pushing a green agenda.
- The collaboration with stakeholders in the port area (DSOs for the expansion of the electricity grid, (local) governments on GHG emission regulations, etc.) is important to enhance decarbonisation of transport.
- The governance of the port authority might be a significant factor as it can differ from port to port how close it is related to (local) governments. A close relation to (local) governments could help to implement measures to reduce GHG emissions from transport in the port area.

IMPACT ON PORT INFRASTRUCTURE

The impact on port infrastructure includes:

- Transhipment terminals need to be adapted to accommodate the modal shift and logistical supply chain for cargo transport. Transportation volumes may be affected by the shift from road to rail/water transport through the port.
- Multifuel energy charging stations for zero/low carbon fuels (e.g., hydrogen refuelling stations) and storage facilities for these fuels such as biofuels and hydrogen.
- Charging stations and infrastructure. There is more space needed for charging infrastructure than fuel stations, as charging of battery-electric vehicles takes more time.
- The capacity of the electricity grid in the port area needs to be increased to facilitate the deployment of electric transport.
- There will also be new storage facilities needed for example exchangeable energy containers. Batteries can play an important role for peak-shaving (reduce peak demand for electricity) and avoid extra cabling.
- Transport infrastructure in port areas needs to be adapted to accommodate the modal shift, e.g., the expansion of rail networks and/or inland waterways.
- Connections to the hinterland are required for the transportation of zero/low carbon fuels for aviation through rail/pipelines.

ENABLING FACTORS

The following factors enable the decarbonisation of transport:

- The decarbonisation of transport is a gradual process. It depends on replacement cycle of equipment (transport companies), these cycles are shorter for trucks than trains and vessels. Therefore, the transition for road transport can be faster.

- Stimulating and subsidising renewable fuels and low-carbon transport as well as investments in infrastructure will accelerate this gradual change.
- Large required investments in new vehicles that is also needed requires financial stimulation. Funding will help companies and costumers to make sustainable decisions.
- Improvements in the rate of market penetration of battery electric vehicles could help reduce the use of fossil fuels for road transport.
- Increased level of investments in information and communication technologies for (autonomous) vehicles to promote car sharing, electric vehicle sharing.
- Deployment of technologies to produce zero/low carbon fuels enable the decarbonisation of long-haul transport (aviation, heavy-duty vehicles).
- The development and deployment of vehicle-to-grid technology helps integrating electric vehicles into the electricity system, for example by adjusting charging times.
- International cooperation on the production, certification and consumption of zero/low carbon fuels for aviation and road transport.
- Innovation and research are needed to build skills in manufacture, maintenance and repair of zero/low carbon vehicles, trains.
- Limit the impact of fossil fuelled internal combustion vehicles, e.g., by government mandates to limit/end the sale of these vehicles or restrictions on the use of these vehicles in urban areas.
- Promoting the use of car sharing, cycling, walking, working from home could reduce the demand for conventional fossil fuelled transport.

MAIN CHALLENGES

The main challenges to enable the decarbonisation of transport are:

- Shift towards inland shipping and trains may require investments in infrastructure. These investments transcend port authorities and even national governments. This is a long-term investment, and it will take time before new connections are operational. A solution for the period in between is necessary.
- Another challenge relates to the necessary investments and replacement cycles. It might occur that investments in infrastructure require the availability of more sustainable vehicles. At the same time, there could not be enough sustainable vehicles because the infrastructure is not sufficiently deployed yet.
- A possible risk is that the focus on zero-emission of local governments leaves better (but not yet zero-emission) alternatives for the transition period untapped. At the same time companies cannot choose the zero-emission options, because the vehicles are not yet developed enough.
- A regulatory framework and the involvement of all relevant stakeholders in the port area are required to deploy the infrastructure required to decarbonise transport

PORT PROFILE

These changes will affect all types of ports. Various distinctions can be made, depending on the type of transport that takes place in/through the port:

- Port with large volumes of container transport will be affected by the modal shift from air/road to rail/inland water transport.
- Ports with large volumes of passenger transport will be affected by the shift from fossil fuelled to zero/low carbon transportation through the port.
- Inland ports could benefit from the modal shift to inland water transport.
- Seaports could play a role in the production and/or import of zero/low carbon fuels for road transport and/or the end use in aviation.
- Ports that are located near urban areas could benefit from the development of decarbonised transport in cities (e.g., electric-vehicle infrastructure).

SOURCES

10, 11, 12, 63, 82, 83, 84

6 Conclusions

The main observations derived from the factsheets in the preceding chapter are discussed here. While the developments are diverse, a number of 'common denominators' can be identified in terms of 1) port infrastructure impact, 2) the main challenges and enablers for ports, 3) the role ports as a whole play in this new energy landscape, and 4) the conclusions and recommendations for port authorities.

6.1 Port infrastructure impact

From the factsheets we can conclude that electrification of equipment, the use of alternative fuels and related operations in the port are expected to require additional space for grid connections and power systems, charging /bunkering facilities, storage and locations, transport of energy and materials via pipelines or vessels, which will impact the overall port and terminal layout. This will be a challenge as land is already used and leased, and there is often a lack of space in ports.

IN THE NEW ENERGY LANDSCAPE, LAND-USE IN PORTS WILL BE DIFFERENT, REQUIRING MORE ENERGY ORIENTATED LONG TERM PLANS AND INTEGRATED SPATIAL PLANNING

In the new energy landscape, space in ports will be used differently. As many ports face scarcity of available land, new trade-offs need to

be made to prioritise activities in the port and achieve the goals of the port authority and its stakeholders. However, the optimal future spatial allocation of activities is highly complex due to uncertainty and diversity in the technical choices to make. Independent of the prevailing techniques, conventional fossil energy sources will be replaced by technologies that will require more space (for example due to safety measures related to toxic energy carriers and alternative fuels, the large size of hydrogen production facilities, space for and on-site renewables) and more connectivity (e.g. expanding grid, or capture, conversion, re-use of carbon emissions). This is expected to result in more focus on energy infrastructure in port plans and more centralised energy facilities in the port to optimise scale and synergies between suppliers and users.

Strict requirements on safety zones, noise, emissions, and air quality are expected to further trigger changes in spatial planning. New activities resulting from the energy transition, such as production of green ammonia, treatment of biowaste and onshore wind, may need to be planned further from current activities, population centres or environmentally sensitive areas. The installation of renewable energy production is an example of a land-intensive project that needs to be well anticipated and integrated into spatial planning. For example, onshore wind farms and large-scale fields of solar panels require several hectares of land. Large land areas are also required if new terminals for storing, handling or producing new liquid bulk such as hydrogen or biofuels fuels are planned in a port.

CHANGING ENERGY AND INDUSTRIAL SUPPLY CHAINS REQUIRE DEDICATED CORRIDORS AND INFRASTRUCTURE IN PORTS

Dedicated waterway corridors, berths, quays, jetty arms and terminals will be needed to enable supply chains for new types of energy and resources, specific (inland) vessel charging and bunkering of new fuels. For example, there are currently 24 large scale LNG regasification terminals operational in Europe. This number will increase to accommodate growing demand for LNG as a transition fuel in the upcoming decade as well as reduce dependence from Russian pipeline gas.

The import and export of waste, biomass, and new energy carriers is also in need of dedicated (transhipment) terminals and hinterland connections to be developed, each with their own space and safety requirements. This will be the case in seaports but dedicated inland supply ports can also build a position in specific or multiple supply chains. In these supply chains, inland ports can facilitate import of specific materials and/or have dedicated production facilities to feed seaports or inland users.

These physical infrastructure changes entail marine construction and civil works for deepening and widening waterways and turning basins, site preparation, reinforcing quays, trenching for cables and pipelines, and construction of roads to create this infrastructure, connections, and cater for the new terminal layout and sufficient operational space. This is illustrated by the need for structural supply, operations and maintenance of offshore wind farms. For ports to facilitate this a draught of 7–9 metres is required to be suitable for support and installation vessels. Direct sea access and increased quayside lengths are also required along with additional space for storing components and helicopter services.

ELECTRIFICATION IN THE PORT AND THE EMERGENCE OF NEW ENERGY CARRIERS REQUIRES NEW AND UPGRADED ENERGY TRANSPORT AND GRID CONNECTIONS

Electrification of port equipment, onshore power supply, transportation within the port and industrial processes demand a secure and safe power network. This means sufficient and reliable power supply, sufficient grid capacity, and charging infrastructure. More advanced power systems will also entail the installation of storage and converters, and potentially facilities which can combine power use with heat. An example is the hydrogen supply chain where production, conversion, and transport infrastructure are needed to convert power to hydrogen.

This will require the installation of cable and pipeline infrastructure in or near the port for power, energy carriers, and CO_2 transport.

When a port is functioning as an energy hub for energy produced offshore, the energy infrastructure will need to be adapted to allow grid connection, storage and distribution. It is not just the energy related facilities that need to be adapted, hinterland connections must also be established as new energy carriers and resources emerge. One example is the transport volumes coming from circular or bio-based materials, which is expected to increase on the back of waste to energy and waste to chemical activities. This could increase and require relevant hinterland and maritime connections (rail/ water/ road) to transit the resources and end-products.

Modality is an important aspect in optimised connectivity. For example, for hydrogen energy carriers' hinterland transport could be through pipelines, inland waterway transport (to inland ports) or rail, while trucks offer a flexible option for smaller ports lacking multimodal hinterland connections. These hinterland connections and new ways of charging and bunkering are expected to have an impact on ship types for inland shipping, the frequency of port calls and loading/off-loading. Particularly in ports close to urban areas, extra attention need to be paid to develop safe and emission free lanes to get new and more hazardous energy products out of the port.

RENEWABLE ENERGY AND NEW ENERGY CARRIERS REQUIRE MORE, LARGE AND SAFE STORAGE SPACES TO ACCOMMODATE SUPPLY-DEMAND VARIATION AND NEW INDUSTRIAL PROCESSES

Storage of energy commodities or feedstock for energy (e.g., biomass) can require large amounts of space for storage and transportation facilities. Significant land area is needed for storing power, and new energy carriers generally have a lower energy density than conventional carriers. Compared to diesel, fuels such as LNG, ammonia, and hydrogen take up respectively two, three, and four times more space for storage. This storage also requires more safe and technical advanced facilities (e.g., low temperature storage of minus 253 degree Celsius storage for liquid hydrogen). At the same time, the increasing share of renewable power generation in the energy mix results in more need for energy storage to match supply and demand.

Servicing offshore wind projects and offshore decommissioning activities in the port also creates a need for storage space in order to handle large offshore wind components, decommissioned platforms, and secure access for larger vessels. This applies to established offshore service ports, but also for marshalling ports, or ports in proximity of component producers.

With the implementation of CCUS and use of residual heat in production, like in LNG or industrial production, facilities might be needed to capture, and reuse flows. Also refuelling stations for alternative fuels in road transport needing storage space could be a factor of development in inland ports.

ENERGY MANAGEMENT, LOCAL RENEWABLE PRODUCTION AND LOCALLY CONNECTED ENERGY FLOWS IN THE PORT WILL REQUIRE OPERATIONS AND MAINTENANCE

A more complex, connected, and decentralised energy system in the port increases the need for Operations and Maintenance (O&M). Factors such as navigation interferences, aviation restrictions, and grid control complicate matters and need to be considered by port management, operators and other stakeholders in the port.

Energy-efficient technology, energy management/mapping systems and renewable energy capacity, all require investments, procurement, installation, operations and maintenance. This means operational control capabilities and energy process expertise have to be available in organisations within the port.

The same argument on O&M also applies to new facilities for storage, handling and distribution of low or zero carbon energy carriers. Examples include Floating Storage and Regassification Units (FSRU) for LNG, ship-to-ship bunkering, floating power-to-gas, and gas-to power structures, and import-export of alternative fuels. Although the main responsibility for operations will lie with the developer and owner, the role of the port authority will often grow in line with the activities being developed. Even when the port authority is merely facilitating these developments, it still has to understand the technology and safety risks, the viability and how to facilitate and restrict activities if needed.

Table 6-1: *Port infrastructure impact. This table summarises the general interpretation of the potenital physical impact on port infrastructure, but the impact in practice will be port specific. This table is focused on throughput, cargo handling and needed facilities (incl. grid, pipelines, road, rail, water) in the port to service energy related logistics*

	MARITIME TRANSPORT	WATERWAY & IWT	QUAYS	TERMINALS	STORAGE	PORT AREA NETWORKS	HINTERLAND CONNECTIONS
A1. Energy saving			✓	✓			
A2. Decarbonisation port equipment			✓	✓		✓	
A3. Onshore power supply	✓	✓	✓			✓	
A4. Clean fuel bunkering	✓	✓	✓		✓	✓	
A5. On-site renewable power				✓		✓	
B1. Waste to energy and chemicals	✓	✓	✓	✓	✓		✓
B2. Offshore energy						✓	
B3. Offshore industry	✓	✓	✓	✓	✓	✓	✓
B4. Industry decarbonisation	✓	✓			✓	✓	✓
B5. Sustainable urban energy						✓	
B6. Energy conversion			✓	✓		✓	✓
B7. Energy storage hubs		✓	✓	✓	✓	✓	✓
B8. CCUS				✓	✓	✓	✓
C1. Zero-/low emission fuel supply chains	✓	✓	✓	✓	✓	✓	✓
C2. Zero-/low emission electron supply chains					✓	✓	✓
C3. Circular economy	✓	✓	✓	✓	✓	✓	✓
C4. Decarbonisation of transport					✓	✓	✓

6.2 Challenges and Enablers

INVESTMENTS AND FUNDING

A key prerequisite for implementation of decarbonisation measures, renewable energy production, and building infrastructure is the ability to create financially healthy projects. Because of limited funds, investments in the port always imply a trade-off and prioritization of plans, whether it is the port authorities, terminal operators or other parties. Port and energy infrastructure investments often require large capital expenditures and a long-term view on returns. Conventional energy markets and technologies are mature, well established and offer convenience as well as attractive business models. This can make the introduction of new technologies costly, complex and risky if no support or intervention takes place. Because of a limited amount of funds, port stakeholders such as port management bodies, have to make a difficult investment trade-offs. This is caused by large upfront investment levels and long-term returns which often exceeds the lifetime of assets (e.g., port equipment and systems of 10-15 years). The lack of price competitiveness of new technologies is also an issue, while conventional energy markets are established and attractive business models. The difference between EU-countries in available public funds, for instance resulting from differences in making use of the the Recovery and Resilience Facility, could also cause an uneven pace of development and playing field within the EU.

THE CHALLENGES THAT PORTS FACE IN THE ENERGY TRANSITION INCLUDE SECURING FUNDING, FINDING THE RIGHT EXPERTISE, STRATEGIC PLANNING OF LAND USE, COMPLEX OPERATIONS, COLLABORATION WITH STAKEHOLDERS, DEALING WITH TECHNOLOGICAL UNCERTAINTY, THE SOCIETAL AND POLITICAL ENVIRONMENT AND GOVERNANCE / ORGANISATION.

The challenge of parties in the port is to identify the most strategically attractive investments, identify new ways of funding, and develop new business models to create alternative revenue streams. For instance, implementing onshore power based on renewable electricity requires a significant investment that can range from EUR 1-25 million in seaports for the installation of a grid connection, cable to berths, a converter station and onshore power facilities on berth and vessel, depending on the available connections and distances. The additional challenge is that vessel owners need to invest roughly EUR 0.5 – 1 million as well and need to make an investment trade-off between electrification and alternative fuels that can also be used for sailing. The average investment for inland ports is estimated at EUR 10,000, due to a lower capacity need, no need for converters and presence of on-board receivers. This makes the adoption of onshore power supply on a smaller scale for inland ports easier, especially in combination with smaller size vessels and shorter sailing distances. However, higher electricity prices and low utilisation still hamper current developments[5].

[5] Source: CE Delft Stimulering walstroom (2020), WPSP OPS Investment examples, ESPO, INIA

Enabling factors to generate sufficient funding and investments include:

- Growing efficiency and effectiveness of solutions will directly contribute to more carbon reduction, operational cost savings and increased competitiveness. Growing efficiency and effectiveness of new technologies for the energy transition will directly contribute to more carbon reduction, operational cost savings and increased competitiveness.
- Increased commercial attractiveness, bankability, and returns on energy efficiency measures, systems, and renewable energy technology.
- Availability of public funding, pricing of emissions, and direct technology support will stimulate investment decisions in solutions for the energy transition..
- Early commitment from and agreements with users for demand of energy and cargo to make an investment economical.
- Future security/expectation on specific demand for energy and cargo to offset investments.
- Collaboration with private funds and financial institutions to increase funding opportunities..
- The identification of new business models to generate more revenues.
- The identification of alternative revenues or pricing of emission reduction to create business models.
- Green financing can have a positive effect on enabling investments for the energy transition, though strict definitions of 'green' could direct the flow of funds away from some types of infrastructure as well. Investments such as dredging do not qualify as sustainable in itself, but can be essential to enable activities that are considered sustainable.
- Demonstrating the value of energy transition projects through social cost-benefit analysis can help make the case for those projects and generate funding.
- The development of cost-benefit analysis that use the societal net added value for project selection and generate funding for projects on the most attractive locations (for example where air quality can be improved for urban areas with the use of OPS).

EXPERTISE

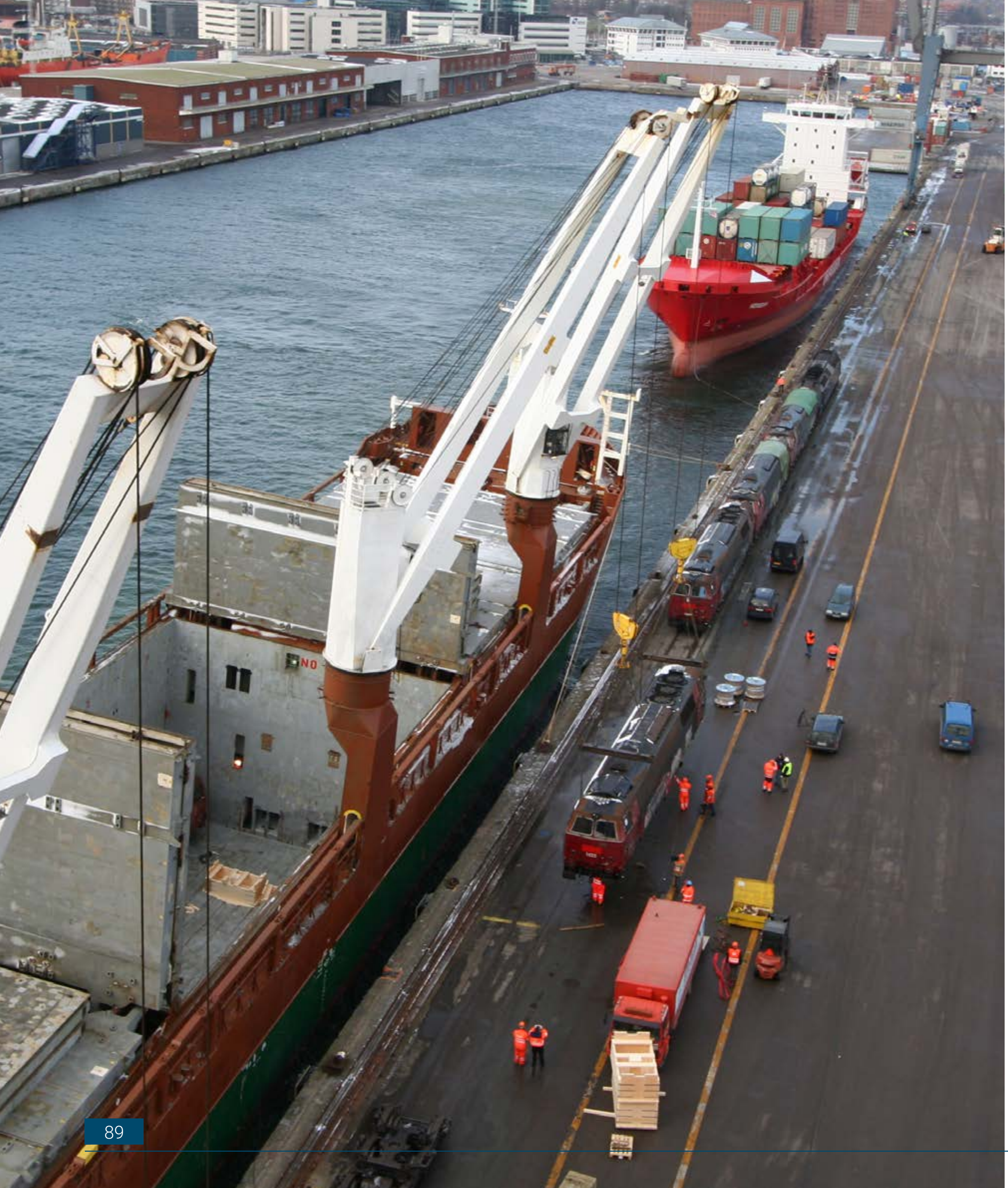
As the role of ports in the energy system is increasing (and vice versa), port authorities and other parties in the port need to develop and attract in-house expertise. In order to improve the knowledge base and development expertise the following skills can be needed to play a more proactive role:

- Management of energy systems
- Strategic planning and business development for energy projects
- Project development
- Specific technological expertise for key energy solutions
- Energy compliance (legislation, requirements, safety)
- Emission monitoring, reporting and verification
- Operations and maintenance
- Ecological expertise

STRATEGIC PLANNING OF LAND USE

The use of land and port space spatial requirements is changing in the new energy landscape. The scarcity of space, securing suitable land, and making the right trade-offs will remain a challenge for ports. Spatial planning of the port will increase in complexity due to the integration of future energy plans, infrastructure, and requirements (e.g., ecology). Zoning requirements and minimum distance from urban settlements to energy handling storage and transport have to be balanced in a new way when for example looking into city ports. Also, permitting for projects in some countries take up more than ten years and port authorities currently face issues with consistency of and public policies related to renewable energy deployment, reallocation of industries, environmental policies, and biodiversity preservation.

Related to the land use impact and spatial planning challenges are the difficulties coming from environmental regulations and social acceptance. The use of land for renewable energy technology, new industrial processes or alternative fuel solutions can conflict with other interests. Some examples are the social and safety acceptance of the proximity of onshore wind farms, carbon capture and storage (CCS) or ammonia production. For example, the



conflict between needing more space for the construction of hydrogen or ammonia production and related cables, pipelines and offshore wind generation. Project developers in the port would have to deal with safety requirements for production but also increasingly have to take into account biodiversity, noise mitigation measures or emission limitations. From a regulatory perspective there might be specific environmental regulations that hamper the development of large scale onshore solar farms, such as rules on nitrogen deposition that conflict with the construction of new energy infrastructure. These interdependencies require consistency and contradiction is to be avoided when developing policy frameworks for topics related to climate targets and renewable energy scale-up.

Reducing the carbon (or ecological) footprint of a port requires strategic planning, using the expertise of the port authority and based on the profile of the port and its potential role in the energy system. This role includes the future flows of energy commodities in the port (both as throughput and use in the port area) and a view on the services and enabling infrastructure the port wants or needs to provide. The strategic planning should also include a programmatic approach on how and when the parties in the port want to reach their climate ambitions as well as plans on building collaborations between stakeholders. A joint energy transition strategy, roadmap and implementation plan covering the port and addressing links with nearby industry and residential areas will enable the parties in a port to proactively develop their position in the energy transition.

Plan-making can also be done together with or by other stakeholders, such as public bodies, industry organisations, and private players. Such plans can enforce, enable and stimulate the role of ports in energy transition and decarbonisation, and should be prioritised in long-term port plans.

OPERATIONS

The energy transition brings substantial changes, but it will take place over a long period time. As the transition is gradually effectuated, the current services and operations often cannot be stopped or interrupted. The implementation of decarbonisation efforts and adjustment of infrastructure should not interfere with the functionality of facilities and ongoing operations within the port. This means that close coordination between the port authority and other parties in the port or linked to the port is essential.

Planning, installation and operation of renewable energy on site involves coordination between the port and affected stakeholders.

The other operational challenge is to service and operate more complex and diverse energy supply chains, and the more central role ports play in connectivity and integration of energy systems. In the energy transition oil and gas will continue to play a role, use of LNG will increase, electrification will increase power demand, renewable energy technology will be used, carbon needs to captured, heat is reused, and new energy carriers and fuels are developed. This will require knowledge of multi-modal transport, a higher diversity in infrastructure to service more diverse and connected energy systems, new services and more energy related knowledge in the port.

COLLABORATION

As the energy system is expected to become more connected and in need of scale, ports are well positioned to play a connecting role between producers and users. In this more demanding role for ports, port authorities also play an important role to be an economic, societal, and energy connector. Play a more prominent role on the energy side requires the following collaborations:

- Cooperation between system and energy providers, users, and port on data and configuration.
- Governance structure of port owners, terminal operators, alternative fuel storage owners, fuel/bunker companies, and shipping lines.

- Setting up dedicated (joint, multidisciplinary) entities to organise specific projects/ pilots for heat, grid development, or renewable power generation.
- Collaboration and alliances with business and industry to create long term commitment, common goals, and joint initiatives with interexchange of energy and resources.
- Connections with municipalities of urban areas, to understand public needs and concerns, and find ways to connect flows of energy and resources to and from cities.

TECHNOLOGY UNCERTAINTY

Supply and demand

The intermittence of renewable power generation and the potential disbalance it creates between energy supply and demand is an important challenge for the development and pace of clean energy production and use. This could hamper the development of renewables and implementation of project in ports. Since energy supply is also expected to become more complex it could potentially interfere with properly (in time, sufficient, right quality/power) servicing clients with the energy they need for their vessels or production process. This could happen for example if there are specific requirements for renewable energy sources for onshore power supply, which if stated wrong or too strict might lead to a risk of inability to supply or strong price increases.

Technology choices and adoption

There is no 'one size fits all' approach for implementing energy transition in ports. Each port needs to optimise its role and use of technology. This creates a challenge to adequately translate external developments in resources, markets and technology into port specific plans. In this phase of transition, where new technology is mostly immature, ports have to make technology choices in the face of uncertainty. Ports are dependent on the available resources, adoption rate within the port and the pace of development of supply chains. The degree to which ports can adopt and integrate new available energy-efficient, management systems, and electrification technology is an important enabler. This is determined by the technological advancement and financial attractiveness of new solutions, but also the ease of gradual replacement and replacement cycles. When hybrid solutions for port equipment are already in place for example, later upgrading to a full electric option can become easier.

Another enabler for adoption of new technology is also the presence of a secure grid with sufficient capacity and renewable sources, making it more attractive to opt for an electrified solution. Cleaner energy supply, charging/ bunkering, and proximity to production can also improve adoption in areas where conventional industry or supply is not allowed due to environmental restrictions.

Standardisation

In general, new technologies often suffer from a lack of standards and the use of some energy carriers such as such as ammonia is even prohibited under current safety regulations for ships. Standardisation issues can delay and hamper the development of green infrastructure investments. Technical standards and harmonisation will improve and drive technology focus and connectivity, since it will stimulate the use of specific solutions or methods improving the ease and spread of technology adoption. These may cover clear harmonised rules on safety and regulations for renewable and alternative fuel production, transport, storage, and use in the port, but also the harmonisation of (stricter) rules for environmental requirements, ecology, and social impact within Europe. Another example is the harmonisation of electricity payment systems for onshore power in inland navigation.

Societal impact and political climate
A growing challenge for ports will be the need to deal with increasingly stricter legislation and public pressure to move faster in decarbonisation, mitigation of noise, improving air quality and preserving and stimulating biodiversity. Social acceptance and safety of new technology must be considered in strategic planning and project development, and they will increasingly affect the public perception of a port.

Legislation and the call for action from stakeholders present both a challenge and an enabler for ports. They stimulate parties in a port to act, but also push developments in markets and technology, resulting in increased public guidance, support, funding, and local content requirements.

In order to make sure policies and legislation give the right incentive and stimulate growth, climate targets and renewable energy development targets have to be taken into account for, or might lead to updating, relevant other policy frameworks (e.g. when developing environmental, land use, or biodiversity policies), to avoid contradiction and complexity.

Governance and port organisation
As the energy system is expected to become more connected and diverse, a closer collaboration between the port authority and stakeholders is important. This collaboration demands an expanding role for the port authority and requires new competencies, (legal)tools and mandates. It can be challenging for port authorities to move from a landlord role to a role as investor and developer. Collaboration can occur for example, between port authorities, terminal operators and local industry in strategic planning of land-use, or by taking on responsibility for energy monitoring and reporting on emission within the port area. While it can be challenging, it is also an important enabler. Port authorities proactively involve themselves in creating clusters for the energy transition, generating knowledge, and building networks and supply chains and attracting companies focused Port authorities could also, if allowed, alter by-laws or regulations to allow for specific production and use of facilities, in collaboration with stakeholders. In working on these types of collaborations and changes in the port governance ports should always take into account the compliance rules, for example the EU rules on public procurement or competition rules. They can stimulate permitting, make revi-

Investments and funding	▪ Reserve, secure and arrange (co-)funding ▪ Find financial and business partners
Expertise	▪ Built and hire energy and project development related skills and expertise ▪ Right balance between own skills/responsibility and third-party hiring
Planning & land use	▪ Create integrated spatial plan for port and energy infrastructure ▪ Upgrade of port infrastructure, creation of space, ▪ Improve hinterland connections with dedicated corridors and multi-modal solutions
Technology uncertainty	▪ Secure supply and demand for alternative energy services and energy and cargo flows ▪ Stimulate technology choices, adoption and standardisation in and between ports
Collaboration	▪ Collaboration between ports, with clients, and stimulate stakeholder engagement ▪ Increased role in connecting and collaborating with energy suppliers and users
Societal impact and political climate	▪ Mission driven, combine commercial interests with societal goals ▪ Policy advise and support on consequent policy making to stimulate energy transition efforts
Governance & port organisation	▪ Role is expanding, requiring more strategic, business development, and alliance building skills ▪ Change from a pure landlord to investor and developer

Source: Based on ESPO energy transition hub requirement figure

Figure 6-1: *Requirements for turning ports into sustainable energy hubs* sion plans, or have preconditions in concession agreements that favour sustainable development. In working on these types of collaborations and changes in the port governance ports have to take into account the compliance rules to make sure such measures are valid with for example the EU public procurement or competition rules.

6.3 Role of ports

EVERY PORT HAS ITS OWN PROFILE DEFINING THEIR OPTIONS, PRIORITIES AND POTENTIAL ROLE. SEAPORTS OFTEN PLAY A LARGER ROLE IN CONNECTING MULTIPLE FLOWS OF CARGO AND ENERGY, WHILE INLAND PORTS ARE FLEXIBLE, CAN ADOPT SOME TECHNOLOGY MORE QUICKLY AND MIGHT DEVELOP A SPECIALIST ROLE IN NEW SUPPLY CHAINS.

PORT PROFILES

Each port is different in terms of port type (sea and/or inland), ownership / governance and organisation, location (region, nearby population centres and industry), infrastructure and connections, hinterland, and the port's commercial portfolio in terms of trade patterns, energy flows, type of clients and industry, and supply chains. These specifics combined result in a certain 'port profile' that determines the options, priorities, and mandate of the port's managing body in terms of playing a role in the energy transition and seizing opportunities. There are many different ports, each with their own profile based

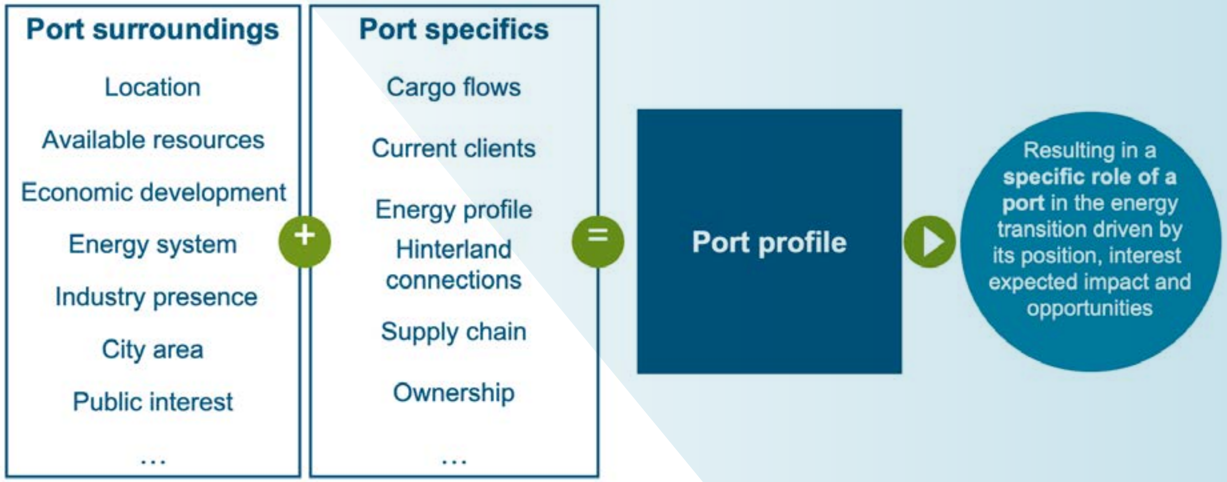


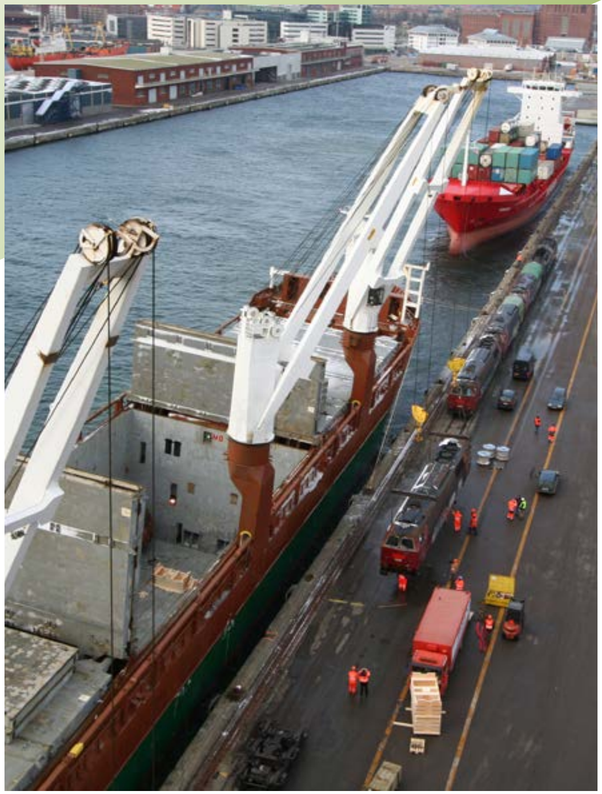
Figure 6.2: *Port profile determination factors*

on port surroundings (location and space, sea or inland, industry, energy mix, hinterland, city) and specific portfolio (trade flows, energy flows, client and industry type, and connected supply chains). For a port these specifics result in a certain value chain positions and a degree to which it can play a role and develop energy transition actions.

Common archetypes are container ports, industrial ports, bunkering ports, logistic and transport ports and urban ports. Whether they are sea or inland ports, these all play different and often multiple roles in energy value chains. The size of a port is often decisive for the degree of land availability, scale, influence, ability to invest and connect. Smaller connectivity power, smaller and more remote ports with limited access to a reliable grid or insufficient number of port calls might be hindered in their transition developments.

Ports and terminals focused on handling of containers or conventional energy commodities such as coal or LNG for example, will have specific priorities and challenges in their agenda for reducing emissions in their current activities and building future activities and infrastructure. Ports with industrial cluster or ports in the proximity of urban areas will have to consider a larger role in renewable energy, and might need to deal with stricter regulations and . This is also driven by a more prominent social engagement.

For energy efficiency, equipment decarbonisation and onshore power, both sea- and inland



ports are mostly dealing with the same technical and demand challenges. Nevertheless, seaports have a higher investment barrier but can easier create scale, while inland ports have a lower investment level but have more difficulty scaling. For options like electrification, use of batteries and alternative fuels for operations and transport, inland ports have the technical advantage of having a lower (peak) energy demand, smaller assets (vessels, equipment), shorter distances and duration of use. Also, non-traditional bunkering solutions can be well established inland to service the transportation sector. Seaports can play a larger role in connecting and integrating multiple new energy and production flows, while inland ports can develop specific or additional specialisms and become a crucial part of new supply chains.

One distinction that was identified factsheets and in the conclusion, is that of seaports and inland ports. From the factsheets we can conclude that for energy efficiency, equipment decarbonisation and OPS both sea and inland ports are mostly dealing with the same technical and demand challenges, with the main distinctive factor being that seaports have a higher investment barrier but can easier create scale, while inland ports have a lower investment level but have difficulty scaling.

When looking at the electrification, use of batteries and alternative fuels for operations and transport, inland ports have the technical advantage of having a lower energy (peak) demand, smaller assets (vessels, equipment), shorter distances and use duration. Non-traditional bunkering solutions can also be well established inland to service the transport sector

Major seaports can serve for example as a main hub for transport of captured CO_2, and further facilitate permanent storage. Smaller ports or inland ports can play a flexible role on a smaller scale, providing tailor made facilities to suit particular industries nearest to them or act as carbon collector. Inland ports could also play a role in the circular economy and logistics for waste to energy due to the proximity to cities and industries waste streams. In the new energy landscape inland ports could also benefit from the modal shift towards inland shipping and rail although for some new energy carriers pipelines may be a more feasible option.

Due to the complexity and diversity in energy transition topics and their impact and the diversification in port profiles there is no 'one-size fits all' approach. For every port the current exposure, interests, and priorities translate into options and challenges for the energy transition. The factsheets highlight factors that determine the port profile in order to identify the current or potential position of a port for a specific energy transition topic.

> **PORTS WILL INCREASINGLY NEED TO BALANCE COMMERCIAL AND ECONOMIC OBJECTIVES WITH A RESPONSIBILITY TO SOCIETY, IMPACT ON THE LOCAL COMMUNITY AND PRIORITIES IN THE ENERGY TRANSITION**

As illustrated, the energy transition is a diverse and impactful transition for ports. Port managing bodies and other parties in the port will have to rethink their business models, and plan ahead on the future in order to remain relevant and maintain market share. They want to future proof their existence by optimising and decarbonising current activities, while developing new activities and a renewed service portfolio to facilitate changing client needs, that create both commercial, economic and societal value.

This is possible if parties in a port can leverage their core competences to the new energy landscape: optimising land-use, efficient trade logistics and cargo handling, energy services (like power supply, heat reuse but also O&M for offshore installation activities and energy and emission monitoring), and connecting processes. An excellent port performance in the energy transition requires changes in port equipment, transport facilities, infrastructure, and energy processes. Besides these changes in physical infrastructural, it is important to build up specific expertise in energy, project development and management, networks and cluster-building, new business models, and governance. This is desirable for energy and industry related ports to secure their future existence but also for ports which are less energy dependent but have to adopt the cost of the energy transition in their business model.

The rethinking on port activities and the commercial port goals have to be brought in line with the societal responsibility and community impact of European ports, and their key priorities in energy transition:

- Reducing emissions of assets and operational processes in the port
- Reducing emissions of shipping, both during navigation and while at berth
- Installing onshore power supply to reduce emissions at berth
- Reducing emissions in industrial and residential areas near the port
- Reducing emissions of hinterland transport and in supply chains
- Upgrade and secure sufficient grid capacity
- Demand-driven facilitation of alternative fuels and new energy carriers, and alternative fuels
- Dialogue and alliances with stakeholders, clients and financiers;
- Pilot project development on new energy technologies.

6.4 Role of port authorities

PORT AUTHORITIES PLAY A CENTRAL ROLE IN PORTS AS LANDLORD, COMMUNITY BUILDER AND SOMETIMES CO-INVESTOR IN THE ENERGY TRANSITION. THEY AIM TO DECARBONISE THEIR OWN FOOTPRINT BUT CAN ONLY STIMULATE AND ENABLE EMISSION REDUCTIONS OF THE MAIN EMITTERS.

Port authorities play a central role within ports as landlord, community builder, enabler and (co-) investor, based on shared responsibilities and involvement in all port related interests together with other players see (figure 6.3). In terms of energy supply and use, ports want to manage overall demand, consumption, and emission in the port footprint together with

Broader mission formulation and target setting…

Future proof port existence

Goal to generate commercial and societal value, develop growth and new business, while reaching climate targets

…supported by…

Excellent port performance
Driven by optimal land use value, service portfolio profit, investment returns, sustainable & efficient energy systems

Optimisation of port facilities
Enabled by upgraded, efficient, integrated, and reliable port equipment, transport facilities, infrastructure, and energy processes

Proactive role of port authorities
Stimulated by a proactive role of ports to develop energy specific plans, create clusters and alliances, pilot and innovate

Figure 6-3: *Port ambition and goal formulation in energy transition* other energy suppliers and users in the port. This starts by taking responsibility for the energy use and emissions within its own assets and operations. The next step is looking at how to facilitate decarbonisation for the wider port area. The motivation for a more proactive role of port authorities can stem from their own mission driven ambitions, their role in the local community, its ownership and governance structure and the necessity to future proof port existence and create new opportunities. This is further encouraged through regulation and European frameworks to become carbon neutral, scale up renewable energy, reduce the environmental impact op transport and enhance biodiversity.

However, despite the central role of port authorities in the port their direct influence on decarbonisation is mainly limited to their own operations and landlord activities, to develop facilitating services, and to stimulate, promote and collaborate with a broad spectrum of port players. This is why port management bodies increasingly aim to address energy transition and become 'part of the solution' by developing ports as sustainable energy hub together with all actors in and around the port area. Clear examples of such strategies are green shipping, decarbonisation of the industry, and low/zero emission port equipment.

The role of the port authority is discussed in each factsheet. The summary below structures the main observations in **three layers: in the port, the wider port area, and in the economy as a whole.**

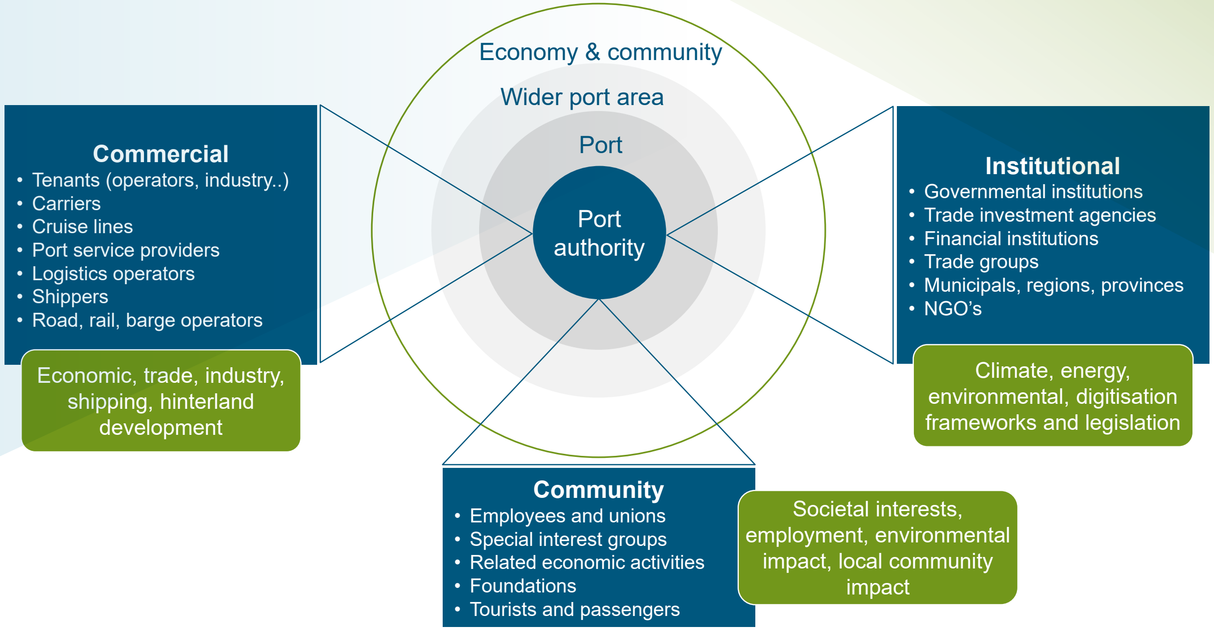


Figure 6-4: *Port environment of port authorities. Source: RHDHV, Port Economics Management, Deloitte.*

> **PORT AUTHORITIES CAN ACCELERATE THEIR OWN DECARBONISATION EFFORTS WHILE FACILITATING AND STIMULATING SCALABLE ENERGY PROJECTS IN THE PORT**

In terms of energy-saving, decarbonisation of port equipment, onshore power supply, alternative fuel bunkering infrastructure, and on-site renewable power generation, all port authorities can act directly in line with their existing activities, facilities and responsibilities. Energy-saving measures can be adopted in the port managing bodies' own facilities and energy consumption, while they can also coordinate and stimulate energy-savings in terminals by setting requirements, offer scalability or facilitating implementation in the port area.

For decarbonisation of port equipment the port authorities can invest in replacements for their own equipment and fleet. Towards terminal operators it can encourage, incentivise or enforce use of decarbonised equipment,

depending on port governance and regulatory powers. For example, the authority can set requirements or stand-out criteria in concession agreements.

Offering onshore power supply, producing on-site renewable energy and offering bunkering of alternative fuels are all options to make headway and facilitate the uptake of clean energy in transportation. This does not necessarily mean that the port managing body will build and/or operate the facilities. Their role depends on the governance structure and the national framework. However, by proactively providing land, developing projects, building alliances, stimulating guidance and regulations, and co-investing, port authorities can contribute and stimulate initiatives.

WITHIN THE WIDER PORT AREA PORT AUTHORITIES CAN LEVERAGE THEIR HUB FUNCTION BY ACTING AS FACILITATOR, DEVELOPER AND INTEGRATOR OF RENEWABLE ENERGY STREAMS AND SUPPLY CHAINS

In the wider port area, meaning the port including its linkages with offshore activities, industrial clusters and residential areas, port authorities can play a role as facilitator, developer and integrator. They are able to provide land and accommodate reallocation of industries, ensure energy supply by integrating power cables or pipelines, stimulate collaboration and stakeholder engagement, and set up clusters to, for example, process large volumes of waste for energy, fuels and chemicals.

Port authorities can leverage the connecting nature of the port in energy transition by bringing stakeholders together, aligning decarbonisation targets from different perspectives, optimising the spatial planning and co-investing in and improving common infrastructure. For instance, they can work with grid operators, terminal operators and industrial companies to expand and build new energy transportation networks. For the distribution of heat and cooling, port authorities can be the initiator and even operator of the network, especially when there is public ownership or when port managing bodies are part of a larger consortium. Overall, the role of port authorities can move from a traditional landlord to a master planner and proactive developer of projects, energy networks, and business consortia.

FOR THE WIDER ECONOMY, PORT AUTHORITIES CAN EMPOWER THE POSITION OF THE PORT BY ENABLING, GUIDING, CO-CREATING AND STIMULATING COLLABORATION AND SUPPLY CHAINS

In the overall economy and community, the port is one of the economic operators in a global or specific market value chain. In the context of the energy transition, this can include supply chains for zero/low carbon fuels and electricity, and circular or bio-based economy concepts.

In global trade and energy value chains the role and impact of the port authority is limited as they are only to some extend able influence market dynamics like supply and demand, pricing, competition, and end-use. However, as ports are often important logistic hubs that streamline transport efficiency, they can empower their position by removing logistic bottlenecks, service as logistics integrator, collaborate with other value chain and port partners.

Port authorities can empower their position and that of the port jointly with other port players. For example, by stimulating international cooperation with other ports, merge activities with neighbouring ports for synergies, developing complementary supply chains with adequate and multi-modal hinterland connections, and

create industrial symbiosis. They can operate as a matchmaker between supply and demand, producers, users and recyclers. The role of port authorities in a broader economic and societal context could focus on being 1) an enabler by (co-)creating plans, conditions, space and facilities, 2) a regulator, establishing guidance and measures, and 3) a stimulator, pushing stakeholders and partnership.

In general, based on their level of influence, port profile, the dependence on others, and the maturity of energy technologies, port authorities can determine their energy transition agenda. They can ACT directly on decarbonising and limiting own energy use, FACILITATE the changing need of clients by servicing new energy demand, STIMULATE initiatives, clusters and supply

Landlord
- ✓ Land-lease focus
- ✓ Responsibility for own activities and emission scope
- ✓ Developments done by operators, business and industry in the port
- ✓ Reactive, act on legislation

Facilitator
- ✓ Landlord model with additional services
- ✓ Upgraded facilities and offering extra services based on client demand
- ✓ Actively engaged with clients

Enabler
- ✓ Future focused landlord
- ✓ Developing plans, services and infrastructure that enable energy transition progress
- ✓ Beyond the port area
- ✓ Proactively with clients and business partners

Investor
- ✓ Investor in needed energy infrastructure and projects initiated in the port
- ✓ Early-on funding of initiatives
- ✓ Public-private initiatives
- ✓ Participations and own developments, result driven

Developer
- ✓ Developer and investor of (joint) energy transition projects
- ✓ Inside and outside the port area
- ✓ Focus on collaboration and alliances
- ✓ Pilot new technologies and ventures
- ✓ Proactive and mission driven

Figure 6-5: *Role development of port authorities*

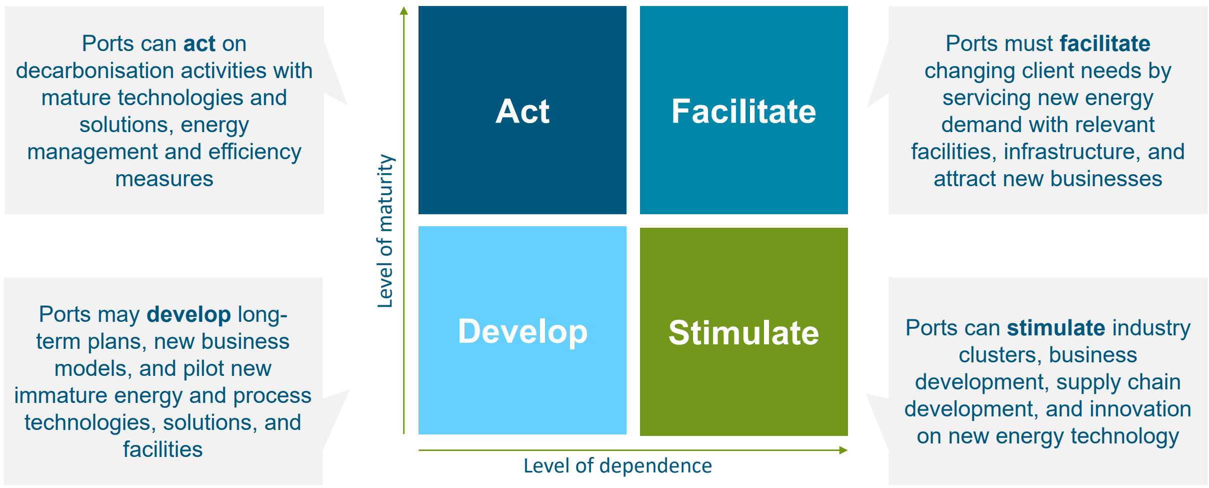


Figure 6-6: *Role identification for port authorities*

chains, while they DEVELOP long-term plans, new energy spatial planning integration, new business ventures and pilot projects.

THE ENERGY TRANSITION WILL ALSO OFFER OPPORTUNITIES TO PORTS IN TERMS OF COST SAVINGS, SECURING MARKET SHARE AND ATTRACTING NEW CARGO, BUSINESS AND INDUSTRIES

Combining the conclusions from the factsheets with the role port authorities can take on, a division of energy transition topics can be made over the quadrants. This creates a starting point to identify what port authorities can do on these specific topics and compose their energy transition strategy. Within these quadrants and for these energy transition topics each port authority can identify their position and develop concrete plans on what is relevant for the port, how to develop this, whom to involve, and what is needed.

Besides the expected challenges, the energy transition also offers opportunities for ports. It is in the port authority's interest to proactively identify these opportunities for themselves and the port as a whole; both from a commercial and from a societal perspective. As demand and processes in the port will change and new businesses emerge, the port will need to adapt in line with the changes.

The factsheets provide a number of opportunities around current and future business activities in the port:

- **Cost savings and returns**: Investments such as energy-savings and renewable power generation can generate energy cost savings, as described in the energy efficiency factsheets for example.
- **Secure trade flows and future proof market share**: Current market shares can be maintained or expanded by proactively moving in line with the market direction; for example, securing new flows of energy commodities or providing alternative fuels.
- **Attract future industry and business**: A proactive role and developing the port area is needed to maintain and expand presence of new industries and businesses, and secure or grow long-term land-use returns; for example, the replacement of fossil fuel based industry and services with clean industry and offshore renewable businesses.
- **Decarbonised services**: By offering and accommodating zero/low carbon facilities ports can contribute to emission reduction of their clients and improve the competitive position of the port.
- **Creation of dedicated services for new revenue streams:** Enabling industries, terminal operators and shipping liners to benefit from energy products, such as heat, CO_2, renewable electricity or hydrogen can generate additional revenue streams.

- **Development of a crucial role in supply chains**: Additional dedicated terminals and corridors, for example for waste and biomass, can be developed in order to secure a crucial sourcing position.
- **Utility type role by managing energy flows**: If a port is able to claim a larger role in the energy system by having a prominent position in transport, conversion and storage of energy, it will be able to get additional revenue streams from these energy flows, acting as a utility company.

> **DUE TO THE COMPLEX AND UNCERTAIN NATURE OF THE ENERGY TRANSITION AND DIVERSITY IN PORTS, IT IS RECOMMENDED FOR PORT AUTHORITIES TO IDENTIFY THEIR OWN TAILORED ROLE ON HOW TO DEVELOP, ACT, FACILITATE AND STIMULATE ENERGY TRANSITION INITIATIVES IN THE PORT.**

The energy transition is a highly complex, diverse and impactful transition for ports. The path, solutions and end-state are not straightforward. As a consequence also making the best choices and seizing opportunities is complex. Port authorities will need to build up knowledge and expertise in order to adequately identify and leverage their port profile and to understand the relevance and impact of specific energy transition topics on their port.

Based on this identification phase, port authorities will better understand the opportunities and challenges that they will face and what role they can and want to play in the future. The aim of this report is to inform this process by providing insight in the various developments within the energy transition.

Specifically for the role of the port authority we hope to have clarified that they often take on a larger responsibility based on their societal engagement and public ownership, but that their actual direct influence on larger greening initiatives is limited to enabling, facilitating and stimulating the other economic operators in their decarbonisation efforts.

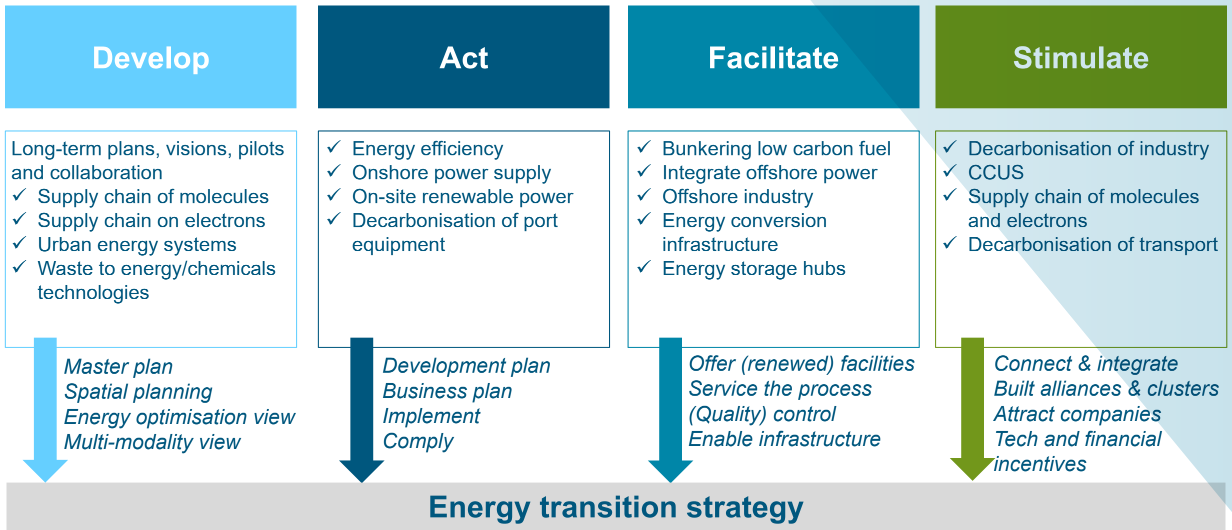


Figure 6-7: *Translation of roles for energy transition topics towards an energy transition strategy*

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8 Case Studies

Port of Ennshafen: investing "5 minutes before the market"

Interview with Mr. Werner Auer (Managing Director), 17 May 2022

Ennshafen is one of the largest inland ports in Austria, handling international cargo on the Rhine-Main-Danube waterway. It is a multi-purpose port handling container traffic, general cargo and cruise vessels, and also offering hinterland connections by road and rail. Ennshafen is owned and operated by two public federal companies which work closely with the private sector in the business parks. A combination of a private industry push to decarbonise logistics and operations and the public plans, stimulation and investments from the port authority is driving energy transition initiatives in the port. A couple of examples are the construction of a LNG filling station, onshore power supply (OPS) facilities throughout the port, a metal recycling plant in the business park and an operational hydraulic cargo crane.

The port has invested in OPS facilities already during the construction of the quays offering a mix of 32 and 63 Ampère stations to serve cargo vessels which stay-over in the port. Ennshafen is looking to expand these facilities with 125 Ampère stations that will be able to serve for example cruise ships during the winter. The port authority generates revenues from land lease and differentiated port due fees and is operating the OPS facilities by itself. Ennshafen experiences that shipowners are willing to switch to OPS, mainly for longer stays, as long as the price and power supply is in line with their needs.

Main challenges are the uncertain market developments, lack of demand and the high investment level resulting from increasing procurement prices, which all influence the price level and hamper the business case and investment ambitions for OPS. Currently, the investment is not paying off as use and price are not aligned. The unclear direction of the market and that of policy frameworks are also a challenge. Driven by TEN-T programs in 2015-17, the port focused on and invested in LNG. Only a few years later, public policy focuses mainly on zero emission technologies.

A lesson learned is to take on the energy transition step-by-step. For example, some OPS facilities were implemented during the construction phase of the quays. This has limited the infrastructure adjustments and the interference with operations. Future expansions of OPS facilities for the required upgrade of the cable sections will be taken on step-by-step during annual maintenance periods.

Recommendations for other ports are to advance plan making in the port. Ennshafen is taking an incremental approach towards investments with a structured approach for cost-benefit analysis, while aiming to make use of the Connecting Europe Facilities. Ennshafen also has a plan to future proof the port, in which it adopts ideas on the future energy infrastructure needs. The main focus is to invest "5 minutes before the market", making sure investments are there to serve the market in time without overinvesting or investing too early when there is no demand.

In its long-term view the port believes in a transition which initially will see an increase in use of LNG and electricity as most economical first steps. The port authority expects the structural use of hydrogen and related energy carriers on a large scale to take longer than most policies envision, emphasizing the difficulty for technical adoption of these fuels in shipping and the (aqua-)toxic nature of new carriers like methanol.

Port of Esbjerg: growing with the offshore wind industry

Interview with Mr. Jesper Bank (CCO), 18 May 2022

The Port of Esbjerg has been involved in handling wind turbines and components for more than 20 years. Traditionally these activities related to the onshore wind industry, serving Danish component manufacturers in the area. In the initial stages of onshore wind and offshore wind, this cargo could be handled as high and heavy project cargo, using a large crane and a typical seaside quay to export from Denmark. **The offshore wind sector has shown a dramatic change** over the past ten years in terms of market growth and scale. The growing demand and size of the components has impacted operations in the port significantly. All the logistics equipment needed to be adjusted, as well as basic infrastructure. For example, roads had to be adjusted to handle the turning radius of wind turbine transportation. As the offshore wind sector will continue to grow and scale up there is a lot of attention for the project execution and installation challenge, but the challenge and the constraints of ports in handling this scale is often underestimated. Stakeholders are often not familiar with port works while handling offshore wind components as very different from the traditional port business.

The impact on infrastructure in the Port of Esbjerg, as market leader in wind turbine transport, is significant. The port lay-out has changed and will require continuous adjustments over time to service offshore wind with dedicated areas. The handling process has shifted from using cranes to RO-RO vessels and specific jetty designs are needed.

The Port of Esbjerg is coping with these changes by adjusting and expanding dedicated areas but also by taking on a different logistic approach. The port moved from a project solution focus to a full scale industrial process with components flowing in and out every day, as it expects the market to grow fast with only about ten ports in Europe able to serve the market on a structural basis. In the coming years, port capacity might turn out to be a limitation as the Port of Esbjerg estimates that current capacity is insufficient to meet demand. It does expect demand and capacity to be in balance over the next five to eight years. For now, the Port of Esbjerg will focus on excellent port performance for the offshore wind sector, by serving component manufacturers, playing a key role in the value chain and service O&M for installation companies. The port authority is cautious to start energy transition activities it considers radical, such as Power to X, although a push from the industry is there.

An important challenge for the port is to adjust in a way that is financially viable. Regular port business such as container handling is commercially more attractive, so the main challenge is to optimise infrastructure and processes to make the offshore wind activities as financially viable as possible. The current port expansions are multi-layered and based on expected growth from multiple cargo flows. In order to limit the investment risks the port is not putting all its eggs in one basket, but has chosen to develop the port expansions as flexible as possible. The aim is to build infrastructure with a flexible and multipurpose use, with large bearing capacity. The investments are done by the port authority itself, in close alignment with the industry to know their needs but without commitment.

The Port of Esbjerg has always been close to the supply chain due to the presence of local nacelle and tower producers. However, this has been very demanding while activity levels have been on and off. **That is why the port is also focussing more on creating a key position in the logistic value chain** by servicing installation vessels. This is driven by the fact that there is a lack of space to accommodate any more production in the area. Another important element is employment: the main target of the port authority and its stakeholders is not to make a profit but to generate jobs in the area. The port authority expects to best achieve this goal by positioning itself in the value chain for handling goods and providing O&M.

As a piece of advice to other ports dealing with similar challenges the Port of Esbjerg recommends to consider each other colleagues rather than competitors. The port is very open and focused on collaboration and dialogue with other ports like Zeebrugge and Eemshaven. These ports are helping each other along the way. Another recommendation is for port authorities to focus on the specific strengths, identify the best role it can play given its position and expertise, and not to get distracted.

Port of Gothenburg: investing to achieve climate goals

Interview with Mr. Jörgen Wrennfors (Manager Production Development), 18 May 2022

The Port of Gothenburg already started in the 1990s with the development of onshore power supply (OPS). Initially these facilities were developed for Stenaline. More recently, the port authority has also developed OPS for RoRo-ferries that regularly visit and stay over in the port. These OPS facilities are an investment and development of the port authority, who has been building and operating the systems. Over time, most of the OPS facilities have been taken over and are operated by the ship owners themselves.

The next step in developing OPS systems is focused on serving tankers visiting the energy terminal. Since the energy terminal is owned and operated by the authority it will do the full investment, development and operations of the OPS systems by itself.

The main reason for developing these facilities, and also for other energy transition initiatives in the port, is the port authority's target to reduce the carbon footprint of transport by 70% in 2030.

The main challenges relate to the technical challenges. Since the port has been developing these OPS systems early on there is a lot of uncertainty. There are no technical standards yet, vessels owners have to adjust and be convinced, and developing OPS for energy carriers is very different and more diverse in its energy use. In order to be in control of the project and of technical developments, the port authority has attracted specific energy engineering skills to their organisation.

The impact of OPS systems on the port infrastructure is significant. The increased electricity consumption and higher peak demand for power requires an upgrade of the power grid in the port. The port authority is working together with Göteburg Energi to develop the grid. Getting the power from the grid to the OPS systems close to shore, while continuing operations in the port, is also a challenge.

The Port of Gothenburg is enabling and stimulating energy transition initiatives by investing in infrastructure like OPS and developing joint projects with the industry on CCS, ship-to-ship bunkering and hydrogen production in the port. For the investments the port got support from a Swedish Climate Fund, which was also available to the ship-owners. The port authority also offers a discount on port dues and OPS is stimulated by a reduced tax level on the price.

An important enabler and recommendation to other ports is to develop a detailed plan and implement projects closely with ship owners and other ports. This will improve the technical feasibility, utilisation and the stimulation of standards. For example, in collaboration with shipowners a solution for an OPS connection in the middle of ships was chosen, offering a solution for different ship sizes. It also de-risks the projects as users are involved early-on, making the investments more future-proof. The Port of Gothenburg is working together with other ports in Sweden, with the Port of Rotterdam on feasibility studies, and exchanges information with other European ports.

CNR Rhone inland waterway: meeting the challenges to create sustainable solutions

Interview with Mr. Alexandre Janin (Project Manager Inland Waterway Transport), 24 May 2022

CNR is the authority managing inland navigation for the river Rhone. The area managed by CNR consists of 330 kilometres of waterway, 18 ports and 22 related industrial sites. CNR is a private company with public interests, as CNR was asked to manage and build all the rivers on behalf of the French state since 1933. The responsibilities do not only relate to river transport (navigation and mobility) but it also comprises the production of energy, irrigation for agricultural use and biodiversity and water quality. Originally, CNR is a developer of energy production facilities, which started on the river Rhone with the construction of a hydropower dam in 1938. Since then, CNR has developed renewable energy which has resulted in a total installed capacity of 3,980 MW and production of 15,4 TWh from hydro, wind and solar energy.

The 18 ports in the area are partially owned and operated by CNR, others are operated by concessionaires. The commercial returns generated from the inland waterways and energy services are used to fund investments in marine and energy infrastructure. As the river Rhone is not connected to other European waters, it operates as a collaborative ecosystem ranging from the Port of Lyon to the Port of Marseille/Fos and Sète. The combination of CNR's expertise, the mission driven targets in the public interest and the common goals of the players along the waterway have driven CNR deeper into the development of greening activities. In order to drive change in the area, CNR is for example increasingly setting sustainability requirements or planning development requirements for new land users in the port. It is also actively engaged with plan-making for existing concessionaires to stimulate more sustainable use of water, electricity and mobility.

CNR is developing several plans, projects and pilots related to the energy transition. A key initiative is the development of two hydrogen production facilities. One electrolyser will be established on the quayside in the Port of Lyon, the second is going to be located in the south of Lyon for the local industry. For the latter, discussions with potential off takers are still ongoing. The hydrogen production facility on the quayside in the Port of Lyon is going to focus on mobility and logistics in the port. Currently, the feasibility study is ongoing and although the timeline of the project is uncertain, the expectations are that the facilities will be operational in 2025-2028. The reason to develop these facilities was to break through the "chicken-and-egg" situation in which producers are awaiting demand, while users are holding off if there is no supply.

The impact on the port infrastructure for the hydrogen facility is significant. CNR had to appoint dedicated land for the electrolysers, which could also have been commercially operated. In consultation with the state government, CNR had to secure sufficient space while meeting the safety requirements. For the electricity source, CNR initially thought of using electricity from the hydro dam but this was technically not feasible. Now CNR is using electricity directly from the local grid by using certificates of origin for green power. In order to make this connection, the grid has to be expanded and upgraded to feed the electrolyser. For the distribution of the hydrogen there will be a filling station on the quay for the first electrolyser, for the second one a pipeline to transport hydrogen from the production facility to local industry users seems the most logical choice. The filling stations on the quay need to be located away from the production facilities and also the vicinity of other fuels (LNG, diesel) should be avoided. For that reason a remote and separate station is needed.

The main challenges CNR has to deal with in developing the hydrogen facilities are:

- **Technical**: Developing a hydrogen project is a challenge as the technology is still new and in development.

- **Financial**: Hydrogen projects are not commercially viable as the prices are not competitive yet, leading to difficulties in finding funding. Applying for funding from the EU is also complicated as electrolysers are already seen as mature and EU funds are currently looking for larger scale production, rather than the 2MW production facility of CNR.
- **Requirements**: Current legislation for safely using and producing hydrogen makes it difficult and time-consuming to develop projects. For example, using hydrogen and combining it with fuelling stations for other fuels is currently prohibited.
- **Demand**: As inland transport is often carried out by individual shipowners, efforts are needed to create demand for hydrogen as a fuel. Ship owners lack the knowledge on hydrogen and are uncertain on what to invest in, and the costs of investing in new or retrofitted systems are also high. CNR is also negotiating to secure demand from the industry, which takes time.

Despite the fact that CNR had already quite some in-house capabilities related to energy and project development, in recent years it had to attract new skills related to new energy production. CNR has been able to find sufficient skills and talent in the region as it is a large and attractive player. Besides attracting new people, current employees are trained to improve their competencies in new energy domains.

In terms of lessons learned for other ports CNR has a couple of recommendations:

- **Collaboration**: Working together with other ports, industry players, shippers and other stakeholders is key to create buy-in, demand and the right solutions. CNR is for example exchanging information on the hydrogen project.
- **Promotion**: In order to make sure demand will be there CNR is very active in promoting the use of renewables and hydrogen. CNR is proactively leading studies, investing in joint developments and creating facilities for local stakeholders and promoting them to be used.
- **Flexibility**: The current focus on hydrogen is not a single bet, CNR is technically neutral towards the best (mix of) solutions and will try to adapt to the best solutions as the future is uncertain.
- **Long-term commitment**: It is important for organisations to have a long-term strategic commitment to energy transition targets and developments. Projects often take time and will sometimes conflict with commercial interests.

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