MAGPIE

SMART GREEN PORTS

STATUS REPORT ON SUSTAINABLE AND GHG-NEUTRAL INITIATIVES WITHIN EUROPEAN PORTS

BUILDING BLOCKS FOR THE CATEGORISATION OF PORTS

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Executive Summary

Decarbonisation and the energy transition are gaining importance in the port industry. Ports play an important role in reducing energy consumption and emissions, as they are key nodes in energy value chains and consume significant amounts of energy. Increasingly, ports are also involved in renewable power generation and are becoming active players in the production, storage, and distribution of low and zero carbon fuels. Many energy-transition studies, pilot projects and investments are taking place in ports in the EU and around the world. Among others, MAGPIE is one of the leading European Horizon projects on energy transition in ports.

MAGPIE project is an international collaborative project, demonstrating technical, operational, and procedural energy supply and digital solutions in a living lab environment. It seeks to stimulate green, smart, and integrated multimodal transport solutions and ensure roll-out thereof through the European Green Port of the Future Master Plan. The consortium, coordinated by the Port of Rotterdam, consists of 3 other ports (DeltaPort, Sines and HAROPA PORT), 9 research institutes and universities, 32 private companies, and 4 other organisations. The project is divided in 10 main Work Packages (WP), which include energy supply chains, digital tools, 10 demonstrators for maritime, inland water, road, and rail transport, non-technological innovations, and the development of a masterplan for European green ports.

Within the MAGPIE project, task 9.1 focuses on establishing the state of the art on sustainable and low carbon initiatives in European seaports and inland ports with a view towards a categorisation of ports based on their energy transition efforts and capabilities. This report is the deliverable of task 9.1 and was prepared on the basis of a detailed study of 15 sea and inland ports, primarily in the EU, which are considered pioneers in terms of energy transition and sustainability. The ports were studied through interviews and the collection and analysis of secondary data.

Although several inland ports were studied, it did not appear that inland ports have characteristics in relation to the energy transition that would require to treat them differently than seaports. Therefore, when referencing ports, both seaports and inland ports are meant. The findings of the report are applicable to both, but specific reference to inland ports will be made when necessary.

The main conclusion of the report is that, although many ports are discussing energy transition strategies, many of these discussions have yet to be translated into action because of technological and regulatory uncertainty, lack of user cases, and funding barriers among other issues. That is why projects, such as MAGPIE, can provide the right test base for facilitating the uptake of emerging technologies and defining pathways along which ports in Europe and globally can develop their energy transition strategies. This is true for both sea and inland ports. The energy transition, however, may be more challenging for inland ports not only because they face similar challenges as seaports, but also, because they tend to be, on average, smaller and face location-specific constraints.

From this study, it is found that there is lack of comprehensive approaches that can help port authorities understand the challenges and opportunities of energy transition. Moreover, the information on this topic is often fragmented, coated in promotional language and rife with technical jargon and complexity. To make sense of many of the complexity around the energy transition in ports, this report, and the research that led to it, highlight three central themes in the energy transition:

- Energy transition infrastructure and technologies.
- Seagoing ships and hinterland transport.
- Governance for energy transition.

Energy transition infrastructure and technologies

The current state of the art on energy transition systems, and energy transition technologies are reviewed. Particular attention is given to electricity and electrification. The focus is the technology readiness level (TRL) and infrastructure. The main conclusion is that renewable electricity is increasingly being used in ports for decarbonising processes and energy transition technologies, although promising, still require substantial testing, investment, and maturity before becoming wide-spread solutions. Among the energy carriers studied in pilot projects, hydrogen, e-fuels/power-to-X, and, to a lesser extent, biofuels such as biogas, and biomethanol seem to be most in the focus of ports. It resulted from the interviews that the amount of concrete tangible initiatives carried out in ports on alternative fuels are mostly limited to pilot projects. Energy transition infrastructure deals with the degree of infrastructure development aimed at supporting the energy transition, and primarily focuses on the commercial readiness level (CRL) of the infrastructure. The report argues that renewable power generation (through wind and solar energy), although promising especially in larger ports, is far from being able to provide sufficient power for port activities. Increasing power supply will be needed to meet onshore power supply (OPS) requirements. While the generation of renewable power for ports may be promising, some ports will be transit points for low- and zero-carbon fuels produced and consumed elsewhere.

Seagoing ships and hinterland transport

The readiness of ports on the production, storage, and distribution of low- and zero-carbon energy carriers such as hydrogen, ammonia, and biofuels, both for bunkering/refuelling and as tradable commodities are reviewed. Currently, low- and zero-carbon fuel bunkering and production in ports are at their infancy in the majority of ports. As demand for these products increases, so will import and export. Hinterland infrastructure, including pipelines and electricity transmission cables, will become then even more critical to this increasing logistics of low- and zero-carbon energy carriers. Port actors, and in particular the port authorities, can assist and in some cases accelerate the adoption of low- and zero carbon technologies in shipping and hinterland modes of transport through coordinated and targeted investments in collaboration with local and regional public actors as well as private enterprises, but are unlikely alone to be able to generate sufficient momentum for the transition beyond the port boundaries. Cooperation between port actors and hinterland transport service providers, local authorities and infrastructure providers is then critical for accelerating the transition outside the port boundaries. These efforts are very important to reduce emissions from inland transport modes and shipping and can be aided by a wide array of emerging and increasingly cheap smart technologies. Smart technologies will also support and accelerate the energy transition in ports.

Governance for energy transition

Critical to the energy transition will be identifying adequate governance models able to support the transition, reconcile priorities among internal and external stakeholders and leverage on the skills and competences of the various actors involved in the energy transition. The report found that various forms of governance have emerged in ports to advance the energy transition and respond to the needs of ports, their stakeholders and industry around the world. These governance structures have emerged either organically, finding their space of manoeuvre within policies and regulations often developed without sustainability in sight, or have been the result of top-down reform efforts. It remains clear, however, that there is an urgent need for clearer and more coherent models and governance framework that prioritise the energy transition in ports.

Table 1: Summary of categories that can be used to characterise ports in relation to the energy transition. The 30 attributes of ports in relation to the energy transition are grouped into six categories and three main themes (energy infrastructure & technologies, seagoing ships & hinterland transport, and governance). The attributes are all noted with a letter indicating the category. When categorising a port, an attribute from each category should be chosen.

Source: created for this report

THEME	CATEGORY	ATTRIBUTES
Energy infrastructure & technologies	Industrial and power generation activities (e)	• No industrial or power activities (e1) • Petrochemical dominated (e2) • Power generation dominated (e3) • Both petrochemical and power generation (e4)
	Energy self-sufficiency of a port (f)	• Import-reliant (f1) • Balanced utility-oriented (f2) • Balanced business-oriented (f3) • Export-driven (f4)
Seagoing ships & hinterland transport	Seaport / Inland port (p)	• Seaport (p1) • Inland port (p2)
	Hinterland transport (h)	• No connections (h0) • No impact (h1) • Limited alternatives (h2) • Minor transport hub (h3) • Major transport hub (h4)
	Dominant modality (m)	• Sea shipping (only for seaports) (m1) • Roads (m2) • Railways (m3) • Inland waterways (m4) • Electricity transmission cables (m5) • Pipelines (m6)
Governance	Governance (g)	• Supported customer-oriented (g1) • Supported external-stakeholders-oriented (g2) • Supported shareholder-oriented (g3) • Unsupported customer-oriented (g4) • Unsupported external-stakeholders-oriented (g5) • Unsupported shareholder-oriented (g6) • Conflictual customer-oriented (g7) • Conflictual external-stakeholders-oriented (g8) • Conflictual shareholder-oriented (g9)

Note: The energy transition strategy is related indirectly also to the digitalisation strategy, biodiversity and sustainability strategy, business strategy, port-city and external relations.

In order to develop categories along which to differentiate ports in relation to the energy transition, three main themes have been identified as critical. For these areas, three categories were developed in order to find common traits for ports. These common traits can be used to develop generalisable recommendations and an energy transition Masterplan as part of the MAGPIE project. These categories are listed in the Table 1 and discussed in Chapter 11.

For each of these themes, the categories that have been proposed can assist future work in developing energy transition pathways that can account for the great diversity of business and infrastructure focus, connectivity, and governance frameworks. These categories should include the commercial and infrastructural characteristics (e.g. in terms of intermodal connections) and will be used in further work on the elaboration of a masterplan in the rest of WP9 work. The masterplan will be developed in the last four years of the MAGPIE project and includes a vision for the energy transition for European ports and roadmaps (reports D9.2 and D9.3 respectively).

The report concludes advocating for increasing exchange of experiences through sharing information and collaborative approaches. The pathway to the energy transition will inevitably results in errors, uncertainty, and waste of resources, but only collectively societal costs can be minimised. These issues are dealt with in more detail in MAGPIE WP7 and WP10. The energy transition requires a fundamental rethinking of the port industry, and, with the climate and biodiversity crises increasingly affecting every aspect of business, the urgency of finding the shortest and most promising pathways to a low-carbon, renewable and sustainable future for ports could not be stronger.

1 Introduction

1.1 Introduction

This chapter introduces the report and describes how the climate crisis affects ports and is the basis for the urgent call for an energy transition. It also describes the objectives of the report within the MAGPIE project and the scope of the analysis. Moreover, this chapter also outlines the approach used, including data sources, and describes the overall structure of the document.

1.2 Ports and the energy transition: context

The Climate Crisis and the Ecological crisis have been featuring prominently in the agenda of ports around the World. In Europe, since the launch of the European Commission's Green Deal strategy in 2019, pressure on the transport sectors and ports has been increasing, as a low-carbon transition for transport is critical for the achievement of the European Green Deal main objectives and ports are instrumental to such transition. Transport accounts for 25% of the EU's greenhouse gas (GHG) emissions, and the Europe Union aims at reducing GHG emissions from transport by 90% by 2050.

In 2020, the European Commission presented its strategy for sustainable and smart mobility (European Commission, 2020). The strategy sets out various short-, medium- and long-term goals, which will have important implications for the transport and port sectors. The strategy entails a substantial decarbonisation of the sector, the replacement of fossil fuel ships and vehicles, with low-carbon ones, the development of a low-carbon infrastructure, the development of zero-carbon ports, an ambitious modal shift target to decarbonise freight transport and policies related to carbon pricing across all transport modes. These sustainability goals are coupled with a vision for smart and resilient transport, leveraging on the use of automation and innovative transport concepts and technologies, considering criteria that will strengthen the single market, a fair and just mobility and transport safety and security.

On July 14, 2021, the European Commission proposed a set of legislative instruments to secure the European Green Deal – the "Fit for 55" package (European Commission, 2021*a*). This sets out how Europe will reduce its net GHG emissions by at least 55% from 1990 levels by 2030. Among the various proposals included in the package several will have implications for the port sector.

The Commission will strengthen the demand for renewable and low-carbon fuels for deep-sea shipping by setting a cap on the GHG content of energy consumed by ships entering European ports and promoting zero-emission technologies at berths (where ships remain in port) using a technology-neutral approach. This will be coupled with the extension of the EU Emissions Trading Scheme (ETS) to include maritime transport, limiting maritime emissions as part of the overall ETS cap, and creating a carbon price signal to encourage GHG emissions reductions in a flexible and cost-effective manner and generate revenue to combat climate change and promote innovation.

On the energy supply side, the Commission is supporting the development of alternative fuels infrastructure by replacing the Alternative Fuels Infrastructure

Directive with a regulation (European Parliament and Council, 2021) that will include mandatory targets for onshore power supply (OPS) in maritime and inland ports that are part of the TEN-T core or comprehensive network. In addition, the Commission will support increasing the supply of renewable energy in the EU through the revision of the Renewable Energy Directive (RED), which raises the current EU target of at least 32% renewables in the overall energy mix to at least 40% by 2030, with a focus on sectors where progress has been slower, such as transport. This also requires the revision of the existing Energy Taxation Directive (ETD), which aims to bring the taxation of energy products in line with the EU's climate objectives and to abolish outdated exemptions such as those for intra-EU maritime transport and the development of a set of guidelines for green finance (EU Taxonomy).

This package of measures reflects the Commission's objective to reduce GHG emissions by addressing the various barriers to decarbonisation of the sector (technological barriers, economic barriers, etc.). The Commission is taking two complementary approaches: first, improving energy efficiency (i.e. using less fuel) and second, increasing the use of renewable and low-carbon fuels (i.e. using cleaner fuels). The objective is to simultaneously strengthen fuel demand, distribution, and supply.

Furthermore, in addition to ongoing support for global action through the International Maritime Organization (IMO), the Commission will continue to support research and innovation towards the decarbonisation of maritime transport, through the Horizon Europe programme and the Innovation Fund. The European Seaport Organisation (ESPO) in its recent environmental report (ESPO, 2022*a*), indicated how the port sector will need to prioritise climate change, air quality and energy efficiency, reiterating the importance that the port sector places on the energy transition. The report points out that, as more and more ports pursue efforts to mitigate climate change, they are playing an increasingly important role as hubs for energy and for the blue and circular economy. The ESPO Trends in Port Governance 2022 Report (ESPO, 2022*b*) notes that energy is increasingly part of the port business. Ports are key entry points for energy commodities, sites for energy production and act as enablers for the energy transition.

While port activities are accountable for a relatively minor share of GHG emissions, given their centrality in global transport chains and their role at the centre of large industrial and urban clusters, port indirectly account for a substantial share of global emissions (Merk, 2014) and they can play a major role in fostering the uptake of cleaner technologies and low-carbon energy sources (Alamoush at al., 2020). In addition, ports, already for decades, have been supporting the development of logistics concepts at sea and on land by acting as interfaces between ocean transportation, short-sea shipping, and hinterland transport (road, rail, inland waterways, electricity transmission cables, and pipeline) to reduce pollution and GHG emissions (Acciaro et al., 2014).

Although inland ports generally do not handle the same volumes as seaports, they are important intermodal hubs that are also ideally located for value-added logistics and industrial activities. Inland ports are critical for inland waterways and intermodal transport and can be instrumental in advancing the developments of low and zero-emission transport corridors (EFIP, 2020). The uptake of batteries and hydrogen seems particularly promising (Breuer et al., 2022). With regard to the energy transition, however, inland ports do not appear to have any characteristics that would require them to be managed in a significantly different way than seaports[1].

1.3 Project and Work Package objectives

In 2021, the MAGPIE consortium, led by the Port of Rotterdam, was awarded a €25 million Horizon 2020 grant until 2026, under the call H2020-LC-GD-2020 entitled "Building a low-carbon, climate resilient future: Research and innovation in support of the European Green Deal". The project leverages on the leading position of Port of Rotterdam and the other ports in the MAGPIE consortium, HAROPA PORT, Port of Sines and DeltaPort, to advance the understanding of the technologies and the role that ports will play in the low-carbon energy transition.

WP9 is the culmination of the project where all results come together in the Master plan for the green port of the future. Task 9.1 was the starting point in which an overview of the current state of the green transition in European ports is made. Based on input from MAGPIE fellow ports and other ports globally, an overview and categorisation are generated. This task concludes with report D9.1 (this report).

The main objective of this report (D9.1) is to determine, based on information collected on ports through secondary data and interviews, commonalities and a set of categories that can be used for the development of best practices and recommendations that will define energy transition pathways. These best practices and recommendations will contribute to the definition of a masterplan for the energy transition in ports that includes a vision for European ports and a roadmap. Task 9.1 is based on a review of the state of the art and the development of a categorisation, as a tool to investigate how the energy transition can be advanced, in the sense that the study is normative by definition.

In task 9.2, the vision for the future green European port is built. Demonstrators and other innovations in MAGPIE will be considered as main input to the bold vision to achieve zero emission transport by 2050. The bold vision will be written in report D9.2. Task 9.3 develops the roadmap from the starting point of task 9.1 to the vision given in report D9.2. This roadmap will consist of clear steps to be taken towards green ports where the timeline is given per decade setting steppingstones for 2030, 2040 and 2050. Since there is no one-size-fits-all solution, the MAGPIE project envisions that a structure is developed to fit the solutions to the different types of ports that exist. The roadmap will describe the solutions with the highest potential and its effects based on categorisation of ports from task 9.1 and their specific boundary conditions. The roadmap is published in report D9.3.

Finally, in task 9.4, a handbook is developed for ports, authorities, and other stakeholders to use in their greening ambition. Lessons learned from the demonstrators will help other stakeholders in their transition. A categorisation of the ports will be used for stakeholders to easily identify what will work in their port. The MAGPIE handbook shows how to become the future European green port with concrete guidance on planning, implementation, replication and scaling-up the deployment of the MAGPIE demonstrators. The handbook is published in report D9.4.

[1] In the following, we refer to ports to include both seaports and inland ports, unless otherwise noted.

The diagram in Figure 1 shows the set-up of WP 9 and the masterplan.

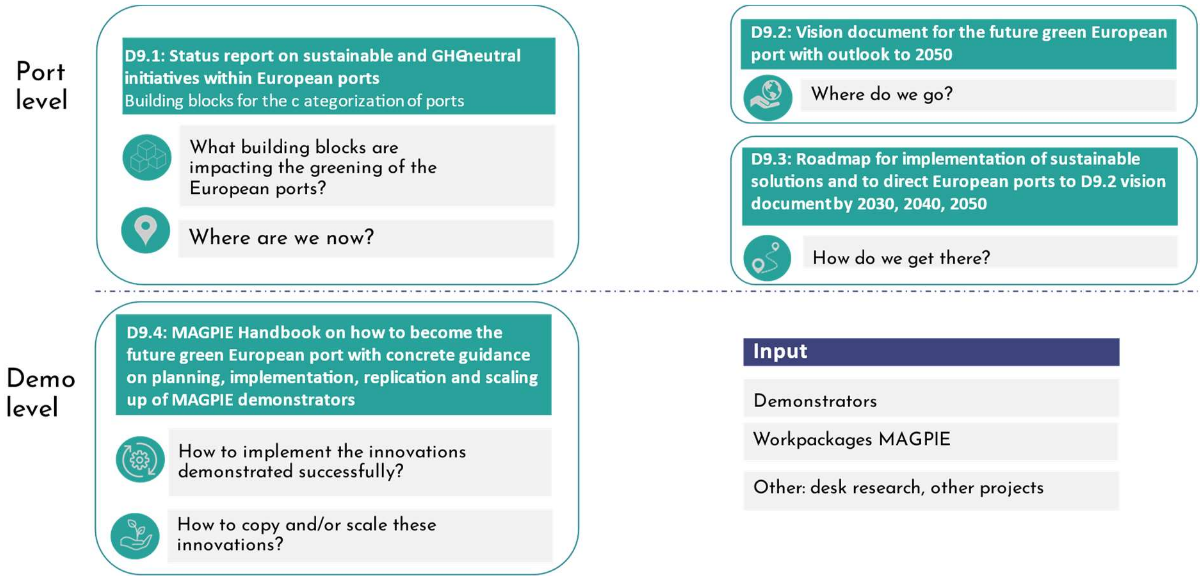


Figure 1: Content of the masterplan.

1.4 Report structure

The report includes 12 chapters, including this introduction. Chapter 2 describes the approach used in the task. Chapter 3 is dedicated to the overview of the throughput and environmental characteristics of ports. The following seven chapters deal with various aspects of the energy transition in ports, presenting the findings of the literature review, interviews with port representatives, and two workshops. They provide a summary of the information collected and represent the background on which further analyses can be built. Chapter 11 proposes a port typology for the energy transition where all information collected is used to created six categories that can be used to advance the energy transition in ports. Chapter 12 ends the report with conclusions. The structure is shown in Figure 2.

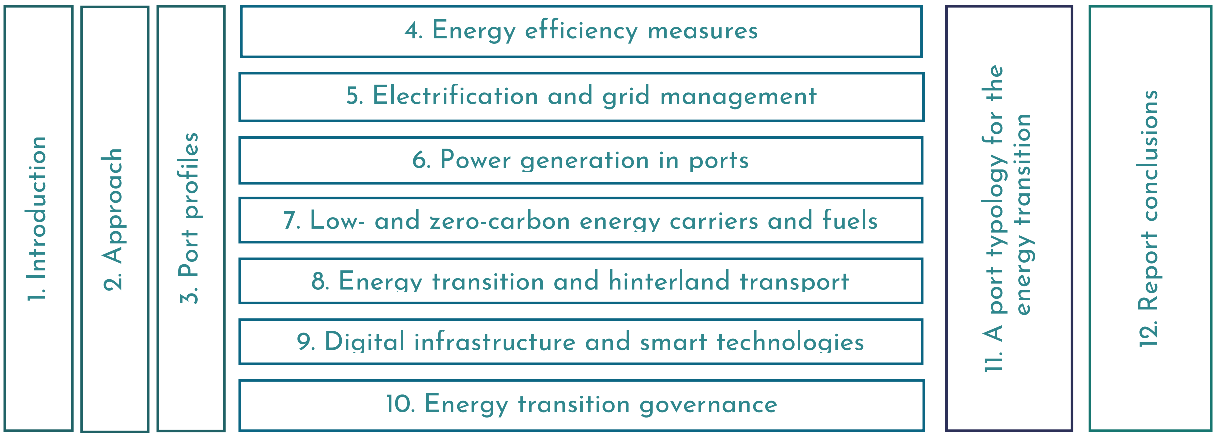


Figure 2: Report structure.

2 Approach

2.1 Introduction

In this chapter, the approach used in this task will be described. In the next section, an overview of the work carried out, including sources and report development, is presented. This is followed by a description of the process used to select and interview a sample of ports focused on the energy transition. The delimitations of the scope of the task is then discussed in Section 2.4.

2.2 Overview of the work carried out

The first step within WP9 was collecting information about the state of the art of low-carbon energy transition in European ports and around the world. This data collection was carried out by making use of secondary sources, such as port websites, academic publications, policy documents, industry report, two workshops, and through a set of interviews with port representatives. The result of the report is, in the end, to determine a list of categories or dimensions along which to develop, in the rest of the WP9 activities, recommendations for other ports to leverage on the experiences of the MAGPIE project. This categorisation was developed on the basis of the data collected and a validation workshop that involved MAGPIE consortium members and external experts.

This document was prepared in the period December 2021 to December 2022 and summarises the findings of desk research and the analysis of 15 global ports through 11 in-depth interviews and additional materials, as well as the result of two workshops, one carried out in Rotterdam, on October 26th, 2021, and a workshop carried out in Sines, Portugal on September 6th, 2022.

2.2.1 Sources

This report has been built on secondary data, and interviews carried out with port experts and executives. The interviews were based on criteria defined through the literature and the Rotterdam workshop with representatives of WP9, that provided in addition suggestions for good practices. The data collected includes:

- Academic publications,
- Industry reports/studies,
- Port authorities' annual reports,
- Industry magazines,
- Policy documents,
- Online materials.

In addition, reference has been made to the AIVP database of good practices (over 7,000 references) and the online World Ports Sustainability Program.

2.2.2 Report development

The report has been developed in three phases. In the first phase, on the basis of secondary data, a set of criteria and issues to be captured in the state-of-the-art review were collected. This information was discussed with partners during the WP9 workshop in Rotterdam. After the workshop, a set of guidelines for carrying out interviews where developed. In the second phase, these guidelines were used for interviews. About 20 port organisations were approached and we succeeded in interviewing 11. The ports interviewed and the criteria used for their selection are discussed in the next section. After data from the interviews was transcribed, a draft report was prepared that was discussed during the Sines validation workshop. The report development process is summarised in Figure 3.

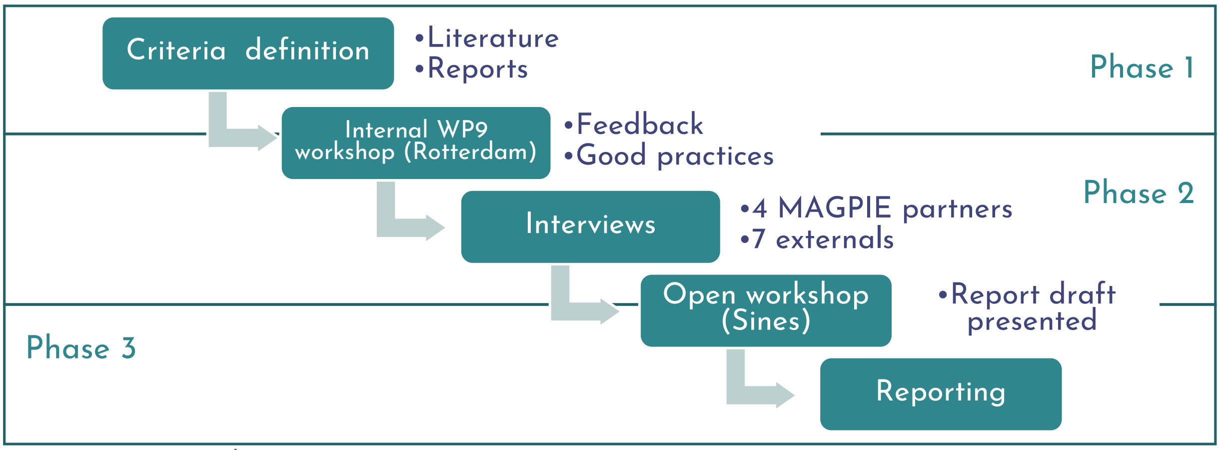


Figure 3: Project work overview.

2.3 Overview of the ports interviewed

Ports have been interviewed between April and August 2022. The selection of ports was based on best practices identified in the literature, feedback during the Rotterdam Workshop and willingness of port representatives to be interviewed. Next to the ports involved in the European MAGPIE and PIONEERS projects, seven other ports were interviewed. Several criteria were applied to choose these ports to be selected. The aim was to have input from both sea and inland ports of a certain size that are active in the energy transition. It was important for us that the ports already had existing actions to stimulate the energy transition or had ongoing projects to commence it, as that experience would provide insight to the different directions that ports could take in this transition. Another criteria was regional diversity and representation from as many continents as possible. Lastly, accessibility and willingness to cooperate were the key determining factors. With the help of the AIVP's network and Port of Rotterdam's connections, several ports were contacted and seven were willing to give an interview.

In most cases, interviews were recorded and, in a few cases, we relied on written answers provided by the port representatives. In addition, information collected in the context of the PIONEERS project as indicated in the report D2.1 "State of the art of the European Green Ports Master Plans" was used. The following is a list of the ports analysed in detail for meeting the objective of the task. 11 of them were interviewed directly.

Table 2: List of ports interviewed.

Port authority[2]	Ports included	MAGPIE/PIONEERS Role	Country	Direct interview
DeltaPort	Orsoy, Voerde, Wesel and Emmerich	MAGPIE partner	Germany	Yes
HAROPA PORT	Le Havre, Paris and Rouen	MAGPIE partner	France	Yes
Port of Antwerp-Bruges	Antwerp, Bruges, Ostend	PIONEERS Lighthouse port	Belgium	No
Port of Barcelona	Barcelona	PIONEERS partner	Spain	No
Port of Brisbane	Brisbane		Australia	Yes
Constantza Port	Constantza, Mangalia, Midia Zone	PIONEERS partner	Romania	No
Port of Duisburg			Germany	Yes
Port of Esbjerg			Denmark	Yes
Port of Hamburg			Germany	Yes
Port of Rotterdam		MAGPIE Lighthouse port	the Netherlands	Yes
Port of Vancouver			Canada	Yes
Port of Venlo		PIONEERS partner	The Netherlands	No
Ports of Los Angeles / Long Beach			USA	Yes
Port of Sines and the Algarve Authority	Sines, Faro, Portimão	MAGPIE partner	Portugal	Yes
Valenciaport	Valencia, Sagunto, and Gandía		Spain	Yes

The subdivision of ports in relation to inland activities is indicated in the table below.

Table 3: Subdivision between inland ports and seaports.

Interviewed ports	Inland port	Seaport
Interviewed directly	3 legal entities 7 ports	8 legal entities 12 ports
Written information	1 legal entity 1 port	4 legal entities 4 ports

[2] In the report the term "port authority" is used to indicate any organisation that is tasked with the management, planning and development, and in some cases the operations and regulation, or port area and infrastructure, independently of whether they are public or private organisations.

Although several inland ports were included in the sample, it did not appear that inland ports have characteristics that would require to treat them differently than seaports. That is why, in what follows, when referencing ports, we will mean both seaports and inland ports. Specific reference to inland ports will be made when necessary but the findings of the report are applicable to both.

An effort has been made to interview ports with different activities. At the onset of the work, a tentative subdivision was made following the one indicated in Table 4. In order to account for port diversity a categorisation of port activities developed by the port of Rotterdam was used.

2.4 Scope of the report

Table 4 summarises what is in scope in the masterplan and what is out of scope, although not all these issues will be addressed in report D9.1, as some are based on future developments instead or the current situation. The analysis has focused primarily on industrial and commercial ports. Within those ports, activities, such as terminals, and port industrial activities, such petrochemicals and steel manufacturing, have been considered as long as they directly impact the overall port energy transition. Although not excluded from the project, less attention has been paid to ports whose primary activities were fisheries and tourism, such as marinas, as this type of activities are generally located in smaller ports, and a literature review did not indicate a focus on energy transition, and when energy transition was dealt with, it was not in ways that differed substantially from commercial ports.

During the project, particular attention was paid to concrete plans such as technologies that are part of committed investment or strategic port development plans, we aimed at understanding why certain ideas have been selected in some ports and what is necessary for the uptake of these technologies. Novel transport modes such as drones and hyperloop (freight) do not seem to be at a mature enough stage to be relevant for task 9.1, therefore they are not discussed in the report.

Table 4: Scope definition.

	In scope	**Out of scope**
Existing transport modes	Modes that can be influenced by the ports: seagoing vessels (cargo + passengers), inland ships (cargo + passengers), trains (cargo), trucks, pipes/cables, work equipment (in port areas and only when affecting demand of other modalities in scope)	Public transport, air transport, passenger cars
Future transport modes	Drones, hyperloop (freight), modality x	
Types of fuels	All zero-emission, biobased and waste-based fuels used by the included modalities. Fossil fuels will be taken into account in efficiency improvement	Fossil fuels (as a supply chain)
Emissions	CO2 (scope 1,2,3) and noxious pollutant emissions (e.g. SOx, NOx, CH4, and particulates), as well as water pollution and noise	
Effect of climate change	Water level, temperature, new tourism patterns, extreme weather events, biodiversity	
Effects on employment	Employment in transport modes	Employment in other parts of supply chain
Governmental targets & policies	EU, IMO, European River Commissions and other relevant regulatory bodies (general), local and national (Rotterdam incl. fellow ports as case study)	National and local level (country specific analysis)

2.5 Conclusions

This chapter has described the approach used to collect and analyse information for this report, including the selection of the ports interviewed and the scope limitations of the work.

3 Port profiles

3.1 Introduction

One of the most challenging aspects of studying ports, is that they all differ in terms of business focus, throughput, infrastructure, location, and governance, among other aspects. Moreover, when approaching the energy transition, finding common characteristics of ports can be helpful in identifying if there are correlations between some port fundamental characteristics and measures adopted by port authorities to accelerate the decarbonisation.

Categorising ports on the basis of their throughput or managerial characteristics, is challenging as there is no consensus on how ports can be grouped together, and typically categorisations are instrumental of some specific aspects of the port or of the port authority that the analyst wants to emphasise. For example, the World Bank (2007) proposed four governance/ownership models to facilitate port reform. But while these models could be relevant for port reform, they do not capture the full complexity of port management options.

In the case of energy transition, no subdivision was found in the literature that appeared useful, and that is why a subdivision based on port throughput and main port functions was proposed at the beginning of the project on the basis of analysis carried out by the Port of Rotterdam Authority. As this subdivision did not include any reference to environmental performance, environmental awareness including climate change perceptions were further investigated during the project.

In this chapter, a typology of ports based on their throughput and main functions is introduced. Firstly, a subdivision of different types of ports is provided. This is followed by an overview of the European port system to understand the different types of ports that exist in Europe and therefore understand the roles that they play with regards to the energy transition. Finally, a discussion on the degree of environmental awareness in the ports studied is presented.

3.2 Port throughput profiles

3.2.1 Port functions and throughput

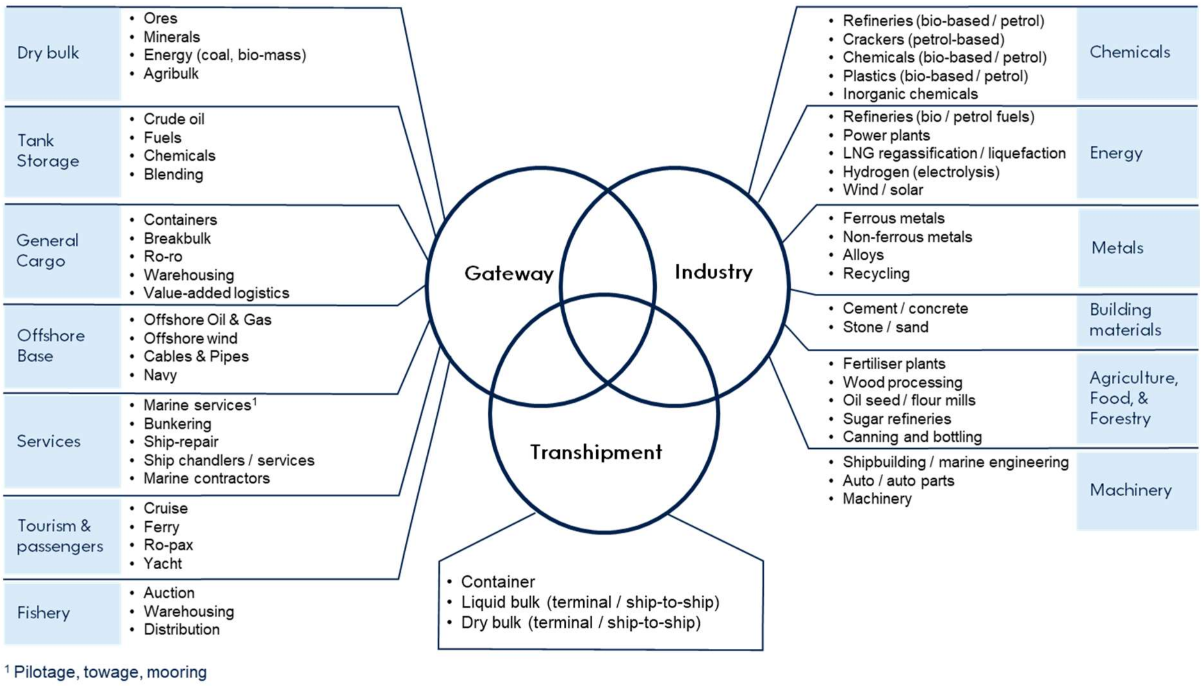
Ports vary enormously; from large industrial logistics complexes hosting thousands of companies and handling a wide variety of cargoes, to small ports with only a handful of users and a limited number of cargo types, not to mention different governance frameworks and business models. The commercial characteristics of the port also determine the physical characteristics of the port with some ports covering thousands of hectares and having large scale nautical infrastructure and hinterland connections to small ports consisting of perhaps a jetty or a handful of berths with limited storage area. Nevertheless, there are some common denominators on the basis of which ports can be compared, contrasted, and benchmarked.

Due to its international activities, Port of Rotterdam Authority has developed an approach for comparing different types of ports based on the functions that they play. All ports, regardless of size or geo-technical characteristics, play at least one of the following three functions: gateway, industrial or transshipment. This categorisation is similar to the ones presented in the literature (e.g. Sorgenfri, 2018:

p. 96-106) even if, at times, industrial ports, are described as single user ports, which is not the case in the definition that is used in what follows.

Each of the different logistics, industrial, and auxiliary activities typically found in a port can be linked to one of these three functions with 13 possible market segments as illustrated in Source: Port of Rotterdam.

Figure 4 below. Sometimes the different functions are deeply intertwined. Tank storage in a port for example, may be directly linked to chemical activities (e.g. refineries, chemical plants) or a container terminal may be handling a mix of gateway, industrial (e.g. chemicals produced in the port), and transshipment cargoes.



Source: Port of Rotterdam.

Figure 4: Categorisation of port activities.

3.2.2 Gateway

Gateway ports typically serve as logistics and transport nodes providing connectivity for their respective hinterlands. The main activities in these ports are therefore cargo un/loading, storage, and distribution with services (e.g. marine services, bunkering, etc.) playing critical auxiliary roles in supporting the above-mentioned logistics activities. Some gateway ports, especially those located in historical city centres, host tourist activities including cruise, yachts, and ferries for transporting passengers. They therefore also serve as gateways for visitors in and out of the "hinterland." Additionally, some gateway ports also host fishery activities including the un/loading of fish unto refrigerated warehousing or auction houses either for local consumption or for consumption elsewhere (including exports). In many places, including the Netherlands, fishery activities tend to be hosted in separate smaller scale ports specialised only in fishery activities as the infrastructure requirements, safety requirements, and business models of fishery ports tend to be different from those of larger "commercial trading" ports.

Gateway ports vary enormously in size, with the smallest gateway ports typically being a few dozen hectares and the largest gateway ports typically being no bigger than 2,000 hectares. Their geo-technical characteristics can vary enormously depending on their location. Some gateway ports are river ports deeply embedded in urban centres and therefore constrained not only by draught restrictions on the rivers but also by their urban surroundings. Other gateway ports are located along exposed coastlines at some distance from urban centres and require breakwaters. Gateway ports may face competition from other nearby ports with hinterland connections, nautical accessibility, and shipping connections often being key success factors.

3.2.3 Industrial

The second function is the industrial function whereby the port serves as an industrial zone where raw and/or semi-finished inputs are processed into (semi) finished outputs. This kind of port may either host stand-alone industrial facilities or highly specialised integrated clusters whereby neighbouring industrial facilities make use of each other's products, by-products, and waste as well as common infrastructure, utilities, and third-party logistics facilities (e.g. tank storage, and containers terminals).

Industrial ports, especially those hosting petrochemical and metal activities, tend to cover significant amounts of space as refineries, steel plants, and alumina smelters can easily require at least a few hundred hectares, not only for the processing facilities themselves, but also for storage and handling of feedstock. Industrial ports may also require significant water depth if feedstocks such as iron ore and crude oil are being brought in large bulk carriers and tankers, respectively. Buffer zones also contribute to the spatial dimensions of industrial ports as industrial activities can generate significant health and safety hazards requiring significant distance from residential or commercial areas.

The role of hinterland connections in industrial ports is somewhat more nuanced as it depends on the specifics of the industries in the port and whether the industrial port also has gateway activities. For some industrial ports, hinterland connections may not be so relevant as the majority of feedstocks as well as outputs may be going in and out by ship. Some industrial ports, however, may be linked to industrial facilities or industrial clusters in the hinterland by pipeline connections or may rely on rail or inland shipping connections to reach important markets or source feedstock inputs. In this case, ports can be seen as a mix of industrial and gateway.

Some industrial ports not only consume but also produce energy. They, for example, host not only refineries producing petrol or biofuels but also power plants which generate electricity. Energy-producing ports may play a role in bunkering and in providing electricity not only for the port itself but also for the electricity grids they are linked to.

3.2.4 Transshipment

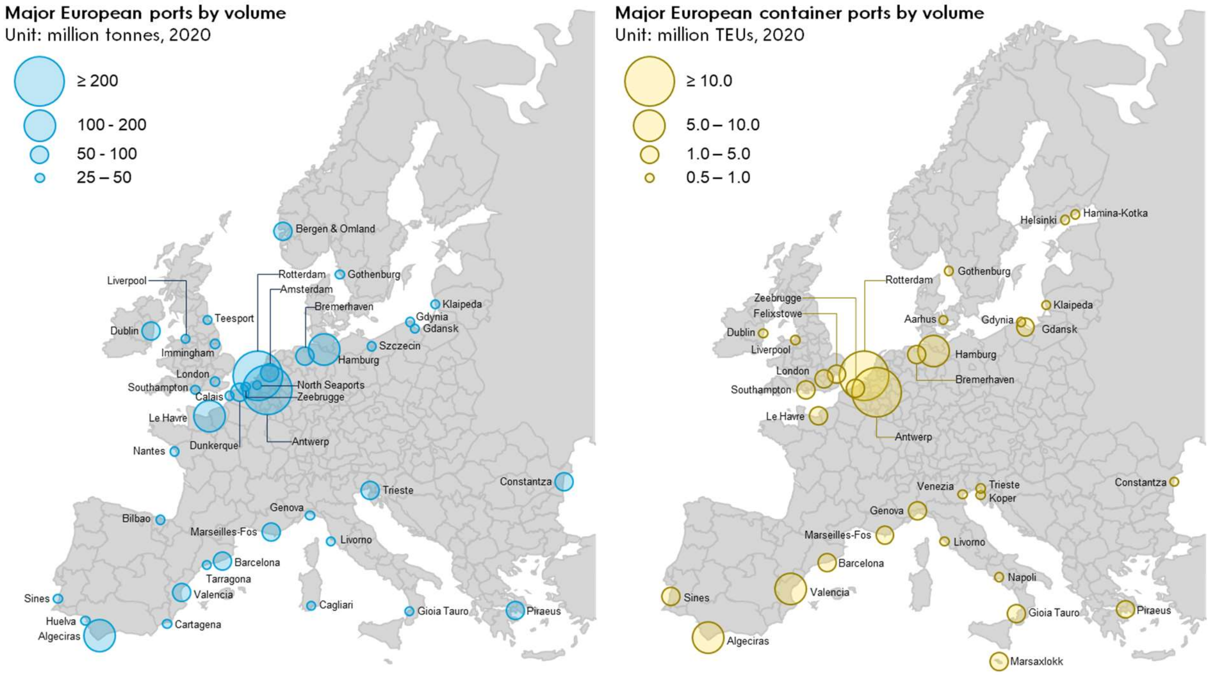
The third and final basic function is transshipment whereby the port serves as a hub, linking regional "spoke" shipping routes with major inter-continental shipping routes. In this function, the cargo does not go into the hinterland as the cargo is merely loaded from one vessel to another, either directly or by way of an onshore facility. Transshipment ports don't always have captive cargo and are sometimes vulnerable to changes in shipping alliances and competition from other nearby ports. Nautical accessibility, proximity to major shipping lanes, and the presence of a major multinational terminal operator and/or shipping line are critical factors for a transshipment port.

Pure transshipment hubs (i.e. ports mainly handling transshipment and in particular container transshipment volumes) range in size from around 100 ha up to somewhere around 1,000 ha depending largely on volumes. Due to their hub and spoke function, transshipment hubs need to be able to accommodate both very large vessels as well as smaller feeder vessels. Sheltered deep water is therefore a critical factor. Due to the types of cargoes and activities in these ports, they often closely resemble gateway ports with some transshipment hubs even located close to city centres.

3.2.5 The European port system

With the port typologies identified, this next section looks at the European port system to identify the most common types of ports. This next section of the analysis is based on first-hand data collected by Port of Rotterdam as well as its own analysis on the basis of secondary data (e.g. publicly available data, maps, etc.). A total of 139 European seaports[3] (Figure 5) were sampled and categorised based on the cargoes they handled, the activities in the ports (e.g. logistics and industrial activities), and the nature of their throughput (i.e. gateway, industrial, transshipment).

[3] Inland ports were excluded from the sample due to lack of data for categorisation.



Sources: Port authorities, Eurostat, ESPO, Port of Rotterdam Authority analysis.

Figure 5: Overview of the European seaport system.

Gateway ports are the most common type of port in Europe, with around half of European ports being gateway ports. Most of the remaining European ports (30%) are industrial gateway hubs. The remaining 20% of ports are a mix of industrial, industrial gateway hubs, and pure transshipment hubs. Industrial activities tend to cluster where they can take advantage of existing "gateway" port infrastructure hence why there are very few pure industrial ports in Europe. Europe also has few pure transshipment hubs and few industrial gateway hubs. Although gateway ports are the most common ports in Europe, around 30% of sampled European ports played more than one role with very few pure industrial or transshipment ports.

European gateway ports tend to range in size from 50 ha up to 2,000 ha with London, Trieste, Dublin, and Riga being examples of this type of port. On average these ports handled 20 million tonnes of cargo annually. The next common category – industrial gateways – tend to be around 500 ha in size and handle an average of 30 million tonnes with Marseilles-Fos, Tees & Hartlepool, Tarragona, and Constantza being examples thereof. Gateway hubs such as Valencia, Genova, and Piraeus which have a mix of gateway and transshipment volumes, tend to range from 200 up to 2,000 ha with an average throughput of 60 million tonnes. The largest European ports are industrial gateway hubs as Rotterdam, Antwerp-Bruges, and Sines[4] which combine all functions. These ports are typically at least 1,000 ha with an average volume of 200 million tonnes per year as illustrated in the table below[5].

[4] Sines Industrial Logistics Zone is also included
[5] Size and throughput refer only to seaports, as inland ports tend to have different sizes.

Table 5 summarises the categories and provides the usual size and average throughput. These, together with the throughput characteristics can be used for determining the port profile based on the combination of the main port functions (gateway, industrial and transshipment). In the last column of the table some examples of European and other global ports are provided. The categorisation refers to both inland and seaports. The ports interviewed in the project have also been included in the table (italics).

Table 5: General port categorisation.

Profile	General characteristics	Usual size (hectares)	Avg. throughput (million tons)	Examples of Global Ports
Industrial gateway hub	Mix of 3 functions and handling a variety of cargoes	1,000 and more	200	*Rotterdam, Antwerp-Bruges, Vancouver, Le Havre, Brisbane*
Industrial gateway	Mix of industrial and logistics activities and handling a variety of cargoes	500	30	Marseille-Fos, Tees & Hartlepool, *Sines, Los Angeles-Long Beach*
Gateway hub	Logistics-focused port with at least 25% of volumes being transshipment	200-2,000	60	*Valencia,* Genoa, Barcelona, *Hamburg,* Busan
Gateway	Logistics-focused port with less than 25% of volumes being transshipment	50-2,000	20	Trieste, London, *DeltaPort, Constanta, Duisburg,* Venlo
Transshipment hub	Logistics-focused port with more than 50% of volumes being transshipment	100-700	60	Marsaxlokk, Gioia Tauro, Tanjung Pelepas, Salalah
Industrial	Ports services as a stand-alone industrial facility or as an integrated cluster	500 and more	10	Sköldvik, Terneuzen, *Esbjerg*

Source: Port of Rotterdam.

3.3 Awareness of environmental issues in the port

3.3.1 Environmental sustainability in ports

In the context of the management of port activities, there is consensus on the importance to consider environmental concerns (e.g. Puig et al. 2015). To comply with sustainable development regulations, policies, and guidelines, environmental sustainability is an integral part of sustainable business strategies and operations in the port sector (Kim & Chiang, 2017). In the past, emphasis was placed on the environmental impacts of port activities such as dredging, the disposal of materials, and the loading and unloading of cargo. Research on port sustainability has focused on these daily activities in order to improve port performance in terms of environmental sustainability, but also to assess how environmental sustainability contributes to port competitiveness (Acciaro, 2015). More recently, more attention has been paid to port external environmental impacts, including, for example, the processing of ship waste, reducing exhaust emissions, generating renewable energy, promoting energy efficiency, and reducing noise, waste, and other pollution-causing substances (e.g. Di Vaio et al., 2018).

So far, a categorisation of ports in relation to their environmental sustainability efforts has not been proposed in the literature, although various attempts have been made to make sense of the fast developments in this area[6]. Such categorisation would not be useful for differentiating ports in terms of the energy transition, as the ports more likely to engage in energy transition are also those that are more likely to have a strong awareness of climate change and of the environmental impacts of the port. It should be noted, however, that some ports were identified (e.g. Port of Brisbane, Port of Los Angeles/Long Beach) that had a strong environmental awareness and had a variety of polices aimed at decarbonising port activities, but did not significantly prioritise energy transition.

3.3.2 Climate change

Seaports are particularly vulnerable to climate change due to their geographic location and exposure to extreme weather events (Becker et al., 2013). As such, many ports are looking at how they can be better prepared to adapt to the changing climate and mitigate its impacts on their operations. To do so, seaports need to assess their risk exposure and develop strategies to reduce the impacts of climate change. This includes developing plans to address sea level rise, increased storm intensity, and other climate impacts (Izaguirre et al., 2021). Additionally, they also need to invest in infrastructure and technology to help them better monitor and respond to climate events. Furthermore, climate change calls for collaboration with stakeholders to ensure that the region has the resources and capacity to adapt to climate change and mitigate its impacts (Becker et al., 2018).

All interviewed ports are clearly aware of the implications of climate change on their infrastructure and business with a handful of them having carried out detailed climate change impact studies and developed port resilience plans. Several ports (e.g. Port of Brisbane, Port of Rotterdam) carried out climate risk assessment studies. The most-commonly reported climate change impacts are flooding of port infrastructure, storms, heatwaves, and draughts, with important impacts for inland ports and

[6] See for example: Lim et al. (2019) or Ashrafi et al. (2019).

potential changes in port business activities. For example, for the Port of Sines climate change issues that are monitored are water level, temperature, new tourism patterns, extreme weather events. Port of Vancouver was, for example, hit by fluctuations in grain production, one of the main cargoes handled in the port, as a result of climate change.

In the Port of Rotterdam, the main concern is water levels in order to prevent floods. These measures are considered for infrastructure development. Changes in ground water are also mentioned as a potential consequence of climate change. Furthermore, water depth in the Rhine is a potential issue, given the importance of river barge traffics for the port and the potential of causing congestion if barges need to sail with lower amounts of cargo in order to sail safely, when water levels in the Rhine are lower. Storms are a concern as they disrupt ship traffic and delay berthing operations.

In order to anticipate the risk of possible floodings due to climate change, the prefecture of Normandy has been drafting a resilience plan, that will define criteria for building new warehouses and industrial infrastructure in HAROPA PORT. The plan affects only a small area in the port. Exceptional floods (one in a century events) would also affect wider areas and impact also Paris. Extreme weather conditions are also a concern, especially in relation to high-speed wind (above 175 km/h), which are becoming more common.

Inland ports are obviously heavily affected by water scarcity but are also impacted by disruptions in the seaports as a result, for example, of storms. DeltaPort explains how port delays have sizeable financial impacts, as they imply the need to make more space available for cargo. Furthermore, while port areas might not be directly affected by flooding, often the warehouse areas and the logistics areas in the proximity of the port are (e.g. DeltaPort).

3.3.3 Pollution and GHG measurements in the port

Environmental performance has been increasing in importance in recent years and it is not possible to review here all efforts that are being carried out in reducing pollution and GHG in ports (Lim et al., 2019), so the following discussion focuses on port environmental monitoring, specifically in the ports analysed in the study.

Almost all seaports carry out some forms of environmental monitoring (Barberi et al., 2021). The focus, frequency and detail of the monitoring however differs among ports, with most ports prioritising air and water pollution, congestion, biodiversity loss and noise. Pollutants such as NOx are monitored regularly. For example, in the case of HAROPA PORT some sensors exist in the port primarily for soot and NOx. Other pollutants are also monitored. For example, Port of Sines monitors PM_{10}, $PM_{2.5}$, CO, NO_2, NO, SO_2, Ozone, Benzene, Toluene, and other pollutants.

Port of Rotterdam is piloting a noise measurement (from marine vessels) that is carried out for above water noise. HAROPA PORT is starting to make some experimentation in Paris as noise has been an issue in the city. In the Le Havre region noise has not been a topic for the moment. But in the coming years, HAROPA PORT plans to have a common framework for water quality, CO_2 emission, and the noise in all its ports. In Port of Sines, noise is not monitored regularly.

In HAROPA PORT, water quality is regularly measured in Paris and in Le Havre. In Port of Sines, water quality is monitored in specific areas (e.g. Vasco da Gama Beach), where the presence of oils and fats residues and total hydrocarbons are measured at regular intervals. Bacteria contamination and other metrics for water quality are also evaluated.

Monitoring is carried out either directly by the port authority, through companies hired by the port authority to carry out such tasks, or by other local or national authorities. In the Netherlands, for example, monitoring emissions from industrial installations is compulsory, and these emissions are reported in a national database. Monitoring of environmental impacts in the Port of Rotterdam is entrusted to different entities.

With many source points throughout the port jurisdiction for pollutants and other contaminants to enter local waters, Vancouver Fraser Port Authority focuses mitigation measures on ongoing monitoring and management of water quality. They do this by, for example, limiting stormwater pollution and spills, reviewing proposed development and construction projects to assess potential impacts on water quality, applying permit conditions to mitigate impacts, and conducting desktop compliance reviews and site visits during construction activities. They are also working on developing steps towards banning open loop scrubbers discharge at Port of Vancouver.

Often monitoring is ad hoc and for a limited time. In some circumstances, most notably green-house gas emissions, monitoring and reporting is done on the basis of estimations based on number of ship visits. The Port of Rotterdam for example uses a model that calculates emissions based on vessel movements. In the case of HAROPA PORT accurate monitoring is starting in Le Havre and data is being integrated with national databases (Atmo network) for Paris and other locations aiming at monitoring GHG emissions and pollutants.

For inland ports the situation is a bit different. DeltaPort, for example, does not directly carry out any environmental monitoring, primarily as the port is located at a distance from urbanised areas.

The extent and focus on environmental monitoring vary extensively among ports, depending on the specific nature and coastal conditions. For example, Port of Brisbane undertake seagrass, saltmarsh, and mangrove monitoring around the port and controlled sites annually. The port also monitors the hard substrate habitat, such as coral and algae growth (every three years), marine sediment (annually), and water quality during land reclamation projects and dredging in real time. They monitor shorebirds monthly. Marine sediment, physical characteristics of seabed are monitored every five years around the port. All monitoring results are publicly available on the port website.

3.3.4 Energy transition and biodiversity

Biodiversity plays a critical role in port and coastal areas. In order to protect the harbour, or because of the port natural geographical position, ports often have areas of salt marshes, wetlands, dune fields, or other important intertidal or marine ecosystems that are locally, regionally, or even nationally important. Given that many ports are situated in riverine estuaries, delicate ecosystems coexist with urban and industrial activities. The many activities that revolve around ports, while stimulating economic and social development, involve some potential environmental risks and pressures on the surrounding natural ecosystems (water, air, land, animals, and plants) and human health (Borja et al., 2000). For example, cargo handling of dry and liquid bulk (e.g. oil-related products, chemicals, coal), hazardous materials (e.g. ammonia, waste products) and waste (e.g. sludges), can result in spills into water bodies (Valdor et al., 2020), that can alter seabed, increase organic loads and turbidity.

In the case of biodiversity, Port of Rotterdam has carried out several projects aimed at assessing the conditions of the fauna and flora in proximity of the port, including in the water. One of the main issues is salinity upstream the river and this is monitored very carefully as changes in water salinity could be the result of infrastructural development downstream in the port. Also, the condition of marine and riverine fauna in the port areas is monitored to assess the impact of industrial installation that, for example, could change water temperature. Vancouver Fraser Port Authority leads the Enhancing Cetacean Habitat and Observation (ECHO) Program focusing on understanding and reducing the cumulative effects of shipping on whales throughout the southern coast of British Columbia. The program focuses on underwater noise, in line with the efforts of the Canadian government that in August 2022 provided $3.1 million for 22 projects to help reduce the impact of underwater vessel noise[7].

While no specific approaches to biodiversity have been proposed in relation to the energy transition, they can be based on general recommendations for biodiversity (e.g. Ferrario et al., 2022) that advocate multidisciplinary approaches to tackle biodiversity loss, transparency in decision making, inclusivity of local communities and non-governmental agencies, and a participatory modelling, where stakeholders can collectively find solutions for biodiversity preservation.

3.3.5 Energy transition and the circular economy

In the circular economy, resources used in production processes are recirculated back into the economy, allowing for greater efficiency and less waste. Ports are key nodes in the circular economy due to their role in the transportation of goods, resources, and energy. In order to support a circular economy and reduce the amount of waste generated by society, seaports must take an active role in the reduction and reuse of materials. Ports, as transportation hubs for goods, are uniquely positioned to serve as centres for the collection, reuse, and recycling of materials.

The circular economy is becoming increasingly important in ports. The LOOP-Port project, an EU-funded project aiming to facilitate the transition to a more circular economy in the port sector with a network of about 40 ports, defines it as enabling the production of goods and services by reducing the consumption and waste of raw materials, water and energy sources. The circular economy is a more sustainable alternative to the linear economic model based on extraction, production, consumption and disposal[8]. The transition towards a circular economy has two main components that can be related to the energy transition. The first is the transition to an economy based on renewable energy (including fuels and electricity) and other

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[7] See also Transport Canada's Quiet Vessel Initiative.
[8] LOOP-Ports project, https://www.loop-ports.eu/

reusable resources, and the second is the transition to the use and reuse of resources that can be renewed as materials for products (de Langen & Sornn-Friese, 2019).

Renewable energy has been discussed elsewhere in this report. What might be worth noting in this section is that circularity allows for the reuse of resources for power generation, the production of energy carriers, and for the provision of transport services. There are many example projects at different stages of maturity such as the use of biomass (i.e. non-recyclable wood) by Bio-Energy Netherlands to produces syngas and the conversion of plastic into fuels by the firm Bin2Barrel (Port of Amsterdam), the conversion of steam into electricity in the Ecluse project in the Port of Antwerp (Haezendonck & Van den Berghe, 2020), the Advanced Methanol project of GIDARA Energy in the Port of Rotterdam and Port of Amsterdam, where non-recyclable waste is converted into biofuels, the project VASCO at Port of Marseille that uses industrial gases to cultivate microalgae to use as biofuels, and waste to energy processes such as in the Port of Moerdijk (de Langen & Sornn-Friese, 2019). Ports are ideally located because of their logistics centrality and their industrial activities for developing the circular economy and many of these applications can be connected to the energy transition.

3.4 Conclusions

In this chapter a categorisation of ports on the basis of their traffic and commercial functions has been described. The categorisation is built on well-known definitions used in practice and in the academic literature[9]. In order to provide a more granular differentiation among the ports, the three main functions have been combined into six typologies. This was the basis used for observing how port traffic and commercial functions are linked to the energy transition.

In the course of the project, five industrial gateway hubs, two industrial gateways, three gateway hubs, four gateways and one industrial port were looked at more closely. The selected ports were chosen for their known leadership and active role in the energy transition, and it was found that a port's commercial profile does not influence how the energy transition is prioritized (see also Chapters 4, 5, 6 and 7).

During the analysis it appeared that industrial ports, industrial gateway, and industrial gateway hub ports were those where the energy transition entailed a more fundamental industry transformation. However, even in larger ports, this industry transformation is still at an initial stage, given the large investments needed for transitioning industrial activities.

Gateway ports and gateway hubs prioritise interaction with ships and hinterland transport modes in terms of energy transition. It was not possible to identify whether there were differences in renewable power generation, and in the production of low- and zero carbon fuels. So, what follows refers to both industrial, gateway ports, and their combinations. Specific references will be made when necessary.

Transshipment hubs, as primarily shipping-focused, could play a role in promoting the use of new bunker fuels. In addition, the energy transition could potentially provide an opportunity to diversify the commercial profile of these ports. However,

[9] See for a more extensive discussion on port functions, for example, Talley (2018) and Sorgenfri (2018).

they are not included in our analysis because the energy transition does not appear so far to have been prioritized at these ports.

In terms of environmental performance and awareness, the topic has become so relevant that virtually all ports engage in some forms of environmental performance, and all those that are actively engaged in the energy transition show both awareness of climate change impacts on port infrastructure and operations as well as of the environmental external effects of port activities. It has not been possible, hence, to develop a categorisation of ports based on environmental awareness, environmental monitoring, or exposure to climate change. The environmental performance of ports is also often linked to the circular economy, and many ports are investigating how to make the energy transition more circular.

4 Energy efficiency measures

4.1 Introduction

Efficiency and fuel efficiency have always been important for ports, whether for competitiveness, environmental or cost reduction reasons. However, over the past years, a new focus on efficiency aimed at reducing GHG emissions and supporting the energy transition has emerged. The port business has made reducing the effects of climate change a top priority.

The availability of sustainable technologies has increased significantly in ports and maritime logistics chains in recent years, but greater energy efficiency can be achieved, not only through technological means, but also through operational and organisational measures. Operational and organisational measures include, for example, virtual arrivals, optimization algorithms for lower energy consumption, software for traffic and congestion management, waste reduction in material handling and storage, improvement of data management or reduction of peak loads. The application of these measures is typically driven by a desire to improve operations, reduce costs, and achieve greater efficiency, but often results in greater energy efficiency and lower emissions.

In what follows, we present the information collected on the energy efficiency, organisational and operational measures, that are available in ports or that are likely to be adopted in ports in the coming year. Given the scope of the project, only measures related to energy within port activities, bunkering and refuelling operations, low-and zero-carbon fuel and energy carrier productions will be analysed. When appropriate, reference will be made to following chapters where these measures are discussed further. For example, this chapter will not focus on intermodality, because this concept and its advantages in terms of energy efficiency are discussed in Chapter 8. In addition, the focus of this chapter is primarily on approaches and technologies, that are novel, rather than on those concepts and measures that have already been extensively applied in ports, although occasionally, reference will be made to well-known measures whose benefits have been well documented.

The rest of the chapter provides and overview of energy efficiency measures in ports. These are discussed in general terms in Section 4.2. Section 4.3 will focus on those measures that are not discussed elsewhere in the report, while Section 4.4, will deal with barriers, although this is analysed more in detail in WP7 of the MAGPIE project.

4.2 Overview of energy efficiency measures

Energy efficiency in ports is defined as the ability to reduce the consumption of energy in port operations and activities, while still maintaining the same level of output. It is the responsibility of port organisations to ensure that energy efficiency measures are implemented to reduce emissions and improve the overall efficiency of the port. This can involve optimising the management of energy resources, such as electricity and fuel, as well as improving the efficiency of port operations. Additionally, port actors can implement measures such as retrofitting port infrastructure with energy efficient equipment, using renewable energy sources, and implementing energy monitoring systems. By using these measures, port actors can ensure that energy efficiency is maintained in order to reduce emissions and improve their overall efficiency.

The Figure 6 below summarises schematically the activities and actors in the port that can engage in improving energy efficiency. In the centre of the diagram is the port authority, that in addition to increasing energy efficiency in its own premises (e.g. offices and wortkers), has the possibility of providing incentives to port tenants and service providers, facilitate the development of low-energy infrastructure and increase efficiency of the operations for which it is in some cases responsible (e.g. marine services and cargo operations). The port authority has legal responsibility for the perimeter of the port, but it is increasingly called to coordinate energy efficiency also for port areas (some of which might not legally fall under the port authority mandate) in the port city or the port industrial cluster. Within the port areas, energy efficiency might be entrusted with port tenants (e.g. terminal operators) or maritime service port service providers (e.g. pilot organsiations or tug operators).

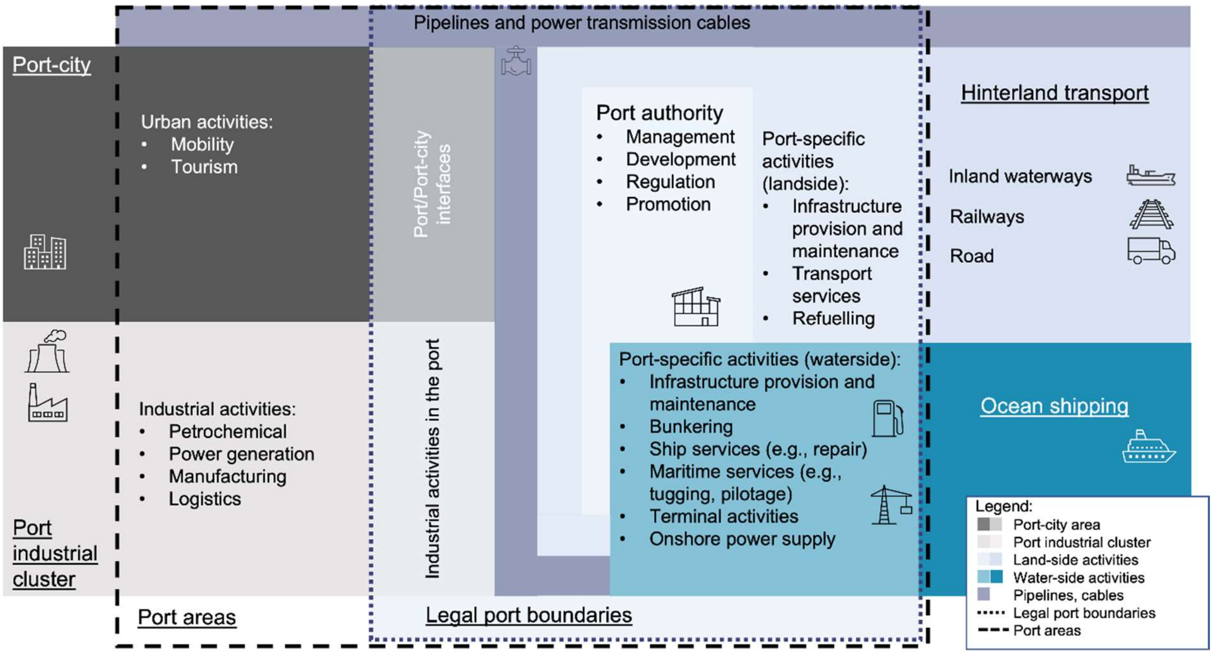

Figure 6: Port activities and boundaries.

Port authorities are also involved in facilitating energy efficiency within port industrial clusters and port-cities, although generally, the main responsibility for energy efficiency falls with energy users, such as private firms, municipalities, or citizens. Particularly relevant is the role of port authorities in incentivising energy efficiency in hinterland transport and marine shipping. While time spent in ports represent only a small fraction of the total time for most transport operations, as ports are important hubs, they can influence energy efficiency. The main users of energy are transport service providers and, indirectly, cargo owners and passengers. Port authorities can incentivise energy efficiency through intermodality and modal shift (among other practices), that will be discussed more in detail in Chapter 8.

When it comes to inland, short-sea and deep-sea shipping, the role of port authorities and, to some extent, other port service providers (such as bunkering and marine service providers), can be important in facilitating the uptake of energy efficiency measures, by reducing waiting times, providing technological interfaces for the uptake of low energy technologies, and allowing access to electricity for OPS or low-carbon fuels. While some of these technology-driven measures are discussed later in the report (e.g. Chapter 5 and Chapter 7), in this section an overview of efficiency measures is provided.

Energy efficiency entails some form of energy management, i.e. the process of improving the efficiency of port operations by reducing energy consumption, rationalising energy flows and minimising energy waste. It involves the organisation, management and implementation of specific measures and activities to reduce the energy consumption of port operations. This can include the use of renewable energy sources, improved energy storage and distribution systems, as well as the use of more efficient equipment and machinery. A comprehensive energy management system ensures that all energy-related activities are monitored and managed in an efficient and effective manner. This system should also provide guidance on the implementation of energy efficiency measures and activities, and should be regularly reviewed and updated to ensure that the port remains energy efficient (Iris & Lam, 2021).

Energy efficiency measures can be applied to all port processes, and different taxonomies of energy efficiency measures for port decarbonisation have been proposed (Iris & Lam, 2019). For example, Iris and Lam (2019), distinguish among operational strategies, technologies and energy management systems. Instead Alzaharani et al. (2021) distinguish among efforts related to carbon reduction, renewable energy adoption, cost optimisation, adoption of smart control technologies for electricity, regulatory measures, smart green ports.

On the basis of these categorisations and the information collected during the project, energy efficiency measures can then be subdivided in operational and organisational measures, and technology-driven measures. As some of these are discussed later in the report, an overview is provided below, indicating in parentheses where in the report they are discussed:

- Operational and organisational measures.
    - Organisational measures (Section 4.3 below)
    - Operational measures (Section 4.3)
    - Incentives and regulation (Chapter 10)
    - Measures related to hinterland transport (Chapter 8)
    - Measures related to shipping (Chapter 7 and Chapter 10)
    - Digital technologies (Chapter 9)
- Energy efficiency technologies and infrastructure:
    - Electrification and electricity management (Chapter 5)
    - Power generation and renewables (Chapter 6)
    - Production and use of low- and zero carbon energy carriers (Chapter 7)

From the review of the literature and the data collected through the project, it did not appear that the throughput profile of a port can be directly linked to any specific energy efficiency measure.

4.3 Operational and organisational measures

One of the first steps when port authorities approach energy transition is to identify techniques to improve energy efficiency in port operations. Energy efficiency is the result of a reduction of energy inputs maintaining similar levels of output. In the case of ports energy, inputs are either fuels (primarily diesel) or the use of electricity. The following port operations have been shown to be able to benefit from energy efficiency improvements:

- Shipping operations within the port and at berth[10] (discussed in Chapter 7)
- Loading and unloading operations
- Movement of cargo within terminals and between terminals (e.g. yard management systems, interterminal cargo movements)
- Maritime services (e.g. pilotage, mooring, towing)
- Buildings, warehouses, other covered areas (e.g. heating, lighting)
- Cargo related energy use (e.g. refrigeration, reefer containers)
- Hinterland transport operations (mainly modal shift and intermodality)[11] (discussed in Chapter 8)
- Movement of port workers and other employees
- Energy efficiency related to port industrial activities (e.g. refineries, steel plants)
- Energy efficiency related to activities shared between the port and neighbouring port-cities (e.g. road lighting, traffic management, bridges, and locks)

The efficiency of port operations is positively correlated with port energy efficiency. The increased operational efficiency resulting from better resource utilisation (such as equipment, berths) would lead to a reduction in energy consumption, which in turn results in higher energy efficiency, independently of whether the energy is originating from electricity or fuel. There is a long tradition of studying operational efficiency in ports, terminals, and hinterland operations, for example yard optimisation (e.g. Covic, 2019), layout optimisation (e.g. Irawan et al., 2017), loading and unloading optimisation (e.g. Dahal et al., 2007), tugboat optimisation (e.g. Zhong et al., 2022), port hinterland transport (e.g. Behdani et al., 2020), so this will not be reviewed here.

Energy efficiency can be achieved though the inclusion of energy considerations in operations management decision that can result in improved port operations, reduced energy costs, and higher efficiency (Damman & Steen, 2021). In some cases, the implementation of new technologies can result in more energy efficient operations, but energy efficiency is not always the main driver of the technological choice. Examples include dock-side berthing automation, cargo-handling automation at port, improved gate systems through face, fingerprint, hand, or document recognition software.

Electrification has gained momentum in port operations in recent years and there is evidence that electrifying port equipment and operations, as well as port industry, reduces emissions and results in positive macroeconomic effects (Schenk et al., 2020).

[10] Port authorities can, at least in theory, provide incentives and issue regulation that also impact shipping operations outside the port, but as the primary focus of the port authority (and of the project) are port areas, the focus here is restricted to shipping operations at port (manouvering, hotelling, etc) and at berth.

[11] While in general emission from hinterland transport are not attributed to the port, given their importance, the project aims at incentivising and facilitating the uptake of energy efficiency technologies in hinterland transport also beyond the port boundaries.

Emission reductions depend on how power is generated in the grid, although, in general, power generation through the grid is more efficient than via diesel engines, even if it originates from fossil fuels. This holds true both for equipment modalities as well as for onshore power supply (see Chapter 5).

Energy efficiency can also result from better management of vehicle movements within port areas, often facilitated by the uptake of new devices. For example, regenerative breaking allows electric vehicles to partially charge their batteries when in operation, and visual recognition technologies can reduce congestion and loading and unloading times. Improving the energy use in building and storage areas, though improving heating, insultation, and lighting can also contribute to energy efficiency in ports. For example, compared to conventional lights, LED lights can reduce energy consumption in port access areas, buildings and storage facilities (Szaruga et al., 2021).

In some cases, energy efficiency cannot be obtained by optimising a single process or adopting a specific technology, as multiple actors and process interfaces are involved, for example, in case of the improvements of intermodal operations, and the planning of cargo efficient flows through terminals. In these cases, energy efficiency requires collaboration and coordination among the actors involved. Port authorities can help coordination among port users, governmental agencies, and port tenants, support the development of information exchange tools (e.g. sensors, internet of things applications), and promote collaboration. This coordination role can be extended to prioritise energy management across port activities and terminals (Acciaro et al., 2014).

Energy management systems control energy usage and optimise the performance of equipment or machines used in port operations. Recently, port operators have begun to use energy management systems to increase energy efficiency at ports, saving large amounts of money and emissions in the process (Roy et al., 2020). A typical example of these system are microgrids (see Chapter 6). These systems have been successfully deployed in terminals (e.g. Port of Singapore), but are more difficult to apply port wide. Different port activities have different requirements and features, so energy management systems must be customised for each location.

Energy management systems can be embedded in technology management systems that ensure that equipment used in the port is managed efficiently, while guaranteeing availability and reliability. Smart grids are an example of a technology that uses a combination of technical (e.g. the smart chargers on electric vehicles) and operational solutions (e.g. peak-load reduction)(Iris & Lam, 2019; 2021) and are discussed more in detail in Chapter 6 and Chapter 9. Technology management systems are often closely coupled with operations and may require the involvement of various actors when applied in ports. For example, in the applications of internet of things in ports, road, bridge and lock administrators need to work together with vessel traffic controllers (e.g. Port of Hamburg) (see also Chapter 9). Similarly, in the Netherlands, the Port of Rotterdam worked together with the Department of Waterways and Public Works to ensure that certain bridges will timely be opened when an inland barge or vessel arrives, so that the ship does not need to stop and start, hence, saving energy.

Achieving higher energy efficiency requires overcoming existing barriers, many of which have already been identified and discussed in the literature (Iris & Lam, 2019; 2021). But even then, and notwithstanding the availability of a great array of well-established energy efficiency practices and technologies, it should be noted that those measures are unlikely, even if compounded, to offer the type of decarbonisation effects that might be expected for ports in the future. This might require the uptake of more radical solutions, that involve a more structural energy system transformation (see next chapters).

4.4 Barriers to energy efficiency

The operations of ports can be complex, and this complexity can create barriers to energy efficiency. Poor organisation and management of operations can lead to inefficient energy use, as can a lack of energy efficiency measures. In addition, ports often have outdated infrastructure, which is not designed with energy efficiency in mind. Furthermore, many ports lack the necessary financial resources to invest in energy efficiency measures. Finally, there is a lack of knowledge and understanding of energy efficiency amongst port operators, leading to a lack of commitment to energy efficiency initiatives.

Even when energy efficiency is a high priority at ports, it is not always easy to achieve because new technologies and organisational or operational changes may be met with resistance or are difficult to implement. During the project, barriers to energy efficiency have been identified[12] and, although they are not being addressed specifically in this report, they need to be kept in mind when looking at best practices and the uptake of energy transition technologies.

These barriers include:

- Technology (maturity)
- Economics (including financing)
- Knowledge (competences)
- Standards and regulations (and their uncertainty)
- Interaction (trust and public perception)
- Directionality (or coordination)
- Infrastructure (availability)

In order to overcome these barriers, ports must implement effective energy management measures. This includes the development of energy efficiency plans and the implementation of energy efficiency technologies. Additionally, ports should ensure that their operations are well organised and managed, and that they have a comprehensive energy management plan in place.

4.5 Conclusions

This chapter has looked at energy efficiency measures, which have been studied for decades in ports, focusing on their relevance for energy efficiency and reducing emissions. Energy efficiency measure in ports con provide important contributions to

[12] Please refer to MAGPIE reports D7.1 and D7.2 for a detailed discussion.

improving the energy profile of ports. These entail energy efficiency measures are the individual port operation level, at the port system level and might include the uptake of new devices and technologies. Particularly relevant in this context are the concepts of energy management and technology management systems. The full potential of energy management technologies can only be achieved when barriers to energy efficiency are overcome.

5 Electrification and grid management

5.1 Introduction

Seaports are increasingly using electricity to reduce their carbon footprint and improve their energy efficiency. This process of electrification includes electrifying equipment in loading and unloading and other port operations (see Chapter 4), but large scale electrification requires changes in the grid structure, power management and electricity supply. Furthermore, onshore power supply (OPS) is an important part of future port developments, providing ships with electricity while they are in port, thereby reducing the amount of fuel they need to use and their emissions. However, the large-scale use of OPS will place unprecedented demands on the port grids, increasing peaks and requiring better electricity management. Peak-load reduction is a common method to reduce energy use.

Many ports are an important location for power generation and are investing in renewables (Chapter 6). But this development also requires adaptation of port grids and power management. Several ports are exploring the use of smart grids and microgrids to further enhance the efficiency of power systems at ports. Smart grids can help to optimize energy usage and minimize energy waste, while microgrids can provide more reliable power in areas with limited access to the main grid. All ports interviewed show awareness of the implications of the use of electricity on the GHG-emissions of the ports and have shown to have taken various initiatives on electrification of the port activities.

This chapter deals with methods to improve the use of electricity in port operations. The next section starts with electrification of port equipment, already introduced in Chapter 4. This is followed by a discussion on the role of batteries in port operations. The important topic of OPS is discussed in Section 5.4 which is followed by interventions at grid level, including peak-load reduction and smart grids.

5.2 Electrification of port equipment

Although the energy transition of port equipment is out of scope for the MAGPIE project, most literature prominently features the electrification of port equipment as one of the low-hanging fruits for improving energy efficiency in ports. Equipment electrification is the process of replacing traditional diesel-powered equipment with electric alternatives. The electrification of port equipment often involves not only loading and unloading machinery, such as cranes and straddle carriers, but also transport equipment within the port (e.g. cars, trucks, tugboats). By electrifying these machines, ports are able to reduce their emissions and improve the overall efficiency of the operation (Lam et al., 2017). Electrification can reduce energy consumption at ports, as it involves replacing traditionally powered equipment with electric equipment using power that can be generated more efficiently than with a diesel engine. Additionally, the use of electric equipment reduces maintenance costs and helps to reduce noise pollution. Electric equipment also has the potential to increase safety, as it can be operated more precisely with fewer errors. Finally, the use of electric equipment can help to reduce energy costs, as electricity is often cheaper than diesel fuel.

For example, using electrically powered gantry cranes can reduce energy consumption by more than 85% (Alzahrani et al., 2021). In the Port of Genoa, using electric vehicles has reported efficiency improvements of up to 20% (Acciaro et al., 2014). Electrification does not apply to all ports, especially those in developing countries. Such countries usually have underdeveloped energy infrastructures that cause the cost of installation and maintenance of electrical equipment to be extremely high. Due to this lack of infrastructure and adequate power supply, electrifying cranes at terminals in these areas requires large amounts of capital.

Most ports report that several of their terminals are making use of electrification or have short-term plan for converting their equipment to batteries. The use of batteries as part of transport equipment (within a terminal, within the port area, between terminals, or to the hinterland) is being used. Some ports report trials (e.g. Port of Duisburg, with the use of electric trucks) but in general refer to limited commercial viability of full electrification of port equipment (Port of Duisburg). Several ports report pilots and further developments in this area. HAROPA PORT indicates that they aim to have zero emissions at quay by deploying electric cranes and other terminal equipment. They report that terminal operators are keen to invest and guarantee the greening of their equipment on quay within the next 5 years.

One important question relates to how much renewable energy is available in the grid for port activities. Some ports (e.g. Valenciaport, Port of Esbjerg) have a clear strategy to fully decarbonise their electricity supply, while others rely on renewable energy provided by the grid (e.g. Port of Vancouver, Ports of Los Angeles/Long Beach). Port of Vancouver is supplied with 98% carbon free hydroelectricity. Other renewable energy generation is not being considered for the port. In 2019, they developed a roadmap to port electrification, including electric infrastructure assessment, and they are actively working on grid upgrades planning with local utility (see Chapter 6 on renewable power generation in ports).

5.3 Use of batteries for general electricity storage

A battery is a device that stores energy for later use, and it typically consists of one or more electrochemical cells that convert chemical energy into electrical energy. Examples of batteries include lead-acid, nickel-cadmium, and lithium-ion batteries. Ports are increasingly using batteries as a way to store energy from renewable sources, such as solar and wind power. Batteries can be used to store excess energy produced during periods of low demand, and then used to meet peak demand during periods of high demand. This helps reduce the cost of electricity and also reduces the impact of energy production on the environment.

Batteries are one of the most common examples of energy storing systems, which collect energy at the point of production and then deliver it when needed (Vichos et al., 2022). They allow for more control over the flow of energy, which may enable more efficient operation. Moreover, they do not require the installation of large-scale infrastructure to avoid transmission losses. Other examples of energy storage systems include thermal storage, flywheels and cryogenic storage. Energy can be stored through pump-storage facilities where a higher power reservoir is placed on top of a lower power reservoir set (Hossain et al., 2021). When there is excess electricity, such as during peak hours during a sunny afternoon, water is pumped up to the higher reservoir and then released to obtain power, such as during peak hours or days when it is dark or rainy outside. Furthermore, energy storage can store excess energy from renewable sources. Several options that can be used as fuels for mobility can also be used as energy storage: swappable batteries, syngas, and e-fuels, such as e-methanol, e-hydrogen, or e-ammonia.

Ports' energy storage systems often serve as a supplemental energy source to reduce power demand and increase overall national system reliability (Bui et al., 2021). As a result, in some areas where utilities have either not been properly sized or are failing, energy storage systems may be deployed for direct current (DC) power sources. In port operations, using energy storage systems is highly beneficial for many reasons (Sornn-Friese et al., 2021). In addition to solving problems with poorly sized electrical infrastructures, energy storage systems address reliability issues by increasing electricity availability.

Although electrification of port equipment is widespread, none of the ports reports currently the exclusive use of batteries as energy storage units, with the exception of a pilot project in Port of Rotterdam being developed. HAROPA PORT also reports interest in the use of batteries specifically for peak-shaving (see also 5.5). They investigate a system in the port with batteries, specifically for energy storage and some terminals have invested in a project but this remains marginal.

5.4 Onshore power supply (OPS)

OPS involves turning off all shipboard AC loads (i.e. devices which receives alternating-current (AC) electrical power from a source in an electrical system), including the auxiliary engine and propulsion machinery, leaving only essential services such as steering, navigation, and anchor watch systems powered by electricity from shore (Zis, 2019). It has been implemented in several ports worldwide, with variable degrees of success. Some ports have adopted OPS more aggressively than others, probably due to the variable amount of time ships spend at berth in each port. Therefore, to quantify and assess the potential benefits of cold ironing (as this technique is also called), there needs to be a tracking mechanism put in place on each vessel. For policy purposes, an assessment by ship type and size is generally used as data becomes available.

The utilization of offshore e-charging buoys for power supply to ships has been proposed as a robust and efficient method of providing electricity to vessels moored in waiting areas or in close proximity to offshore wind farms.These buoys are floating, self-contained electrical stations, which are capable of receiving electricity from a renewable source and providing it to the vessels in their vicinity. The process of charging the vessels is extremely efficient, as the buoys are expected to be able to charge multiple vessels simultaneously. The use of e-charging buoys would allow ships to be powered through renewable sources, even though their deployment is still at a pilot stage (see for example MAGPIE WP5, task 3.2, demo 5 – *Offshore charging buoy*).

A recent review of the literature (Williamsson et al., 2022) identifies a variety of barriers associated with the uptake of OPS. They identify barriers related to ports, transmission and vessels, and report that for the ports the main obstacles are:

- Berth design—space for sub-stations, cable reels, etc.

- Positioning of connection point(s).
- Local power production and storage.

For the transmission, they identify as main barriers:

- Main substation (connecting to national grid).
- Port grid.
- Shore-side substation.
- Fixed or mobile connection point at berth.
- Cable (dimensions, and length) and cable reel at berth.
- Converter
- Safety protocols

While for vessels the main issues identified are:

- Cable
- Cable-management system
- Switchboard
- Final step-down transformer

They also report on organisational and institutional barriers as well as economic issues.

Almost all ports interviewed have developed or are in the process of developing facilities for OPS, for both seagoing and inland waterway vessels. For European ports this is in line with the measures and OPS obligations, included in the "Fit for 55" package and in particular in the FuelEU Maritime (Council of the European Union, 2021*b*). In most cases in which plans are being made, several will be completed in the short term. It is important to distinguish between inland ports and seaports, as for the former, the use of OPS can be more easily mandated while for seagoing vessels, it will take a longer time for the majority of vessels to be OPS ready. For example, port of Duisburg, which already has six shore power supply stations currently, will have all terminals equipped with OPS by end of 2023. Port of Vancouver has equipped 2 cruise ship berths since 2009 and 2 container terminals since 2019. HAROPA PORT is developing an integrated OPS strategy along the Seine Axis by 2024 with 3 connections in Le Havre (primarily for cruise ships), 2 in Rouen and 1 in Honfleur. They signed an MOU declaration with other ports to provide OPS to container vessels.

From a technological perspective, the implementation of OPS requires the installation of compatible hardware in ports and vessels, which, given the many years of previous experience, entails particular complexity. Yet, the uptake of OPS for seagoing vessels is low. In Europe, OPS facilities are available in only 31 seaports. European Maritime Safety Agency and European Environment Agency (2021) indicate that the number of OPS-ready vessels globally is below 10%, even for cruise ships and container ships that are among the segments with the highest uptake. There is concern that, as an increasing number of vessels will be required to use OPS, this will put a strain on energy supply to ports (Cascajo et al., 2019). While renewable energy can be sufficient to power OPS installation in ports, substantial investment in power generation is required (see also Chapter 6, and for example for the port of Cartagena in Spain, Gutierrez-Romero et al., 2019).

5.5 Peak-load reduction

Peak-load reduction refers to when a port installation reduces energy usage during high-demand periods (Damman & Steen, 2021). For example, when a ship arrives at a terminal, there is usually an increase in the energy consumption of cranes, tugboats, gantry cranes, and other equipment used in handling, as well as onshore power supply currently or in the future. Through peak-load reduction, electricity usage can be reduced elsewhere, until the ship has left the terminal. A study (Geerlings et al., 2018) has shown that it is possible to reduce peak demand and related costs by 50%, as well as reduce container operation and handling times, by either decreasing the maximum energy demand of all cranes that are operating simultaneously, or by limiting the number of cranes that are operating simultaneously; in addition, implementing such measures has been demonstrated to result in a savings of approximately EUR 250,000 per year, which is approximately 48% of the peak-related total energy cost for that period. By setting peak demand limits for each month, it is possible to improve energy management and lower energy billing costs for seaports by using peak shaving strategy, which has been proven to be more efficient than cycle charging (Sifakis et al., 2021).

Port operations are heavily influenced by peak periods when the need for electricity is at its highest. Peak-load reduction can be achieved using information from predictive models to optimise equipment operation (see Chapter 4 and Chapter 9), control electricity use, or manage demand through a battery system. Using peak load reduction strategies requires considering factors that affect battery performance, such as discharge rates and the number of charging cycles (Sornn-Friese et al., 2021). In addition to battery systems, advanced inverters may achieve peak load reduction by operating equipment in a coordinated manner and reducing losses associated with current conversion. Lastly, electric vehicles can be deployed as storage in large ports, where traffic constantly moves between berths or terminals and access roads. There is, however, little evidence of the wide-spread use of peak-shaving in ports so far.

Predictive models created to project future energy demand or consumption at a port can aid in planning future scenarios, including discontinuous supply during peak periods (Di Vaio & Varriale, 2018; see also MAGPIE WP4, Demo 2 *Smart Energy Systems*). These models can be used for daily forecasting and predicting the amount of electricity needed over the year. The available data and monitoring technologies influence the creation of predictive models and they can be helpful when anticipating future demand or analysing energy use pattern changes in ports.

Peak-load shaving can be accompanied by incentives in the forms of differentiated charges (peak-load pricing). Marginal cost pricing can be implemented to accommodate peak demand periods due to its flexibility. In Singapore, for example, the National Environment Agency installs time-of-use meters at households and businesses to charge a higher rate during peak hours. Similar approaches could be used for transport applications, when for example, port land activities compete with OPS.

5.6 Smart Grid Solutions

A smart grid is an electrical grid that uses digital technology and communication to monitor, control, and optimize the distribution and consumption of electricity (see also Chapter 9 on smart technologies). It provides a more efficient and reliable energy infrastructure, and helps to reduce costs, improve energy efficiency, and increase the reliability of energy supply. Smart grids also provide increased visibility into energy sources and usage, enabling better energy management and decision making. Examples of smart grid technologies include smart meters, distributed energy resources, and advanced communication networks. Benefits of a smart grid include improved energy efficiency, better reliability, and reduced costs for consumers. Additionally, smart grids can help reduce carbon emissions, improve grid security, and provide better access to renewable energy sources.

Port authorities may reduce costs by incorporating smart grid technology into port operations. The technology lets port operators know when electricity usage is at its peak, allowing them to use alternative energy sources, such as solar energy or wind turbines, during off-peak hours and avoid purchasing additional energy during peak times (Sadiq et al., 2021). Additionally, it allows port operators to maintain better track of all equipment used in their facilities so they can schedule battery loading when equipment is not needed and electricity is available. The scheduling of charging also makes it easier for port managers to predict how much money they will save by using alternative energy sources rather than purchasing additional electricity during peak hours.

In order to develop a smart grid solution, port authorities need to collect information on energy use and power generation from the community and authorities in the area or port where they are located (Sifakis et al., 2021). Smart grid technology also lets port authorities implement protocols that are related to energy usage, by rationalising energy demand and connecting it to availability of renewables. Several ports are already making use of renewables, but, although smart energy management systems have been used, their uptake is still limited (Sifakis & Tsoutsos, 2021).

Port authorities face several challenges when implementing smart grids (Barberi et al., 2021). One major challenge is that all parties must agree on implementing and utilising the technology. This includes determining what aspects of the operations will be monitored by the technology. Additionally, it must be determined who will have access to the data collected by the technology so everyone can benefit from it. Another main challenge port authorities face is finding effective smart grid solutions for their operations. Since different ports have different requirements, a solution suitable for one port may not be effective for another due to its unique operating characteristics or environmental conditions.

The advent of smart technologies has enabled the development of innovative and efficient energy management systems in ports, thereby providing an avenue for the growth of renewable energy. A key component of these systems is the creation of Virtual Power Plants (VPPs) and the implementation of distributed power generation and microgrids. VPPs involve pooling together multiple generators and other resources, such as storage systems, to provide reliable and cost-effective electricity to port users. This aggregation of resources provides a flexible, decentralized energy system, allowing for the sharing of energy across multiple sources and the integration of more renewable energy sources into the grid. Additionally, distributed power generation and microgrids can be used to further support these energy systems, providing localized renewable energy sources, as well as greater flexibility in energy use for port operations. These technologies are described in chapter 8, but notwithstanding their benefits, their uptake in ports has been so far limited (Bakar et al., 2021).

5.7 Use of electricity for production of low- or zero-carbon fuels.

It is possible to use electricity to produce low- or zero-carbon fuels. Notwithstanding its potential, this, so far, is of marginal relevance for ports because quantities are small and there is no direct connection between the fuel production and any transport uses. However, in the near future, ports might become the location for major zero- and low-carbon fuel and energy carrier production. Ports might also maintain their gateway function and become import locations for e-fuels, similarly to what has currently happened with LNG. This function might also require extensive investment (Hajonides van der Meulen et al., 2022).

In the Port of Rotterdam, the dominant part of the hydrogen programme is focused on fuels (sometimes for feedstock and sometime for production processes). In the EU, a promising business case for the use of green hydrogen is in mobility due to the provision in the renewable energy directive (RED 2) (Council of the European Union, 2021*a*).

In the Port of Duisburg, STEAG is planning to build an electrolyser next to one of its main coal-fired power-plants, that are scheduled to be decommissioned. However, these activities are not port specific and there is no direct connection with the hydrogen produced and transport or maritime use. Several ports are involved in the development of the so-called hydrogen valleys (e.g. Port of Antwerp-Bruges, Port of Amsterdam). A hydrogen valley bundles several industrial and research initiatives to carry out pilot projects along the entire hydrogen value chain (production, transport, distribution, and final consumption, sometimes storage). In the future, it is possible that hydrogen and other green fuels will be produced in the proximity of ports or traded through ports. There are plans for example in the Port of Sines and in the Port of Esbjerg.

5.8 The role of electricity for the energy transition

Electricity plays an important role for the energy transition and among the ports analyzed and the examples reviewed in the literature, it appears that existing renewable power, and in general, the existence of power generation activities can be an advantage for ports to leverage on renewable electricity for decarbonisation of their processes. Electrification, OPS and the production of e-fuels will require larger quantities of renewable energy, so that will be critical for the success of such measures, whether power will be generated at port or elsewhere on the grid. All ports interviewed have good connections to the grid, so the use of microgrids has not been observed. The use of peak-load reduction strategies, the use of batteries as energy storage, and the uptake of smart grids, appear at an initial stage, primarily because renewable power is not yet widely available. From the analysis, it can be concluded that having power generation facilities especially for renewables at the port or in its proximity can be an advantage for the energy transition.

The table below (Table 6) summarizes the uptake of the measures discussed in the chapter. While there is increasing focus on the use of electricity for the energy transition, only in a few cases these are implemented at scale.

Table 6: Electricity-related measures´ uptake in ports.

	Electric equipment	Batteries (storage)	OPS (marine & inland)	Land transport	Peak-load reduction	Smart grids	E-fuels
DeltaPort	◔	○	◑	●	◔	○	○
HAROPA PORT	◔	○	◑	●	◔	○	◑
Port of Antwerp-Bruges	◑	◔	●	●	◔	○	◑
Port of Barcelona	◔	◔	◑	○	◔	○	◑
Port of Brisbane	◔	○	◔	○	◔	○	◑
Port of Constanta	◔	◔	◔	◔	◔	○	○
Port of Duisburg	◔	○	◑	●	◔	○	◑
Port of Esbjerg	◔	○	◑	◑	◑	◑	◑
Port of Hamburg	◔	◔	◑	●	◔	○	◔
Port of Rotterdam	◔	◔	◑	●	◔	◑	◑
Port of Vancouver	◔	◔	◑	◔	◔	○	○
Port Venlo	◔	◔	◑	●	◔	○	◔
Ports of Los Angeles/ Long Beach	◔	○	●	◔	◔	○	◔
Port of Sines	◔	○	◔	◑	○	○	◔
Valenciaport	◔	○	◑	◑	◔	◔	◔

Note: The qualitative assessment of the measures´ uptake has been conducted on the basis of information obtained during the interviews, literature, and port authority press releases and websites. While every effort has been made to ensure accuracy of the assessment, it is possible that some installations, recent developments, and plans have been overlooked.

Legend

●	In use
◑	Available, but low uptake or minor role
◔	Planned, foreseen or pilots
○	No plans

5.9 Conclusions

This chapter has focused on the use of electricity for the energy transition in ports. Many ports globally are relying on electricity as main source to reduce their carbon footprint. This has been done so far primarily through electrification of port equipment and vehicles and industry. The large-scale use of electrification for port operations and equipment, might challenge current port grids, especially as OPS is further implemented. This call for ports to find better ways to manage their grid loads. One possible technique is peak shaving, that can rely additionally on the use of batteries. As ports become increasingly focused on renewable energy, grid management tools will become even more critical. This can be a valuable opportunity for ports also to enter the market for e-fuels and other renewable energy carriers.

6 Power generation in ports

6.1 Introduction

Ports are integral to the global economy and are often hubs of industrial activity. As such, they require a reliable source of power to ensure their operations remain uninterrupted. To meet this need, ports have traditionally relied on fossil fuels such as coal, oil and natural gas. However, in recent years, there has been a shift towards more sustainable sources of energy, such as nuclear and renewables. This shift is driven by the need to reduce the environmental impact of power generation and to meet the growing demand for energy in the port's industrial cluster. Nuclear power can be an attractive option for ports as it is reliable and has a low environmental impact and many ports are already in proximity of nuclear power stations (e.g. Doel in the Port of Antwerp-Bruges, Borssele near Flushing/North Sea Port, and Vandella II near Port of Tarragona). Renewables such as solar, wind and hydropower are also becoming increasingly popular as they offer a more sustainable form of energy without the difficulties of nuclear waste. Additionally, the industrial cluster within a port is often powered by its own dedicated power plant. The availability of power, and especially renewable power, can also allow ports to produce energy carriers for export or as feedstock for industry(see Chapter 7).

It should be noted that the uptake of energy transition technologies and in particular, low- and zero-carbon fuels depends not only on the maturity of the technology (e.g. engines, on-board storage), but also on the development of production, storage and distribution infrastructure. The Getting to Zero Coalition estimates that 87% of funding needs for decarbonising shipping relate to land investment, primarily production, storage, and distribution of low- and zero-carbon energy carriers (Getting to Zero Coalition, 2020). As ports become increasingly hubs for use and distribution of low-and zero carbon electricity (Chapter 5) and energy carriers (Chapter 7), harnessing renewable energy at ports, in particular for greening the shipping industry, becomes more attractive and it has gained popularity as many ports have the unique opportunity to use solar energy (such as the Port of Singapore and Jurong Ports), wind energy (such as the Port of Hamburg and the Port of Rotterdam), waves and tides (such as the Port of Valencia), etc. In this chapter, the development of infrastructure for renewable power generation in ports is discussed.

6.2 Renewable power generation in ports

There is an increasing interest in the use of renewable electricity (e.g. wind energy, solar energy) and power generation using renewable electricity in ports. As a result of an increasing global energy demand, it can sometimes be possible to produce energy within the port area itself. However, the use of traditional energy sources, such as fossil fuels can create environmental issues. As opposed to conventional energy sources, the integration of renewable energy resources, such as photovoltaic and wind power, poses a challenge for grid management because the supply of power fluctuates (Sadiq et al., 2021). However, because of the positive environmental impacts of renewable power generation and its economic feasibility, renewable power is growing also in ports (Nnachi et al., 2013). Renewable energy is derived from resources that are replenishable, such as wind, solar lights, hydropower, geothermal heat, and biomass energy. The integration of renewable energy in conventional energy systems can be challenging because of the system's low inertia. When the grid of the seaport is not connected to the stiff grid, with the large capacity of synchronous generators, the grid can become unstable, causing power outages. A second challenge is related to over-generation, when the amount of energy produced by photovoltaic panels or wind turbines exceeds the amount of energy that is needed at ports during those periods (Ustun et al., 2012). There are technical solutions to manage these problems (e.g. Venkataraman et al., 2018) and some are discussed in Chapter 5 and in Chapter 9.

As most renewable energy sources are located in the proximity of ports, and an increasing number of ports are developing renewable power generation infrastructure, ports are seen as critical in this development (Iris & Lam, 2019). Cases have been discussed in the literature in various countries, such as Malaysia (Lim & Lam, 2014), Egypt (Balbaa & El-Amary, 2017), Brazil (Fossile et al., 2020), the Netherlands (de Langen & Sornn-Friese, 2019) and Spain (Cascajo et al., 2019). By using renewable sources, ports are able to reduce their reliance on fossil fuels and take advantage of the financial savings that come with using renewable sources (Sadek & Elgohary, 2020). Additionally, the infrastructure requirements associated with renewable power generation can be more efficient than those associated with traditional energy sources (Tröndle et al., 2020). For example, wind turbines and solar panels can be installed in a relatively short amount of time and require less maintenance than traditional energy sources.

Most European ports have considered or have engaged with firms that operate renewable energy facilities, while ports in North America (i.e. Port of Vancouver and Ports of Los Angeles/ Long Beach) do not seem to see the development of renewable energy facilities within the boundaries of the port to be in focus. For the Port of Brisbane, reliance is primarily based on green energy production of electricity from the grid, but except for small solar installations, power generation is not considered a responsibility of the port. Renewable energy infrastructure is often difficult to place within the port areas, as land availability is constrained and certain installation, such as for example, windmills, require large clearance in proximity of the ports. Wind installations are among those most often considered, but it is photovoltaic panels (solar panels) that are the most used, although generally the size of such an installation is minor. One exception is Valenciaport that intends to rely extensively on solar installation for decarbonising their energy supply.

The following (see Table 7) is an overview of the focus on renewable power generation infrastructure in the ports that have been interviewed. It should be noted that while the traffic profile does not seem to influence the type of power generation infrastructure that is prioritised in the port, proximity to existing installations and the availability of sun, wind, or tidal differences seem to be the determining conditions. In order to decarbonize ports and reduce their dependence on fossil fuels, renewable electricity will be critical, but in a large part of the European ports, there is a limited supply and industrial activities in ports will compete with other uses of renewable electricity.

Table 7: Overview of power generation activities in the interviewed ports.

	Wind	Solar	Tidal	Wave	Biomass	Geothermal	Nuclear	Waste
DeltaPort	○	○	○	○	○	○	○	○
HAROPA PORT	◔	○	○	○	◑	○	◑	●
Port of Antwerp-Bruges	●	◑	◑	○	●	◑	●	●
Port of Barcelona	◑	●	○	◑	●	○	○	●
Port of Brisbane	○	◑	○	○	○	○	○	○
Port of Constanta	●	◔	○	○	○	○	●	○
Port of Duisburg	◔	◑	○	○	○	○	○	○
Port of Esbjerg	●	○	○	○	●	○	○	●
Port of Hamburg	●	○	○	○	●	●	●	●
Port of Rotterdam	●	◑	○	○	●	○	○	●
Port of Vancouver	○	○	○	○	○	○	○	●
Port Venlo	●	●	○	○	◔	●	○	○
Ports of Los Angeles/ Long Beach	○	○	○	○	○	○	○	●
Port of Sines	◔	◑	◔	○	○	○	○	○
Valenciaport	◔	●	◑	◑	○	○	○	○

Note: The qualitative assessment of the power generation activities has been conducted on the basis of information obtained during the interviews, literature, and port authority press releases and websites. While every effort has been made to ensure accuracy of the assessment, it is possible that some installations, recent developments, and plans have been overlooked.

Legend

●	Existing in the port or in its proximity
◑	Existing but of marginal relevance
◔	Planned or foreseen
○	No plans

6.2.1 Wind

Wind power is provided in the proximity of several ports and in some cases can be an important source of business (e.g. Port of Esbjerg). Several ports host windmills on port areas or in their proximity, but in general the number and extent of these installations is limited for safety reasons. Various ports have considered to rely in the future on wind installations (onshore, but more often offshore) for their energy supply and are active in attracting/influencing the landing of the offshore windfarms to their ports. The infrastructure relevant for ports are power cables and wind turbines.

6.2.2 Solar

Solar power is also commonly used in ports, although generally it constitutes only a small fraction of the power used for port activities. Solar panels can be installed on warehouses and projects to install them at sea are being evaluated (e.g. Valenciaport). However, most warehouses cannot take the weight of solar panels and need to be redeveloped. At Port of Duisburg, for example, solar panels are installed whenever possible during the development of new projects. Several ports argue that the main challenge with using solar panels in ports is lack of space and that scalability will remain limited. Port of Sines is planning to develop photovoltaic power in 2023 and Valenciaport has a strategy to expand power generated within the port from solar to almost a third of total current power needs of the port. The infrastructure would include also power cables.

6.2.3 Tidal and wave

The ports interviewed do not report projects in this area. Only Valenciaport reports looking into wave energy. Wave energy has been piloted in other parts of the world, for example in Port of Los Angeles in the USA, and in Port Kembla in Australia, but power generated this way in port areas remains marginal. Similarly for tidal energy the role of ports in this type of installations is seen secondary. There are cases, for example Port of London, in the UK, where trials for tidal energy with the involvement of the port authority are being carried out. A necessary condition for this type of energy is obviously adequate tidal differences. The infrastructure relevant in this case is, apart from the installations, power cables.

6.2.4 Biomass

Biomass can be used for biofuel production (see Chapter 7) and power generation. The use of biomass for power generation is limited in ports. Most ports do not plan to rely extensively on biomass for the energy transition, although there are examples where it plays a minor role (e.g. Port of Hamburg). In some ports, biomass is used for industrial processes, but so far there are limited uses that have an impact on port decarbonisation. Port of Rotterdam, for example, is a major hub for biomass commodities, such as remainders of sugar, sugarcane, sugar beet or woody biomass, even if these are not produced in the proximity of the port. There are reports of biomass from algae being investigated in some ports (e.g. Port of Venice), however generally biomass projects in ports make use of traditional feedstock such as woodchips (e.g. Port of Esbjerg, Port of Rotterdam). The biomass plant however is small and is not at the centre of the energy transition strategy for the port. Also, HAROPA PORT reports some minor projects on biomass, but they indicate that their role is marginal. They are considering however that this could be scaled up in the future as one of their industrial partners is interested. The port authorities do not perceive the availability of feedstock for biomass as an issue, as in most cases they are not concerned with power generation or biofuel production themselves.

6.2.5 Geothermal

The use of geothermal energy is marginal in ports. Port of Hamburg for example uses geothermal energy to maintain the operability of rail switches within the port railways. While it is possible that in location with strong geothermal possibilities this can be used in ports, it is not the case in the ports interviewed. The infrastructure in this case would include power cables and pipelines.

6.2.6 Nuclear

Several ports are located in proximity of nuclear power plants but none of them has plans to actively develop nuclear projects. Nuclear power generation is seen as a separate sect of activities with limited interaction possible with ports. The Belledune Port Authority (BPA) in Canada, is currently collaborating with Cross River Infrastructure Partners to explore the potential for utilizing advanced small modular reactor (SMR) technology, in order to expand the Port of Belledune, located in northern New Brunswick, Canada. This partnership is an ambitious endeavour, as SMR technology is a relatively new, yet rapidly advancing field. It stands to revolutionize the energy industry, providing a source of clean, reliable, and cost-effective electricity. In order for this project to be successful, the BPA and Cross River Infrastructure Partners will need to secure the necessary funding and permits, as well as ensuring that the proposed SMR technology is capable of meeting the port's energy needs.

6.2.7 Waste to energy

Waste to energy (WtE) is a process whereby energy is extracted from the waste generated in proximity of the ports in order to provide useful energy resources. This process works by utilizing the combustible materials found in the waste and converting them into energy sources, such as steam or electricity. In addition to incineration, WtE can also make use of anaerobic digestion, which involves the breakdown of organic waste in a sealed chamber. This process generates methane gas, which can then be used to generate electricity. WtE processes has been often carried out in the proximity of ports, although often without the direct involvement of the port authority (Karimpour et al., 2019). There are WtE plants near and in Port of Rotterdam, Port of Antwerp, and HAROPA PORT, among other, but their activities are not directly linked to the port (CEWEP, 2021).

6.3 Land use and availability

As the world seeks to transition away from fossil fuel energy sources to renewable energy sources, the infrastructure required to generate power, produce, and store e-fuels and other types of energy related infrastructures require land. This land can be used for the installation of wind turbines, solar panels, and other energy generating technologies, to the development of energy storage and production facilities.

The energy transition in ports may also lead to extensive land use and, especially for ports where land is scarce, may become a barrier to the activities that ports can develop within the boundaries of their industrial clusters. The ports interviewed all agreed that land use plays an important role in the energy transition. The ability to convert existing industrial sites for energy transition activities was cited as good practice. In the Port of Rotterdam, for example, it was explained during the interview that all hydrogen storage developments to date have had to use existing port space, even though some of the developers would have liked to have additional space.

In some cases, it is possible to reuse existing infrastructure for energy transition, such as through the installation of photovoltaic panels on terminals. For example, in the Port of Valencia, Valenciaport allocated 27,700 m^2 over the Grimaldi terminal solar power generation. The completed the project will account for about 3% of the total energy use of the port.

6.4 Overview of energy self-sufficiency

In general, it can be argued that renewable power is not generated in large quantities in ports and when large power generation infrastructures are located in proximity of the port, they are often not directly linked to it. In some cases, as in The Netherlands, the offshore wind farm is connected to the area, which has a large demand in the proximity of the wind-park, which could include ports. So, while ports might be using renewable energy for the majority of their activities (e.g. Port of Vancouver), this is generally provided through the grid. The list below summarises the amount of energy generated in the port in comparison to its use (for the ports where the information was provided).

The following ports report a stable supply of renewable electricity, insufficient for all port operations:

- Port of Sines
- Valenciaport
- DeltaPort
- Port of Rotterdam
- Port of Antwerp-Bruges

The following ports report a stable supply of renewable electricity, which they deem sufficient for all port operations and use within the industrial cluster:

- Port of Hamburg
- Port of Duisburg
- Port of Vancouver

For the following ports a variable supply of renewable electricity, insufficient for port operations can be inferred:

- HAROPA PORT
- Port of Esbjerg

On the basis of this overview, it can be concluded that no port is at the moment able to use renewable energy to produce low or zero carbon fuels/energy carriers for export and as the demand for renewable energy will increase in the future, meeting port demand might be challenging.

All ports interviewed have availability of pipelines for fossil fuels and storage facilities. Several argue that this infrastructure could be converted, if needed, to assist the energy transition, but concrete projects in this area are limited. A potential issue is the rate of conversion of pipelines and how to maintain connectivity among ports.

An important aspect is related to the grid capacity. As many ports are expanding their OPS capabilities or further developing renewable power generation, the ability of the port electricity grid has been identified as a potential bottleneck. For example, while Port of Vancouver is supplied with renewable hydroelectric energy, grid infrastructure upgrades are planned in order to meet electrification of cargo handling equipment and transportation requirements. In Port of Rotterdam, the electrolysers are located next to the landing of the offshore windfarms, since the grid cannot accommodate the large electricity supply and then energy can be transported as hydrogen using pipelines.

All ports are connected to the public grid and several ports know of tenants that are planning to develop energy production facilities, although they are often not connected to the overall port. A discussion on the role of pipelines and cables as hinterland transport mode is provided in the Chapter 8.

Inland ports can also benefit from being part of energy value chains due to their generally high connectivity and logistics capabilities. While they may not be as well-positioned as seaports to take advantage of renewable power generation, they can still make use of their high connectivity and logistics capabilities to become an integral part of the energy value chain, either acting as transport hub for low- and zero-carbon energy carriers (see Chapter 7), or by investing in infrastructure that allows for the integration of renewable energy sources. Inland ports can become a hub for the storage and distribution of clean energy, providing a significant contribution to the transition towards a greener economy.

6.5 Conclusions

Ports have long been hubs of energy generation, primarily through the burning of fossil fuels. As we move towards a more sustainable future, ports have an opportunity to lead the way in transitioning to renewable energy sources. Solar, wind and waste-to-energy are the primary renewable energy sources being explored at ports, with some even considering the use of nuclear energy. These renewable energy sources have many benefits, including reduced emissions of greenhouse gases and lower costs of electricity production. However, there are also issues to consider, such as the availability of land and the intermittency of wind and solar, meaning that energy sources need to be balanced to ensure a consistent electricity supply. In order for ports to effectively incorporate renewable energy sources into their power generation, careful consideration and evaluation of the various benefits and issues associated with each source must be undertaken. This includes assessing the economic, environmental, and social impacts of each source. It should be noted that most initiatives require the active involvement of private actors already engaging in power generation activities or distribution and that many installation are not located within the port perimeters.

7 Low- and zero-carbon energy carriers and fuels

7.1 Introduction

As the demand for renewable energy increases, the production of low and zero-carbon energy carriers in ports is becoming more and more likely. As ports are turning to renewable energy sources, such as solar or wind (see Chapter 6) to obtain clean, reliable, and cost-effective energy that can be used to power port operations, electric vehicles and electric vessels, this energy can be used also to produce low-and zero carbon energy carriers. Low and zero-carbon energy carriers can reduce the environmental impact of firms and meet the growing demand for energy.

Ports are increasingly investing in the handling, storage, and production of low and zero-carbon energy carriers. Production and storage of these energy carriers is becoming a necessity in ports as firms within ports, transport service providers and ships need to reduce emissions and meet sustainability goals. Examples of low and zero-carbon energy carriers include hydrogen, biogas, and ammonia. Hydrogen can be produced from renewable sources, such as solar or wind, and can be used as a fuel for vessels or to generate electricity. Biogas is produced from organic waste and can be used to generate electricity or as a fuel for vessels or trucks. Ammonia can be produced using electricity from renewable sources and transported or burned as a fuel on board of ships and other vehicles.

Low- and zero-carbon energy carriers are being investigated extensively by firms, regulators, and technology developers and it is not possible to review all that is happening within this chapter. The focus of this chapter is then on the role of these energy carriers as products and fuels and what their developments might mean for ports. After a brief overview of the importance and attractiveness of these products, the readiness of ports to produce and use them is discussed. This is followed by a discussion on the uses of low- and zero-carbon energy carriers, especially as fuels for the different modalities. A section on the development of technologies to capture and store CO_2, which might be a game changer for these energy carriers and in ports, is then discussed.

7.2 The role of low and zero-carbon energy carriers and fuels

One of the solutions gaining traction is the use of green hydrogen for maritime operations. This can reduce emissions and provide an alternative energy source for ships, port facilities and storage units. For example, green hydrogen can be used to power electric vehicles for cargo handling or to generate electricity for port lighting and cooling systems. In addition, it can be stored in H2 cylinders and used as a fuel by ships, replacing traditional fossil fuels. By introducing green hydrogen at ports, harmful emissions can be significantly reduced while also increasing the efficiency of global shipping operations.

One of the more innovative alternatives that is being explored for seaport decarbonisation is the use of green ammonia. This fuel is produced through electrolysis with renewable energy and is expected to be used in large-scale ships and smaller auxiliary vessels. Green ammonia could potentially be a transformative technology for reducing seaport emissions, and its implementation should be explored further by port authorities in order to create a more sustainable future.

7.3 Energy carrier readiness in surveyed ports

7.3.1 Production of low- and zero energy-carriers in ports

All ports interviewed in this study have been investigating the use of alternative energy carriers either as a commodity being handled in the port or for bunkering and for refuelling of hinterland transport modes. Although all zero-emissions, biobased and waste-based fuels are in scope of the MAGPIE project, we have focused this analysis on the fuels that are currently in developments in ports. Fuels produced with plastic or RDF (fuel produced from various types of waste such as municipal solid waste (MSW), industrial waste or commercial waste), for example, do not have a accepted status in RED2 and are therefore not in development for the transport sector yet.

Furthermore, in the last decade, a lot of attention has been paid on synthetic and e-fuels. Synthetic and e-fuels are man-made fuels created from renewable energy sources such as solar, wind, and hydroelectric power. They can be used as energy carriers and are designed to replace traditional fossil fuels, even if they might be chemically non-distinguishable from traditional fossil fuels. Synthetic fuels are produced by converting a variety of carbon-based feedstocks, such as natural gas, biomass, and waste products, into liquid hydrocarbons. E-fuels are generally produced by combining hydrogen with carbon dioxide. Both synthetic and e-fuels can be used for transportation, as they can be blended with traditional fuels or used in their pure form. Synthetic and e-fuels offer several advantages over traditional fossil fuels, including lower emissions, higher efficiency, and increased energy security. Additionally, they can also be used to store energy from renewable sources, such as solar and wind, for later use.

While this report does not deal with the different production pathways for low- and zero-carbon energy carriers and fuels (addressed in WP3), it is valuable to highlight that the life-cycle analysis of these fuels is a fundamental component in assessing the carbon reduction potential of a fuel. Some alternative fuels may result in higher life-cycle emissions than traditional fossil fuels, and that is why some ports have committed to invest or be involved exclusively in green alternatives.

Comparing different types of ports in relation to their commitment to low- and zero-carbon fuels, it can be observed that naturally ports that have already an important chemical or petrochemical cluster, are likely to be more proactive in exploring the potential of alternative energy carriers' production and distribution. Moreover, ports that are located in the proximity of renewable energy power generation facilities appear better placed to produce low- and zero-carbon fuels.

Inland ports, which are typically situated away from the coast and are connected to the coasts by inland waterways, have the potential to play an important role in the future of transportation, storage, and distribution of e-fuels and low- and zero-carbon energy carriers. The proximity to large industrial or population areas and major logistics capabilities places inland ports in an advantageous position for participating in the energy value chains. During the interviews, port representatives indicated that the development of production infrastructure for low- and zero-energy carriers could also benefit from the reconversion or expansion of existing fossil energy source infrastructure.

In Table 8 we provide an overview of the use of alternative fuels in the ports being studied.

Table 8: Overview of energy carrier-readiness in the surveyed ports (production, bunkering), including e-fuels, synthetic fuels, and waste-to-fuel.

	Ammonia (incl. green & e-ammonia)	Biofuels* (incl. biogas & syngas)	Ethanol	Hydrogen (incl. blue, green)	LNG/CNG (incl. biogas)	Methanol (incl. bio- & e-methanol)	Oil-based*	Waste to fuel
DeltaPort	◑ ○	○ ◑	○ ○	◔ ◔	○ ○	○ ○	● ●	○ ○
HAROPA PORT	◑ ○ (shaded)	○ ● (shaded)	◔ ◔ (shaded)	◔ ◔	● ●	◔ ◔	● ● (shaded)	◑ ◑ (shaded)
Port of Antwerp-Bruges	◔ ◔ (shaded)	◑ ◑ (shaded)	○ ○ (shaded)	◑ ◑	● ● (shaded)	◑ ○ (shaded)	● ● (shaded)	◑ ◑ (shaded)
Port of Barcelona	○ ○	◔ ◔	○ ○	◑ ◑	● ● (shaded)	◔ ○	● ●	○ ○
Port of Brisbane	◔ ◔	◔ ◔	○ ○	◔ ◔	◔ ◔	◔ ◔	● ●	○ ○
Port of Constanta	○ ○	○ ○	○ ○	○ ○	◔ ◔	○ ○	○ ○	○ ○
Port of Duisburg	◔ ◔	◔ ◔	○ ○	◔ ◔	● ○	◔ ◔	● ●	○ ○
Port of Esbjerg	◔ ◔ (shaded)	◔ ◔	○ ○	◑ ◑	◔ ◔	◔ ◔	● ●	◑ ◑ (shaded)
Port of Hamburg	◔ ◔	○ ○	○ ○	◑ ● (shaded)	○ ○ (shaded)	◔ ○	● ●	○ ○
Port of Rotterdam	◑ ○ (shaded)	● ● (shaded)	○ ○ (shaded)	◑ ● (shaded)	● ● (shaded)	◑ ◑ (shaded)	● ● (shaded)	◑ ◑ (shaded)
Port of Vancouver	○ ○	◑ ◑	○ ○	○ ◑	● ○	○ ○	● ●	○ ○
Port Venlo	○ ◑	◔ ◔	○ ○	◔ ◔	◔ ◔	○ ○	● ●	◔ ◔
Ports of Los Angeles/ Long Beach	○ ○	◔ ◔ (shaded)	○ ○ (shaded)	○ ○	○ ○	○ ○	● ●	○ ○ (shaded)
Ports of Sines	◑ ○	◑ ○	○ ○	◑ ○ (shaded)	◑ ○ (shaded)	○ ○	● ●	○ ○
Valenciaport	◔ ◔	◔ ◔	◔ ◔	◔ ◔	● ○	◔ ◔	● ●	○ ○

Notes: The qualitative assessment of the energy-carrier readiness has been conducted on the basis of information obtained during the interviews, literature, and port authority press releases and websites. While every effort has been made to ensure accuracy of the assessment, it is possible that some installations, recent developments, and plans have been overlooked. *Oil-based fuels include for example ULSFO, VLSFO, HSFO, MGO, MDO. Biofuels include FAME biodiesel, FT Diesel, DME, Hydrotreated renewable diesel, and other biofuels not listed above.

Source: interviewees and literature[13]

Legend

(shaded)	Production in the port (existing or planned)
● (dark)	Established use for ship/barge bunkering
◑ (dark)	Use for ship/barge bunkering in concrete plans or only pilot or small quantities
● (teal)	Primarily used for land transport
◑ (teal)	Land- transport use, but only pilot or small quantities
◔ ◔	No current use or plans, but being considered
○ ○	No current use, no plans

[13] In particular: Pillory: https://www.thehydrogenmap.com/; The Clean Energy Wire: https://www.cleanenergywire.org/; The Methanol Institute: https://www.methanol.org/the-methanol-industry/; Ammonia Energy Association: https://www.ammoniaenergy.org/; WasteFuel: https://www.wastefuel.com/; EIA: https://www.eia.gov/; and IEA: https://www.iea.org/, as well as the port authorities websites and press-releases.

Except for fossil fuels, it resulted from the interviews that the amount of concrete, tangible initiatives carried out in ports on alternative fuels are mostly limited to pilot projects and plans. While all ports are investigating or developing plans to develop the use of alternative low carbon energy carriers, in most cases these projects are at an initial stage and their outcomes are uncertain. All ports interviewed have expressed their interest to investigate or even support companies to develop production or distribution of such energy carriers. However, with a few exceptions, the port authorities do not seem in a position to actively finance these developments or be involved in the development or production phases.

7.3.2 Hydrogen

The production of hydrogen in ports is an increasingly important part of the energy landscape due to its low-carbon emissions and potential for energy storage. Hydrogen is produced by the electrolysis of water, using electricity generated from renewable sources. Seaports are ideal locations for hydrogen production due to their access to renewable energy sources, such as offshore wind and wave power and their proximity to transport links. This makes them ideal sites for the large-scale production of hydrogen, which can be used as an energy source in a variety of applications, including transport and heating. Furthermore, the production of grey hydrogen can also be combined with the capture and storage of carbon dioxide, resulting in a clean and sustainable energy source.

Investments in ports for the production of hydrogen have been seen in many different locations around the world, such as the Port of Rotterdam, the Port of Hamburg, the Port of Zeebrugge, the Port of Antwerp-Bruges, and the Port of Felixstowe, to name a few. The Port of Rotterdam, in particular, has seen considerable development in the use and production of electrolysers. For example, a 14,000 square metre factory built for Battolyser Systems, a company that designs and builds machines that are capable of both storing battery energy and producing green hydrogen. Similarly, in the Port of Gothenburg and in partnership with Norwegian energy company Statkraft, plans have been made for the construction of a hydrogen production facility at the port to become operational in 2023.

7.3.3 Ammonia

Ports often serve as hubs for the production and distribution of ammonia, an essential chemical compound composed of nitrogen and hydrogen. Ammonia has a wide variety of uses, ranging from industrial applications such as fertilizer production, to the manufacture of consumer products, like polyurethane foams. In order to meet the demands of these industries, ports must be equipped with the necessary infrastructure to facilitate the production and distribution of ammonia. This typically involves the construction of facilities for the storage and transportation of ammonia, as well as the installation of equipment for the conversion of raw materials into the final product.

Several ports are active in the development of ammonia production and import facilities. In the Port of Rotterdam, among others, Gasunie, HES International (HES), and Vopak are collaborating to develop an import terminal for green ammonia that will start operations in 2026. There is also a plan to develop a green ammonia import plant at the Port of Hamburg. Air Products, a leading industrial gas supplier, has signed a joint development agreement with Mabanaft's Oiltanking Deutschland to build the green ammonia distribution and import infrastructure. There have been announcements of production hubs in Australia, the United Kingdom, South Africa, the United States, and Canada that have substantial potential for producing green ammonia near ports and that will focus on exports.

7.3.4 Biofuels and e-fuels

Ports have become increasingly important in the production of biofuels and e-fuels due to their access to natural resources and their ability to facilitate international trade. Biofuels are produced from renewable organic materials such as plant oils, animal fats, and agricultural waste, while e-fuels are produced from renewable electricity. Both of these types of fuels have a lower environmental impact than traditional fossil fuels, making them attractive for use in transportation, energy generation, and other sectors. Ports are uniquely positioned to take advantage of their access to natural resources and their ability to facilitate international trade to develop production of these types of fuels. The production of both biofuels and e-fuels requires significant upfront investments in infrastructure.

For example, Port of Rotterdam is ideally positioned for the supply of raw materials and biofuels from all over the world and this also holds true for the distribution of biofuels in the rest of Europe. This is because large industrial ports are good locations for the production, trade, storage and transhipment of biofuels. The port has facilities for the production of biofuels (Alco Group, Biopetrol, Lyondell, Basell, and Neste) and the port is expected to grow as more biofuel companies come online. The port also has several biofuel supply chain nodes, among them are ADM, Cargill, Bunge-Loders Croklaan, Sime Darby and Wilmar, which import and handle biofuel feedstock through the port. Several oil majors, midstream companies, and traders blend and distribute the biofuel across the continent, with Koole, Vopak, BTT, Maastank, and Neste Terminal (which they just purchased the former Count Terminal) storing products, and several oil majors, midstream companies, and traders distributing the biofuel across the continent.

Ports are also active in the production of e-fuels. For example, a letter of intent between European Energy, a Danish developer of renewable energy, and the Port of Aalborg has been signed with the objective of starting the production of e-methanol near the port. European Energy has established already an e-methanol manufacturing plant in Aabenraa, in Southern Denmark, but the new plant will be approximately twice the size with expected production of 75,000 metric tons of e-methanol per year.

7.3.5 Waste to fuel

Waste to fuel production is the process of converting waste materials into energy sources such as electricity, heat, and biofuels. This process has a variety of benefits, including reducing the amount of waste sent to landfills, reducing emissions, and providing an alternative energy source. In ports, waste to fuel production can be used to power ships and other modaltities, as well as provide electricity for port operations. Examples of waste to fuel production in ports include biogas from food waste and sewage, vegetable oil and animal fat, and the use of plastic and other waste materials to generate electricity. By utilizing waste to fuel production, ports can reduce their environmental impact. In most cases, waste and sources of waste biomass are handled by specialised companies, so port authorities do not engage in such operations.

Wastefuel, a Los Angeles-based start-up funded in 2018, is planning, following a partnership with Maersk, to produce methanol from waste for the use in ships. The fuels will be produced initially in Manila, Philippines Some ports are also investigating how to transform municipal and agriculture waste in fuel (e.g. Port of Seattle, Port of Los Angeles/Long Beach). As a pilot project, in the Port of Rotterdam, biofuels are being made with the use of waste plastic collected in the port. But quantities are limited, so the concept is not scalable. Other initiatives to use waste plastic for biofuels were advanced in Port of Amsterdam. River plastic has been an important focus for ports. In Rotterdam, the development of the Waste Shark helps Rotterdam in gathering river plastic. The Waste Shark could be used in other locations as well. Plastic Energy has also signed an agreement with Exxon mobile to build a plastic recycling plant near Le Havre, although HAROPA PORT is not directly involved.

The production of biofuels from waste is restricted to a few locations of which the port of Rotterdam is the largest globally. For biofuels, Used Cooking Oils (UCO) is mainly used, but other sources of liquid and solid biomass are also possible. Biofuels are dominantly blended in fossil fuels for road transport, since the EC has set blending standards for these demand areas. A small part is consumed by other demand groups, like ships. Therefore, biofuels are only to a limited extent used for consumption within the port and the resulting biofuels are often sold or consumed elsewhere.

Another example, from HAROPA PORT, is the project Salamander, which aims at the production of biomethane by pyro-gasification. The project could be established in Le Havre, following the outcome of the call for expressions of interest ("appel à manifestation d'intérêt-AMI" in French). The process entails heating at very high temperature waste that cannot be used to transform it into gas, in this case dry biomass from local wood waste and solid recovered fuels. The project is a collaboration between CMA CGM and ENGIE, who partnered with the objective of developing and producing a low-carbon fuel for maritime transport. The project plans to produce 11,000 tons per year of second-generation biomethane starting in 2026, for a total investment of 150 million euros, according to a joint press release.

In the Port of Hamina-Kotka in Finland, biogas is produced from sewage from cargo ships. This is a collaboration of Baltic Sea Action Group with various companies, including Gasum, that will process the wastewater sludge resulting from treatment of ship sewage in their biogas plant. The biogas will be used as fuel by the heavy-duty transport sector.

Other biomass projects have been reported in Amsterdam, where biomass from waste will be converted into bio-methanol. The project is an initiative of GIDARA Energy and will take place in the BioPark, an industrial location in the Port of Amsterdam developed especially for producers of renewable fuels. The facility will produce around 87.5 KTA (kilotons per annum) of renewable methanol by converting non-recyclable waste equivalent to that of 290,000 households yearly, which otherwise would be landfilled or incinerated. Also, in Port of Antwerp-Bruges, an area of 88 hectares (the NextGen District) has been planned for the development of circular economy facilities, including the processing of biomass.

7.4 Use of low-carbon fuels including e-fuels

7.4.1 Non-shipping related use of low- and zero-carbon fuels

Low and zero carbon energy carriers can help reduce the carbon footprint of ports, by providing an alternative to traditional fossil fuels. As such, these fuels represent a significant step forward in terms of decarbonising ports and contributing to the global effort to reduce greenhouse gas emissions. Utilizing low and zero carbon energy sources also helps ports create a more sustainable supply chain by reducing fuel consumption and emissions.

Low- and zero-carbon fuels have multiple uses, that will not be reviewed in detail here, but ports are ideally located for providing low- and zero-carbon fuels for:

- Use in shipping (see next section)
- Port activities such as loading and unloading equipment, tugs and other marine service ships, mobility within port areas
- Use to hinterland transport modes, such as railways and road transport
- City uses, including public transport
- Industrial uses in the proximity of the port, such as the chemical industry
- Exports.

Given the centrality of ports in many industrial clusters and transport networks, and the expertise of ports as energy hubs, it can be argued that ports are ideally placed to act as transition, storage or even production sites for low- and zero-carbon fuels.

For example, Oakland is a suitable place to develop a green hydrogen economy beyond the shipping industry because of its potential for renewable electricity generation, while Tacoma can help implement zero-carbon fuels and decarbonize local transportation, while also supporting a green hydrogen economy. If Vancouver invests in producing and supplying electrofuels, it will be able to counteract the loss of revenue and jobs that will result from the expected decline in coal exports.

7.4.2 Bunkering

The shipping industry uses about 300 million tonnes of fossil fuel oil to produce 12 billion litres of energy, emitting more than one gigatonne of greenhouse gases every year. The main alternatives to fossil fuel oil are low-GHG alternatives, including biomethane, e-methane, bio-methanol, e-methanol, blue ammonia, e-ammonia, bio-oils, and e-diesel, which will help reach our decarbonisation goals. In the future, we anticipate that the industry will be using multiple fuels, but all alternatives face technical, safety, commercial, and regulatory obstacles. It appears that the current plans for alternative fuel production capacity will not be sufficient to meet the demand within the next few decades if we do not begin securing adequate capacity for alternative fuels now. Due to the long lead times, we need to begin now to make sure we have enough capacity for alternative fuels in 2030.

In order to prepare for scaling up alternative fuels in the maritime industry, there are a few things to consider (Mærsk-McKinney Møller Center for Zero Carbon Shipping, 2022):

- Ensure that all alternative fuel pathways are technologically ready to take on the future challenges ahead as well as developing standards and regulations for their use as well as ensuring that they are used responsibly and in a safe manner.
- Developing a solid investment commitment in large-scale fuel production infrastructure and building the competencies necessary to scale up all alternate fuel pathways is a key component to addressing the imbalance between planned alternative fuel production supply and demand.
- In order to ensure alternative fuel pathways become economically attractive, it will be necessary to develop regulations and measures to ensure this happens.

All the ports interviewed have some form of bunkering facilities available when it comes down to oil-based fuels. Some ports are able to provide also LNG bunkering, primarily by means of barge bunkering or truck to barge (e.g. Port of Rotterdam). Liquified natural gas is a viable alternative to diesel fuel for maritime shipping because of its availability and relative ease of transport (e.g. Song et al., 2022). It is a clean-burning fuel that reduces CO_2 emissions, which is however partly nullified by methane slip (CH_4). Although liquified natural gas is not yet widely implemented as a fuel in ports, it is becoming more popular. Notwithstanding the current high prices of LNG due to the gas crisis of 2022, its use could increase significantly in the next few years.

In a very limited number of ports bunkering of other fuels is also available, primarily at a pilot stage (e.g. methanol and ammonia) or on land (e.g. hydrogen). In the Port of Rotterdam, for example legislation was changed so that ships can sail with any licenced fuel.

In most ports, bunkering operations are carried out similarly. For example, in the Port of Sines bunkering is carried out primarily for oil-based fuels, with planned facilities for hydrogen and ammonia in the future. Bunkering is carried out by means of fixed installations (flexible hose or loading arm), through a specialized terminal for handling liquid bulk, or through mobile floating means (ship-to-ship), through a license issued to a specialized operator. Occasionally, for smaller vessels/ships, by truck-to-ship (including lubricating oils). In some ports (e.g. Port of Vancouver) bunkering activities may be limited to some vessel types. For example, in Port of Vancouver, marine fuel is provided primarily to cruise vessels (ship-to-ship bunkering). In the case of DeltaPort, there are no bunkering facilities at the moment, but the port is considering swapping containers with hydrogen as a possibility in the future.

Bunkering for barges follows similar patterns as in seaports. Europe's first shore-to-ship Liquefied Natural Gas (LNG) bunker station for inland barges was recently opened at the Niehler Hafen, near Cologne. With the development of the EU Alternative Fuel Infrastructure Regulation, it is expected that more bunkering stations for barges will become available.

Table 9: Energy carriers for different modalities.

Modality	Energy carrier
Maritime shipping	(Bio-)Methanol, Bio-diesel, Green Hydrogen, Ammonia, (Bio-)LNG and Electricity
Inland shipping	Green Hydrogen, (Bio-)LNG, Bio-diesel (in the form of Hydrogenated Vegetable Oil (HVO)), Bio-Methanol and Electricity
Trucks	Green Hydrogen, (Bio-)LNG and Electricity
Rail	Electricity

Source: MAGPIE D3.1 Transport Energy Requirements

Similarly in relation to bunkering and land transport use, all ports provide basic infrastructure on bunkering (see Table 9). Substantial differences exist between bunkering hubs (such as Port of Rotterdam) and other ports that, either because of their geographical position or their size, do not expect bunkering activities to be substantial. LNG is the second most common energy carrier that is provided for bunkering, although almost all ports provide bunkering for LNG exclusively from barge or truck to ship. It appears that further installations can be developed, especially in those ports that handle natural gas, but the outlook, in view of the cost of natural gas and climate concerns, does not seem to indicate a strong interest in these developments.

For example, Valenciaport indicated that they have been open to the use of LNG for years and participated in three projects for the implementation of LNG in the ports. So, these three projects permitted the port authority to know a little bit more about LNG and the different possibilities offered by the fuel. There was also interest expressed by ship operators, who had invested in dual-fuel vessels and that regularly traded to the Iberian Peninsula. However, the interest in developing infrastructure has further decreased in view of the high costs of LNG. In the past two years, they had also seen some bunkering operations with LNG for a handful of vessels from the same owner. But more recently the interest in LNG has been limited to the trading of the commodity through the port and the use of LNG for one of the local power plants.

Some ports are still further developing LNG infrastructure further. For example, Port of Vancouver is also developing LNG bunkering capabilities for LNG propelled ocean-going vessels. There are already LNG powered commercial and passenger ferries operating within the jurisdiction of the port, but they are currently bunkered by trucks. LNG bunkering capabilities are established in Port of Rotterdam, Port of Antwerp-Bruges, and other major ports. LNG infrastructure was also being developed for inland transport mode (barges and trucks), but these developments are not driven by ports.

Another alternative to diesel fuel is methanol. Methanol is a clean-burning fuel that can be used in cold weather and reduces NOx-emissions by 50% compared to conventional Tier II marine diesel engine (Song et al., 2022). Methanol is a potential alternative to diesel fuel but has some drawbacks because of its high-cost in comparison with diesel. However, bio- and e-methanol produces fewer carbon emissions and is better for the environment than other fuels (Zis, 2019). The use of methanol without ammonia, but with other igniters, is possible as well[14]. There are now multiple vessels (12 of Maersk, Jack-Up Vessel of Van Oord, etc.) on order that will be dual fuel, running on methanol and MGO. The investments in these energy carriers are reported as marginal so far although, following interest by several shipowners, various port authorities are considering how to implement bunkering operations if required.

A variety of developments are also affecting fuelling for inland transportation. Several ports report the development of electric recharging points for cars and light transport vehicles, and some can provide refuelling for hydrogen vehicles, but most ports see refuelling of road vehicles as a marginal service for port authorities. In the Port of Rotterdam, it is also possible to exchange swappable containers that are used to fuel electric barges. This is in operation and part of the pilot project in cooperation with Heineken involving switching batteries in Alphen aan den Rijn.

Almost all ports are able to provide electricity to land-based vehicles and are developing, or already have them in operations on a small number of berths, OPS for ships. When it comes to bunkering, we observe that for some ports, this is an important type of business (e.g. Port of Rotterdam, HAROPA PORT), while other recognise the limited role played by bunkering (e.g. Port of Esbjerg, Port of Brisbane). Port of Rotterdam and HAROPA PORT have significant industrial clusters and are therefore able to play a role in bunkering, whereas Port of Esbjerg and Port of Brisbane are primarily gateway ports where bunkering fuels may not be readily available.

As an example, in the case of the Port of Vancouver, the port authority in cooperation with the provincial government, manages the Low-emission Technology Initiative. The initiative facilitates adoption of low-emission technology in trucks, terminal locomotives and tractors, and vessels (e.g. cargo ferries, patrol vessels, service tugs). They organize pilots involving biodiesel for commercial ferries, renewable diesel for port authority patrol vessel, grain terminal locomotive and drayage trucks, battery electric drayage trucks and terminal tractors, and renewable compressed natural gas (CNG) drayage trucks. The port authority also contributed to demonstration of hydrogen fuel cell terminal equipment, drayage truck, and terminal tractors demonstrators. These demonstrations, however, are in planning stages.

Hydrogen is a potential alternative to traditional diesel fuel. There are pilot projects to use hydrogen, mainly in trucking, for standard use, and it is possible that in the future internal combustion engines running on hydrogen will become more widespread. For example, the Port of Los Angeles has recently rolled-out the Shore-to-Shore project, where five new hydrogen-powered fuel cell electric vehicles and two hydrogen fuelling stations were the first steps towards zero-emission transit. Alternatively, hydrogen can provide additional energy savings by serving as a medium for reactivity in chemical reactions. Marine-related industries in Asia and Europe are moving towards adopting hydrogen for its environmental benefits. Costs are still high and a market for marine use of hydrogen does not yet exist. Several ports are investing in hydrogen for industry use. Most notably Port of Hamburg, among others, will rely on hydrogen as main energy carrier for decarbonisation.

Other fuels with high potential in shipping and hinterland transportation are ammonia and biofuels. Ammonia appears very promising because of the maturity of

[14] See the MAGPIE D3.1, annex B, pg. 83 for additional information.

engine technology, the wide availability of the fuel, the low storage costs, and low costs, even if green ammonia will be in high demand also for other non-transport related uses. Some safety and regulatory issues still need to be resolved (European Maritime Safety Agency, 2022*a*). Similarly, although many biofuel types are available for transport, costs, availability, and competition with non-port related uses might limit their uptake in shipping and port hinterland transportation (European Maritime Safety Agency, 2022*b*).

7.5 Carbon Capture and Storage (CCS) and Use (CCU)

Carbon capture and storage (CCS) is a process that involves capturing carbon dioxide from large sources, such as power plants, industrial facilities, and other sources, or directly from the atmosphere and storing it in the form of liquid or solid, deep underground or in disused gas or oil fields. CCS is considered an important part of the global effort to reduce greenhouse gas emissions, even if the technology is not yet available at large scale. Seaports are increasingly being seen as potential sites for CCS. This is because they are well-positioned to collect and store large amounts of CO_2 in empty gasfields in the seabottom. Ports can also be seen as transit points for carbon capture and use (CCU). CCU is a process that involves capturing CO_2 and using it for various industrial processes. The captured CO_2 can be stored and used for chemical processes, refrigeration, manufacturing (fuels and chemicals), and agriculture.

No port reports the use of CCS or CCU at the moment. They are all aware of the possibilities offered by the technology but indicate that the technology does not appear yet mature. No port expressed interest in investing directly in CCS or CCU, but several ports (e.g. DeltaPort, Port of Rotterdam, HAROPA PORT) are supporting interested parties in finding adequate locations for the facility as well as developing the necessary infrastructure. Probably the most important project in this area is Porthos, that entails the transportation of CO_2 from industry in the Port of Rotterdam and store it in empty gas fields under the North Sea. Several ports recognise the potential business opportunities offered by the transportation of carbon. In 2021, TotalEnergies, Yara, Exxon, Borealis and Air Liquide France Industrie signed an agreement setting up a Consortium, with the aim to create, as of 2027, France's first CCSU hub along the Seine valley with potential benefits for HAROPA PORT. Port of Duisburg reports companies interested in transporting CO_2 through Duisburg to Norway, where in Port of Oslo projects are being considered as well. In particular carbon capture appears attractive to companies that have difficulty decarbonising. However, most processes within the port areas are believed to be able to decarbonise entirely within the medium term. Some ports (Port of Sines and Port of Vancouver) have no plan to develop CCS or CCU. In Malaysia, there are plans to use captured carbon as feedstock for an electrolyser.

CCS on board of ships are starting to be possible, and some ports will need to develop plans to accommodate the captured of CO_2. For example, Value Maritime, a green shipping equipment company, announced their intention to install a CO_2 capture and storage unit on Visser Shipping's vessel Nordica in 2021. This will be the first instance of a vessel being fitted with such a device, potentially paving the way for a more sustainable shipping industry. The CCS unit will be capable of capturing up to 95% of the CO2 produced by the vessel during operation and can store it safely until the vessel reaches port.

Ports around the North Sea might therefore play an important role as a hub within the carbon dioxide infrastructure. If CCS takes off, they can provide the necessary infrastructure for shipping captured carbon dioxide to empty offshore oil and gas fields. The Port of Rotterdam in the Netherlands, and the Northern Light consortium involving the Ports of Oslo and Bergen in Norway are including the possibility of developing CO_2 reception facilities in their CCS plans.

7.6 Conclusions

This chapter has investigated one of the most important developments in ports in terms of the energy transition. Ports have the potential to be quite central in the handling, storage and production of low- and zero-carbon energy carriers and fuels for inland transport and ocean shipping.

While there are many discussions and plans on the developments of low- and zero-carbon energy carriers, in the interview process, it emerged that the amount of concrete initiatives on alternative fuels being implemented in ports, except in the case of fossil fuels, is mostly limited to pilot projects.

No single low-carbon fuel has been identified as the most promising for bunkering of ocean-going vessels and barges, for port railways and for fuelling trucks. This implies that in the coming decades a variety of low-carbon fuels will coexist.

There is no evidence that low-carbon or zero-carbon fuels produced in proximity of ports are intended exclusively or primarily for activities within the port or for inland transportation activities to and from the production port, which could complicate the energy transition in the shipping and inland transportation industries.

Carbon capture and storage/use is at its infancy and its potential for ports is yet difficult to establish.

8 Energy transition and hinterland transport

8.1 Introduction

Hinterland transport is a term used to describe the movement of freight between inland locations and ports. In Europe, hinterland transport accounts for over 60% of the total freight movements in ton-km (Otten et al., 2020). This implies that hinterland transport is responsible for a large portion of the embodied energy associated with European port activities. Most hinterland transport emissions are linked to road transport to and from the port, hence decarbonising port hinterland transport often entails decarbonising road freight. There are five broad strategies proposed for decarbonizing road freight (McKinnon, 2016): (1) reducing freight demand; (2) optimizing the use and loading of vehicles; (3) increasing freight vehicle efficiency; (4) reducing the carbon content of fuels used to transport freight; and (5) shifting freight to modes with low carbon intensity. Similar strategies can also be considered for other modes of transport. This chapter focuses on the strategies that have been used more frequently in ports, namely fostering intermodality and modal shift, and the provision of infrastructure for facilitating modal shift and the transition to low- and zero carbon fuels (discussed more in general in chapter 4).

Hinterland transport accounts for about 10% of the port industrial cluster emissions, although this figure might be higher for gateway ports, since industrial activities might be less prominent, and will depend on the modal split on how cargo is moved out of the port. An average figure for ports is therefore non informative and each port should assess its own impact of hinterland transportation on its footprint. As an example, CO_2 emissions in the Port of Rotterdam's industrial cluster, excluding hinterland transport, were 26.3 million tonnes in 2018, according to the Port Authority, although they fell by 15% in 2020 and account for only about 16.5% of total emissions in the Netherlands. According to EU MRV[15] data, emissions from shipping were about 13.7 million tonnes in 2018 in Rotterdam, to which about 0.65 million tonnes need to be added for port operations and about 2.2 million tonnes for hinterland transport. This brings the total footprint of the port of Rotterdam, the largest in Europe, to over 42 million tonnes, which is a quarter of the total emissions of the Netherlands.

However, ports, and specifically gateway ports, are quite central in hinterland transport chains and the energy transition for the port hinterland should be a priority for many ports, even if arguably port authorities often have little to no influence on the technology and operational choices of hinterland transport service providers. Port authorities can influence the energy transition in the hinterland by fostering intermodally and modal shift and by supporting the provision of energy supply systems. The rest of the chapter is structured around these two themes: intermodality and modal shift, and energy supply systems and infrastructure provision.

[15] Regulation (EU) 2015/757 on monitoring, reporting on the monitoring and verification of carbon dioxide emissions from maritime transport, known as MRV Regulation, came into force in 2015 and requires ships above 5,000 GT calling on the ports of the European Economic Area EEA (EU, Iceland and Norway) to report their CO_2 emissions from 2018 onwards.

8.2 Intermodality

Ports can accelerate the decarbonisation of the economy by exerting influence on transport modes, facilitating modal shift and supporting intermodality[16]. Intermodality has been seen as a potential tool to reduce carbon emissions and meet the Paris Agreement targets by shifting cargo from carbon intense modes to low carbon modes and improving the connectivity of intermodal nodes. There is evidence that intermodal transport can reduce emissions substantially in comparison to truck-only transport (Craig et al. 2013). It is difficult to estimate the potential reductions in carbon emissions when shipping by intermodal methods since the carbon intensity of an intermodal shipment is dependent on the types and shares of modes used. The potential for reduction of GHG emissions from intermodal shipments is largely determined by their origin, destination, and proximity to terminals. A large number of different routes is generally investigated in order to obtain a distribution of carbon intensity levels when attempting to quantify the environmental benefits of a shift to intermodal transportation systems.

The 2009 report of the International Energy Agency, found intermodal shipments in Europe consume 16% less energy than road shipments on average and that varied from 45% less to over 10% more energy than road shipments (International Energy Agency 2009). Intermodal rail and truck shipments have an average carbon intensity of 67 g CO2/ton-mile compared to 125 g CO2/ton-mile for trucks. Due to greenhouse gas emissions from terminal operations, there are some intensity levels which exceed those for trucks, but the distribution is very wide with some intensities exceeding those for trucks (Craig et al., 2013). As rail freight and water freight are limited in their ability to deliver last-mile goods, the mode shift focuses on long-haul road freight (Alessandrini et al., 2012). With technology, it is comparatively easier to decarbonize the last mile of a shipment, for example, by using low-carbon vehicles or electric vehicles, as they are comparatively cheaper to operate (Oliverira et al., 2017). While several ports have been exploring the use of electric vehicles also in cooperation with cities (e.g. Port of Stockholm), the focus has been on passenger mobility and not freight (Cavallaro & Nocera, 2021).

Improving intermodal connections will not only reduce carbon emission on transport chains, but can also benefit the port by reducing congesting, favouring a better use of land and port areas, and reducing costs. Bettering intermodal processes involves improving interfaces between ship and container or dry bulk terminals, ship and pipelines, between pipelines, between terminals, terminals and rail, and improving last-mile connection. By relying on low-carbon transport modes, one of the most widely recognised benefits of intermodality is the ability to reduce carbon emissions, without affecting connectivity and service quality (e.g. de Miranda Pinto et al., 2018). In most cases, intermodality requires further coordination, standardisation, and better information sharing, and its economic benefits are often not clear (Agamez-Arias, & Moyano-Fuentes, 2017). Intermodal transport remains less attractive as a result of lower service performance and, while digital technologies can support its development, the multi-actor nature of intermodal transport results in slower uptake (Vural et al., 2020).

[16] i.e., improving the efficiency and attractiveness of a single trip made with more than one transport mode (e.g. barge, train and truck), with the aim of offering a seamless journey.

Port authorities are generally assumed to be able to impact intermodal transport by, among other aspects, developing adequate infrastructure at port, improving information exchanges, facilitating cargo consolidation, supporting the development of hinterland intermodal points (dryports) (Kreutzberger, & Konings, 2016). Several port authorities in Europe are involved in the development of intermodal connections. In 2005, the Antwerp Port Authority took the lead in analysing opportunities for the development of new rail shuttles. By identifying existing cargo volumes from shipping companies and agents, the port authority identified a number of destinations to which new rail shuttles could be developed. Similar initiatives have been carried out in other ports (e.g. Port of Barcelona) (Van den Berg et al., 2012).

The port authorities interviewed recognise the importance of intermodal processes, but refer that they have limited influence on these processes. Port customers often have insight in Tier 1 connections, sometimes Tier 2, but almost never beyond that. A port authority is able to fulfil that role, if customers are willing to share the needed data. The measures that port authorities can adopt to foster intermodality include using digitalisation to streamline administrative procedures, improving the efficiency of intermodal nodes, increasing opportunities for cargo consolidation on certain modes, supporting automation of equipment and processes, fostering cooperation and a low-carbon culture among port customers and internal stakeholders, providing incentives, and introducing of charges penalizing carbon-intensive transport modes.

8.3 Modal shift

Road freight transportation is responsible for approximately 7% of all greenhouse gas emissions worldwide. Globally, the ratio of road and rail modes for freight transport is around 60:40, which is indicative of the energy and emission reductions that can be made by switching freight to rail or water modes, both of which are much more energy efficient than road modes (Kaack et al. 2018). The road freight industry is experiencing strong growth in most countries, notwithstanding the efforts to shift cargo from road to rail transportation. It is essential to have a targeted design of freight systems, in order for rail intermodal transportation to replace carbon-intensive and fast-growing road freight. There are policies which can promote a shift in mode by targeting infrastructure investments and internalizing external costs of road freight. However, not all countries have these policies in place and, even when incentives are in place the shift has revealed difficult to achieve[17].

In certain seaports (e.g. Port of Rotterdam, Port of Antwerp-Bruges), inland waterway transport is an important share of the goods moved to and from the port towards the hinterland, with substantial benefits in terms of congestion, pollution and energy use. Given the high energy efficiency per tonne/km of inland waterway transport, its CO_2 emissions per tonne/km are comparable to those of rail transport and substantially lower than those of road transport (pg. 15, Klein et al., 2021). While CO_2 and PM emissions factors are generally lower that road transport, inland vessels are characterised by relatively high levels of NOx emissions. Notwithstanding the current high NOx levels, inland waterway transport's energy efficiency, combined with further

[17] E.g. Pittman, R., Jandová, M., Król, M., Nekrasenko, L., & Paleta, T. (2020). The effectiveness of EC policies to move freight from road to rail: Evidence from CEE grain markets. *Research in Transportation Business & Management*, *37*, 100482.

technological improvements, con substantially contribute to European ports' energy transition (de Barros et al., 2022).

For decades, ports have been trying to favour modal shift towards low-carbon modes. For example, HAROPA PORT, where currently the modal split favours trucks (80%) over rail (8%) and barge (12%), aims to enhance freight movement on river and reduce congestion and emissions. The target is to increase rail and barge transport to 20% each of total port volumes, especially in the case of containerized cargo. Among the projects that should help achieve this objective is the development of railways around Le Havre and directly to south of France, Spain, etc. Among the main obstacles is the central role of Paris on French railway networks, that creates potential for congestion. Improvements in port infrastructure in Paris, through the construction of a new inland port in Achevre, could free space for container transport favouring modal shift to barge.

Many ports have been involved in large rail redevelopment projects to increase the use of railways, reduce emissions and facilitate modal shift. In addition to the examples mentioned above, additional examples include the Port of Long Beach (USA), where 52.3 million dollars is awarded to help fund a rail facility to move cargo more efficiently and with less emissions to and from the port. The grant is part of a large set of grants provided by the Maritime Administration's Port Infrastructure Development Program. Virtually any rail development project can be seen as reducing road use. In the Port of Bilbao, for example, an investment of about 15.7 million euros, cofounded by local authorities, the Basque Country government and the port authorities, will favour modal shift by further developing the Arasur logistics platform and railways (see also section on railways below).

8.4 Energy supply systems

Port authorities can also support the decarbonisation of each transport mode to the port by the provision of energy supply systems (e.g. OPS, electric charging points, infrastructure for swapping batteries, hydrogen-fuelled stations, biofuel bunkering barges) and fostering the uptake of low-carbon fuels or supporting investment in combined transport terminals that are well-designed, provide adequate access to low-carbon transport modes, and account for last-mile delivery and storage. Energy supply systems are generally specific to individual modes, so a brief overview of current practices in various ports are discussed per main mode of transport: railways, road, barge, pipelines, and cables for electricity transmission. It should be noted, however, that potential for alternative fuels would increase when a multi-mode strategy could be developed, but, with the exception maybe of hydrogen, electricity, and to some extent LNG, there is limited evidence of integrated alternative fuel transition strategies in ports that address multiple modalities at the same time. This is probably as alternative fuels are still at their infancy. Low- and zero carbon fuels are discussed in Chapter 5, while decarbonisation through decarbonising the (port) electricity grid are discussed in Chapter 4.

8.5 Hinterland transport infrastructure

8.5.1 Railways

Trains are considered one of the most environmentally friendly modes of transport. Most of the trains run on electricity. Only in areas where no catenary lines are present, like container terminals, the locomotives run on diesel. This raises issue related to other pollutants, most notably NOx emissions, that tend to be quite high given the operational profile of diesel trains in port areas. Most of the developments of rail in ports are aimed at modal shift (moving cargo from trucks to trains), either by building new tracks (recently for North Sea ports and the Port of Brussels) or by improving the capacity of tracks and trains (like Port of Algeciras with the installation of an Automated Single Track Blocking System, that doubles the use of the same tracks, or the Portshuttle of the Port of Rotterdam, which books empty spaces on trains already travelling to the port for cargo that needs to be transported between terminals within the port, saving cost and increasing efficiency). Several rail operators, among which MAGPIE partner Rail Innovators Group, offer the possibility to their customers to use green electricity for transporting their cargo (for a fee). We also see some developments on trains run on hydrogen, although those are mostly on small scale and for passenger trains. For freight, the Port of Malaga has done research on the use of hydrogen power trains.

The electrification of railway infrastructure is a major element in decarbonising hinterland transport (see also Section 4.3). However, ports have a marginal role to play in electrification. For example, Port of Vancouver is served by 3 class 1 rail lines that use diesel locomotives and the port has no impact on the electrification of the lines. Even in those ports that have electrified catenary lines and where rail transport has been present in the port for a long time, there might be difficulties in changing modal split as a result of the characteristics of the cargo transported. In the Port of Sines, where oil products constitute the majority of the cargo handled in the port, modal split favours pipeline, which represents 50.6% of the 46.6 million tonnes of total maritime traffic. Road and rail transport accounts for 6.4% and 7.6% of total maritime traffic respectively.

Several port railways have also been investigating the use of alternative fuels, such as the use of fuel cells and batteries in shunting locomotives (MAGPIE WP6, demo 8). In the Port of Trieste for example, Adriafer, which is the operator of the port railways and which has also made a partnership with gas transport and storage operator Snam, will do a test with a locomotive manufacturer for a vehicle powered by a hydrogen engine. The Eastern Adriatic Sea Port Authority, that manages the port, recently started a project for 65 million euros to improve the hinterland accessibility and multimodal connections of the port, increase the train capacity of the marshalling yard by 80%, allow 750 metres long trains, thus increasing the train length by 35% and the speed of marshalling operations.

8.5.2 Road transport

In most ports, road transport remains the dominant cargo and passenger movement modality. We can distinguish between three types of traffic that are related to the port. The first, although out of scope of the MAGPIE project, is the movement of people, either as passengers or as workers, to the port. This type of traffic is difficult to impact for the port authorities. However, given the development of electric cars, port authorities have been supporting the decarbonisation of passenger transport by offering recharging columns in proximity of port areas, that are often located in the centre of urban areas, such as in the case of HAROPA PORT and Valenciaport, or by providing alternative fuels, such as hydrogen or CNG, as in the case of Port of Hamburg. Port of Hamburg is also one of the ports that has supported the transition of the Port Authority's land vehicles to electric vehicles. It should also be mentioned how several ports, e.g. Port of Antwerp-Bruges and Port of Rotterdam, have been developing bike infrastructure to facilitate mobility within the port areas and across the city.

The second type of traffic is light cargo vehicles, for which, similarly to passenger vehicles, port authorities have limited ability to impact technology transition, as this traffic is often only partially port related, and operators are very fragmented.

The third type of vehicles that transit through the port, are heavy duty vehicles and, in this segment, several ports have developed stricter rules and provided incentives for vehicle improvements. For this type, low-carbon technologies are not yet fully available, and in many ports, transitioning heavy-duty trucks to better engines would improve port performance already (Acciaro & McKinnon, 2015). For the heavy-duty vehicles, specific fuelling stations need to be available or developed when they are transferring to a zero-carbon fuel, due to their size. The most well know effort is probably the Californian Clean Truck programme, which was able to reduce air pollution from harbour trucks by more than 90 percent. In 2008, the Port of Los Angeles banned pre-1989 trucks, followed by a progressive ban on all trucks that did not meet 2007 emission standards by 2012.

The complexity of implementing vehicle-renewal policies impacting heavy-duty vehicles, however, should not be underestimated. For example, there are about 1,800 diesel-powered drayage/container trucks licensed to operate with port terminals in Vancouver. As all Canadian ports are federal, policy decisions are centrally made and need to account for the needs of various ports. In this context, port authorities may have limited influence on mandating energy transition. However, they can participate in voluntary actions. A potential strategy is for ports to participate join projects and pilots. For example, the Port of Sines has participated in several national and international projects in the context of the energy transition, with a focus on transport chains looking at Portuguese import and exports. The port of Vancouver has many voluntary initiatives that target drayage (e.g. truck licencing system), as well a variety of international collaborative initiatives, such as the World Ports Climate Action Program.

8.5.3 Inland waterway transport

Barge and inland vessel operators are independent from ports and there is limited evidence of inland ports or large ports being able to impact technology transition in this modality. Port of Rotterdam can set rules (Havenverordening) about entering the port for inland barges (and sea-going vessels). In this regulation, emissions are the largest factor and, due to Port of Rotterdam's position in inland shipping, it affects a large part of the inland shipping in EU. It should be noted that bunkering for barge transport generally takes place in seaports. As low carbon alternative fuels are less-energy dense, reducing the risk of loss of carrying capacity on barges, might result in heavier reliance on inland ports for bunkering operations. New bunkering facilities can be developed in individual ports, but one of the main challenges is the development of a network of refuelling points.

The main infrastructure needs for decarbonising barge transport now are the uptake of OPS refuelling points (already discussed) and the provision of facilities for exchanging batteries. Inland ports report that intervening in the hinterland is difficult and that the choice of alternative forms of propulsion is left to rail/road/barge operators.

There have been successful examples of hydrogen or batteries, although these technologies are not yet fully adopted. As an example, the Port of Rotterdam collaborates with a group of companies, including Wärtsilä, ING Bank, Engie, to launch the Zero Emission Services B.V. (ZES) consortium, with the goal to expand zero-emission inland shipping. To achieve this they are developing a fully electric barge with replaceable battery containers, the so-called ZESPacks, which would be able to go 50-100 km (31-62 miles) and then swap the pack (see also MAGPIE WP5, Demo 7). For such battery swaps, however, infrastructure can be relatively easily developed[18]since infrastructure for containers can be used.

The use of hydrogen is still at the pilot stage, so the type of infrastructure that will be required for the energy transition and the viability of the technology for inland ports is yet unclear. The H2SHIPS project, which includes HAROPA PORT will develop a plan for the implementation of a pilot on the river Seine in Paris after the end of the project. The project aims to demonstrate the added value of hydrogen for inland water transport and develop a blueprint for its adoption across Europe[19]. Port of Antwerp-Bruges has developed a hydrogen fuelling station for barges as well.

8.5.4 Pipeline

Pipelines are the perfect modality when large volumes of gas or liquid cargo need to be transported either within a port or to and from the hinterland. It is safe, low in OPEX and, since it runs on electricity, can easily be transformed to a zero-emission modality. The energy transition results in major developments in pipeline infrastructure, either transforming current pipelines (like the European Hydrogen Backbone initiative) or building new ones (like Porthos, a CO_2 pipeline in the Port of Rotterdam, or the Deltacorridor, a pipeline bundle between the port of Rotterdam and Ruhr area). Pipelines are often the accelerator of other developments, as can be seen in the 'Cluster Energie Strategie' of the Port of Rotterdam and Moerdijk for the energy transition related developments in these ports. Within the Hytruck project (1,000 heavy hydrogen trucks on the road and 25 hydrogen filling stations, between Duisport port, Port of Rotterdam and Port of Antwerp-Bruges), for example, the hydrogen pipelines are used to supply the hydrogen filling stations and will determine the locations of these stations.

[18] Zero Emission Services (ZES), https://zeroemissionservices.nl/en/homepage/
[19] Interreg Project H2SHIPS - System-Based Solutions for H2-Fuelled Water Transport in North-West Europe.

8.5.5 Electricity transmission cables

Electricity has been discussed extensively in Chapter 4. In this section on infrastructure, it is worth noting that during the project it emerged that ports do not have any impact on the development of electricity grids to and from the port. As many ports globally are increasingly becoming reliant on (renewable) electricity and (renewable) power generation within the port is increasing, connecting lines to the port will need to be upgraded. From the interviews carried out during the project, there does not seem to be an active role, besides lobby, for port authorities, if not in upgrading the port internal grid to meet OPS requirements among others. Valenciaport, for example, explicitly plans to upgrade and expand their power grid.

8.6 Conclusions

Ports, and especially gateway ports, play a central role in hinterland transport chains. The energy transition in the port hinterland should be a priority for many ports, even though port authorities often have little to no influence on the technological and operational decisions of hinterland transport service providers. A lot of efforts have been put in fostering emission reductions through modal shift and intermodality, but the road transport remains in most ports the preferred choice for moving cargo to and from the port. Efforts at facilitating the transition to low- or zero carbon vehicles, by providing incentives and offering adequate refuelling and recharging infrastructure are underway, but generally require a mix of policies and collaboration among port authorities, infrastructure providers, city and regional authorities, haulage companies, vehicle manufacturers.

9 Digital infrastructure and smart technologies

9.1 Introduction

The term "digitalisation" is used to describe the process of implementing a variety of digital technologies to enhance the productivity, efficiency, sustainability, and transparency of processes (Agatić & Kolanović, 2020), as well as enhance the efficiency and transparency. The use of information and communication technologies has become increasingly crucial in the transportation industry, as ships, ports, and offshore facilities have become increasingly dependent on them (Sanchez-Gonzalez et al., 2019). It may also provide a competitive advantage by connecting all the involved stakeholders in the value chain (Feibert et al., 2017). The maritime transport sector and ports are seeing a slower rate of digitalisation and digital transformation compared to other transportation sectors, despite the opportunities (Kapidani et al., 2020).

It is possible to use digital solutions for port operations to identify, monitor, and aggregate the necessary data in order to improve the port's environmental and operational efficiency. Digital technologies are used in smart ports to overcome the challenges that occur as a result of the increased number of ships, vehicles, and other equipment in ports, such as congestion. In addition to reducing CO_2 emissions, operating costs, and chances of system failures, these advanced digital technologies, such as remote sensors and big data analytics, can also improve information security, warehouse management, and smart energy management, among other things. In addition, digital technologies, such as Internet of Things, can be used to monitor logistic operations as well as fuel utilization in a smart port. The exchange of electronic data between the shipping lines and port terminals is essential to facilitating a successful exchange of information (Acciaro et al., 2020).

In the last decade, digitalisation has become one of the main priorities of ports globally and industrial and academic interest has increased enormously. A recent literature review (Jović et al., 2022), identified 100 new publications only between 2019 and 2020, without considering industry and regulatory reports. It is therefore beyond the scope of this chapter to provide a review of the current debate on digitalisation in ports. This chapter, therefore, focuses on the role of digitalisation for the energy transition. This chapter focuses on digital technologies (Section 9.2) and digital infrastructure (Section 9.5).

9.2 The role of digitalisation in the energy transition in ports

It is possible to significantly reduce greenhouse gas emissions and improve the overall efficiency of the port systems by using smart energy technology at the seaport level. Moreover, with this technology, shipping, fishing, and maritime tourism will be able to become more efficient and competitive on the global market as a result (Alzahrani et al., 2021).

Digitalisation is an integral part of the energy transition, and it is clear that, without digital infrastructure, it would not be possible to advance the energy transition as some technologies are reliant on digitalisation. For example, several ports mention virtual power plants and peak shaving as the most direct potential uses of such digital interactions (see also Chapter 5). Monitoring is also mentioned as an area of potential improvement. The actual use, however, of these technologies remains at best at pilot level, except for in larger ports (e.g. Port of Rotterdam, and Port of Antwerp-Bruges). An interesting examples is the Port of Esbjerg, where digitalisation has been advanced by creating a close partnership with a technology supplier.

A recent review of decarbonisation efforts in ports (Alzahrani et al., 2021), list the following digitalisation technologies as having an impact on the port energy transition:

- *Smart grids:* A smart grid in a seaport is an intelligent network of electricity distribution and usage that uses digital technology to monitor and control the flow of electricity. It is designed to be more efficient and reliable than traditional power grids, and can also provide real-time information on the energy consumption of individual users and businesses. Smart grids in ports can help to reduce energy costs and emissions, while also improving the overall efficiency of the port. Smart grids can also help to reduce the risk of blackouts, reduce the need for costly infrastructure upgrades, and enable the port to better manage its energy resources. Smart grids in ports can also help to improve the safety of the port and its environment, by providing real-time information on the energy.
- *Microgrids:* A microgrid is a localized energy system that is connected to the main grid but can also operate independently. In ports, microgrids are used to provide reliable and resilient power to port operations and services. Microgrids can be used to reduce the cost of energy, enhance efficiency, and improve the reliability of energy supply. They can also help reduce emissions, increase the use of renewable energy sources, and provide a more secure and reliable source of power. By utilizing a combination of different sources of energy, microgrids can provide an efficient, reliable, and cost-effective way to power ports.
- *Distributed power generation:* Distributed power generation in ports is a concept that involves the generation of electricity closer to the point of use, rather than relying on large-scale, centralized power plants. This type of power generation is typically done with distributed renewable energy sources such as solar, wind, and biomass. By utilizing these sources of energy, ports are able to reduce their carbon footprint and become more sustainable. Additionally, distributed power generation in ports can provide a more reliable source of power, reduce the cost of energy, and help to protect the environment. Ultimately, distributed power generation in ports is a great way to reduce the environmental impact of energy production, while providing a more reliable and cost-effective source of energy.
- *Energy management systems:* Energy management systems in ports are systems designed to improve the efficiency of energy use and reduce the environmental impact of port operations. The systems help identify and manage energy consumption, optimize energy use and reduce energy costs. They also help to monitor energy consumption and identify areas for improvement. The definition of an energy management system in a seaport is a set of tools, processes, and technologies used to monitor, measure, analyze, and control energy consumption and costs. The system can help to identify and prioritize energy-saving opportunities, reduce emissions, and improve operational efficiency. The system also provides data to help make more informed decisions about energy use and investments in energy-saving technologies.

- *Virtual power plants:* A Virtual Power Plant (VPP) is a type of energy infrastructure that uses digitalisation and digital technologies to aggregate and control distributed energy resources (DERs) such as solar, wind, and other renewable energy sources. VPPs are designed to optimize the performance of distributed energy resources while increasing the reliability and efficiency of the power grid. In ports, VPPs can be used to generate electricity from renewable sources, such as solar and wind, while also providing energy storage and demand response services. By utilizing digital technologies, VPPs can provide efficient energy solutions to ports, enabling them to reduce their reliance on traditional energy sources and reduce their carbon footprint. VPPs can also facilitate the integration of electric vehicles into energy storage.
- *Artificial intelligence (AI)*: AI-driven digitalisation could enable the automation of port operations, such as vessel tracking, berth scheduling, cargo handling, and route optimization. AI can also be used to monitor emissions from ships and identify potential sources of pollution. AI can be used to monitor and analyse data on port emissions, helping port authorities identify areas of improvement and develop strategies for reducing emissions. In addition, AI can be used to improve the safety of ports and reduce the risk of accidents, in this way facilitating the adoption of new energy transition technologies.
- *Information and communication technology (ICT):* In ports, ICT is increasingly being used to digitalize operations and processes, optimize resources and increase efficiency. Digital technologies are being used to reduce the environmental impact of port operations, increase safety and security, and enable the decarbonisation and energy transition of the port industry. For example, ICT is being used to monitor port operations, improve navigation and traffic, and manage cargo handling and storage. Additionally, ICT is being used to develop smart port systems that enable real-time monitoring and control of port operations, as well as facilitate data sharing and collaboration with stakeholders.
- *Internet of Things (IoT):* The Internet of Things (IoT) is defined as a network of physical objects, such as port equipment, locks, bridges, traffic signals, connected to the internet and able to exchange data. IoT is often associated with digitalisation in ports as it could transform the way ports operate by automating and optimising processes. Digital technologies, such as sensors, devices, and software, are used to collect data on port operations, which can then be analysed and used to improve performance. IoT also enables decarbonisation and energy transition in ports by providing real-time data on energy consumption and enabling smart energy management.
- Smart ports: Smart ports are defined as ports that have embraced the digitalisation of their operations, integrating digital technologies such as automation, artificial intelligence, and the Internet of Things into their core operations. These technologies enable ports to reduce their environmental footprint, optimize their operations, and improve their overall efficiency.

All ports interviewed showed interest and a strong focus on digitalisation. The main drivers of the use of digitalisation in relation to the energy transition are linked to the usual benefits of digital technologies such as:

- Improved supply chain visibility

- Better documentation management and reporting procedures (customs, inspections, etc.)
- Improved communication with internal and external stakeholders
- More efficient and effective training of new staff and digital literacy
- Improvement in coordination of cargo movement/intermodality
- Improvement in visibility of vessels, trucks, trains, and/or barges
- Benefits associated with the development of the port single window
- Benefits associated with the use of digital twin technologies, such as cost reductions and ability to run more precise simulations
- Growth of start-up environment near the port
- Supporting of intermodality and modal shift
- Support of rail and barge modes (rationalising infrastructure development, visibility)

9.3 The purpose of smart technologies

Smart technologies are tools to achieve the decarbonisation of logistic processes associated with ports, but often it is unclear in what way they can contribute to the energy transition. As seen in the previous paragraph, smart technologies are becoming widely available to ports, but if it is not clearly defined which efforts should be prioritised in terms of energy transition, the implementation of innovative technological solutions may be in vain.

During the interviews, the following uses of smart technologies for the energy transition were identified as promising:

- *Enhancing the efficient use of energy*: Smart technologies can support achieving a better match between the energy supply and demand, i.e. efficient supply and consumption of energy (e.g. smart grids, microgrids)
- *Increasing reliability of information*. Smart technologies can help improve the quality of information regarding the real impact low and zero carbon fuels and energy carriers (e.g. sensors, ICT)
- *Transparency*: Information technologies are crucial to increase the transparency of port operations, both inside and outside the port itself. Some of the drivers for the energy transition come from outside the port (e.g. national/local governments, civil organizations, etc.), and smart technologies can help with sharing information, best practices and efforts made within the port on improving its social acceptability.
- *Efficient environmental monitoring*. Currently, there is available technology to address several environmental dimensions (e.g. air and water quality). However, this monitoring is not as systematic nor transparent as it could. Smart tech should play a role in this, especially considering the maturity of the different solutions.

- *Better overview of the port.* Today, there are many blind spots regarding port operations (their impact, efficiency, externalities) or even the land use and infrastructural conditions, i.e. often it is not clear enough what is happening in the port and to get a real image takes time. Smart technologies can help improve the mapping of the port (e.g. digital twins) to improve the efficient use of resources.

9.4 Recommendations on the uptake of smart technologies in ports

The potential and uptake of smart technologies in ports for energy transition depend on the port profile, including issues such as scale, resources, corporate culture, business model, and governance model. These will have significant influence in the implementation of smart technologies. In particular, corporate culture can play a very relevant role in the capacity or willingness of a port to implement innovative technologies.

The vision and culture that the port adopts will be critical in the successful uptake of smart technologies for advancing the energy transition. When port organisations strive to promote the sustainable development of the maritime sector, they could be seen as blue economy hubs (European Commission, 2021*b*). A blue economy hub is defined as an integrated system of digital technologies, services, and activities that enable the transition to a low-carbon, climate-resilient, and resource-efficient economy. The hub is designed to drive digitalisation, energy transition, and climate change mitigation initiatives in the transport/port sector.

In this perspective, a port would provide access to data, information, and services that enable the efficient use of resources, the implementation of green technologies, and the development of innovative port business models. The hub also contributes to the development of a sustainable port industry by promoting the use of renewable energy sources and the adoption of energy-efficient technologies. If the port sees itself as more than just a logistic infrastructure, also embracing its role as blue economy hub, it will be more willing to support new technological solutions.

So far, the use of smart technologies has been primarily driven by improving operational efficiency and information transparency. But accelerating the energy transition will require leveraging on smart technologies, even if it is still unclear what technologies will lead the way. For majors ports such as Port of Rotterdam, Port of Antwerp-Bruges or Port of Hamburg, certain investments on smart tech can be easily justified due to the potential gains connected to their size. For other smaller ports, it would be harder to justify the risk to invest in one new tech, since the potential impact is reduced, particularly for solutions that are not very mature yet.

Furthermore, it should be noted that digitalisation in ports consists of primarily digitalising transactions in the port, that often involve multiple private and public parties (e.g. customs, harbour master, marine service providers, terminal operators, shipping lines, etc.). Digitalisation is therefore not something which port authorities can implement entirely on their own.

9.5 Digital infrastructure

The digitalisation of ports is essential in the energy transition and tackling climate change, but the development of smart technologies also requires adequate digital infrastructures. Digital infrastructure brings together and interconnects physical and virtual technologies such as computer, storage, network, applications, and cloud computing platforms to build the foundation for a company's digital operations. In the case of ports, these include data exchange terminals, servers, data networks, and sensors. These developments are integral to the digitalisation strategy of the port and are not specific to the energy transition.

Digital infrastructure can be used to collect, store and analyse data to identify inefficiencies and areas for improvement. Among the concepts that have been often associated with the energy transition in ports, there is a wide array of potential applications, such as digital twin, artificial intelligence, data analytics, and automation among others. The success of these concepts is linked to security, information sharing, efficiency and monitoring.

Internal corporate networks, multicloud and back-end data infrastructure locations can be utilized to create an efficient, secure and reliable platform for the exchange of data. These networks provide a secure platform for the transmission of sensitive information, such as shipping manifests and customs declarations, as well as providing access to real-time tracking of vessels and cargo. In addition, these networks can be used to store and protect large volumes of data, enabling seaport users to store and access data from multiple locations. By leveraging digital infrastructure, ports could ensure that their operations are secure and efficient, while providing customers with the highest level of service.

A seaport is a complex business system that is increasingly becoming a global hub of data exchange for a variety of stakeholders, within a complex infrastructure system. A coherent approach is needed to digitalize complex systems, aiming to bring together managerial and digitalisation goals at the same time. IT-services are a key component of creating a digital-based system of business processes, which is characterized as an extension of the business functions themselves. A coherent system of business processes for ports can then be identified that could be further developed into a complex Applications Architecture for ports, based on the adaptation of enterprise architecture standards. The Applications Architecture can be further enhanced with modern digital technologies and a variety of information systems of various types to create an even more comprehensive applications architecture (Lepekhin et al., 2020).

An example of digital infrastructure with relevance for ports is the development of 5G technology, that can be used to optimise port operations, reduce emissions, and improve efficiency. It can also be used to provide real-time data on vessel and port operations and to monitor and control the energy consumption of port infrastructure and vessels, allowing for improved decision making. In addition, 5G technology can be used to facilitate the development of smart ports, enabling the integration of renewable energy sources and the automation of port operations.

5G networks are an example of an enabling technology that can be applied in ports with potential benefits for the energy transition. HAROPA PORT, for example, signed in 2019 a memorandum of understanding with Nokia to improve the connectivity within the port. The EU 5G Mobile Network Architecture research project (MoNArch) set up a 5G network in the Port of Hamburg to test three different applications:

- real-time monitoring of environmental data.
- traffic management; and
- transmission of large amount of data available, for example, to 3D applications.

Similarly in the Port of Antwerp-Bruges, the country's first 5G network was set up in 2019. In the Port of Rotterdam, 5G technologies were used to improve pipeline maintenance. It goes without saying that these technologies can be used also for accelerating the energy transition (Uyttendaele, 2020).

In order to realize the potential of smart technologies, it is important to identify applications that are specifically tailored to the needs of each port, particularly in relation to its scale, resources, and energy transition needs.

9.6 Conclusions

In this chapter, an overview of the state of the art of digitalisation in relation to the energy transition has been provided, focusing on the purpose and benefits of digital technologies, how they can successfully be implemented and the importance of the digital infrastructure in ports. A clear distinction between a port digitalisation strategy and the energy transition cannot be proposed easily, as digital technologies are instrumental and fully embedded on the one side in the strategy the port has adopted and on the other side cannot be separated from the specific processes it supports.

A categorisation of ports, based only on the smart technologies they have implemented, will not be meaningful for accelerating the energy transition, since this will be connected to the specific needs of each port and will depend on the scale, resources, and ultimately port strategy. There is also the risk that a categorisation would be dominated by larger ports, that can more easily justify the implementation of smart technologies, while it would neglect the diversity of port profiles. A potential categorisation, regarding base conditions to implement smart technology solutions, would need to account for the following considerations:

- It is important to have a clear definition of the goals the smart technologies would want to achieve in relation to the energy transition.
- A masterplan for the energy transition should define key areas to be prioritized, which could assist in choosing smart technologies.
- In order for smart technologies to take off, it would be necessary to mitigate the impact of traditional barriers to data sharing, such as contracts and legislation.
- The port should be characterised by a corporate culture, which enables innovation to flourish.
- It can be beneficial if the port is involved in a research or innovation cluster (e.g. Port XL) and if the port is collaborating with local or international research institutions.

10 Energy transition governance

10.1 Introduction

The governance of energy transition in ports is a complex process, requiring the involvement of many different actors. Port authorities, as the governing bodies of the port and often of the port cluster, play a pivotal role in this governance. Through the development of policies and regulations, port authorities can provide a framework for the efficient transition to more sustainable energy sources. In addition, they can provide incentives to promote the adoption of sustainable energy solutions. Additionally, port authorities can facilitate the involvement of other stakeholders, such as private companies, non-governmental organizations, public entities, and citizens. These stakeholders can contribute to the energy transition through the development of innovative technologies, the implementation of energy-efficient practices, and the promotion of public awareness on the importance of sustainable energy sources.

Energy transition governance in ports is the process of managing the transition of ports to a more sustainable energy system. This includes the development of new energy policies, the implementation of renewable energy technologies, the promotion of energy efficiency, and the adoption of new energy management practices. It also involves the coordination of public and private stakeholders to ensure that the energy transition is successful and beneficial for all stakeholders. The key to successful energy transition governance in ports is to ensure that all stakeholders are engaged in the process and that the resulting changes are beneficial to all. This means that there must be a clear definition of the roles and responsibilities of each stakeholder, as well as an understanding of the potential benefits and challenges associated with the transition.

The energy transition governance can be seen as the set of mechanisms, rules, and responsibilities that govern the interaction and decision-making processes among port stakeholders and port actors. Stakeholders are those who have an interest in the port and its operations, such as government and local authorities, port users, and environmental groups. Port actors are the people and organizations who actually take, or directly impact, decisions on the development of the port, these can be shareholders, port customers, or port managers. The industrial cluster around the port is also a key player in the energy transition, consisting of businesses and industries that depend on the port for their goods and services. Stakeholders and port actors work together to ensure the port's success and the port authority is responsible for managing the various interests of all parties involved.

This chapter is structured in the following way. In the next section the importance of governance for port energy transition is discussed. This is followed by an overview of governance models seen in ports (Section 10.3). The role of different actors is then discussed in Section 10.4. How the energy transition can enhance competitiveness of ports is the topic of Section 10.5

10.2 The importance of governance for the energy transition

Port authorities play a central role in the development and management of industrial port clusters. This role also includes coordinating, supporting, and incentivizing the energy transition. However, the role and potential of this function clearly depends on the governance structure chosen by the port. A crucial dimension here is the collaboration with internal and external stakeholders and the role that the energy transition plays in the strategic vision of the port authority. Over the years, port authorities have developed different approaches to managing the energy transition, in some cases, for example, developing specific bodies entrusted with the coordination of stakeholders, while in other cases relying on the collaborative platforms provided by regional or state actors.

Most strategies entail developing partnerships with the community or local businesses. In some cases, we observe also cross-port collaborations, in the case of Europe, often facilitated by ESPO or EU-funded projects. By working with other businesses, port authorities can facilitate the development of cooperative projects and share their risks, costs, and benefits. Port authorities are also interested in developing solutions that apply to other ports or similar industries, so they can be used as templates for implementation at multiple ports or improve a business case (like, for example, the implementation of OPS)(Mudronja et al., 2022). This is valuable because ports are complex and have unique challenges when implementing different types of sustainable solutions.

In the literature, institutional barriers and organisational constraints are often identified as major obstacles to the energy transition(e.g. Notteboom et al., 2020; and Damman & Steen, 2021). These include jurisdictional issues, lack of coordination, lack of information and incentives, standard definitions, and governance. Identifying successful governance models to accelerate the energy transition is critical, as port authorities can act as catalysts for the energy transition, as discussed in MAGPIE WP 7 (D7.1) in more detail. This role might be linked to information sharing, acting as facilitators, providing incentives, and streamlining administrative practices, among other activities. As cooperation and coordination are linked to the governance structure that is used for the energy transition, also the extent to which other actors are driving or being involved in the transition is relevant.

The extent to which the port authority is able to influence or drive the energy transition is also related to the level of environmental awareness that exists at the port. Environmental awareness is directly linked to the information being collected in the port. Those ports that have extensive environmental data will be in a better position to realize the benefits of energy transition and, in turn, those ports where environmental problems are particularly evident will have to prioritize energy transition. For this reason, it is valuable to also observe what environmental monitoring systems are in place at ports and how exposed they are to one of the main drivers of the energy transition, climate change. While all ports interviewed, and an increasingly large number of ports worldwide, have extensive environmental programs, it is often difficult to distinguish between aspirational goals and actions carried out on the ground.

A port's capacity and drive for energy transition are also influenced by organisational, governance, and cultural aspects. These relate in particular to the port's relationship with its stakeholders (e.g. the city), the port's governance structure, and the political framework in which the port operates. Both the public role and commercial expectations of ports have increased. More than in the past, ports are expected to be commercial, but at the same time, the public function and role of ports is on the rise again, largely because of their increasing importance as strategic assets and the role they play in greening transportation, industry, and energy production (Deloitte-ESPO, 2021).

The latest ESPO Environmental Report (ESPO, 2022*a*) shows that climate change is the top environmental priority for port managers in 2022, followed by air quality and energy efficiency. While air quality and pollution in general, as well as energy consumption, have been high priorities for more than a decade, climate change only appeared in the top ten environmental priorities in 2016 (at number 7), gaining urgency year by year.

Awareness is one of the preconditions for action, so it is valuable to assess the exposure of ports to climate change, the extent of environmental monitoring that is carried out, as well as the perspective of ports on biodiversity and the circular economy (see also Chapter 3). This allows to frame the governance of the port within the specific environmental context of the port. This is also important for determining the pressure that might be exerted on the port in terms of energy transition from external and internal stakeholders.

10.3 Governance models for energy transition

Port governance is the process of managing and overseeing the operations of a port. This includes decisions about the infrastructure, resources, personnel, and activities of the port. It also involves ensuring the port is compliant with relevant regulations and laws and the strategic development the port shall pursue. It involves collaboration between port authorities, government agencies, and other stakeholders to ensure the port is managed in a way that best serves the interests of all parties. The dominant governance model in a port is the result of a complex interaction between port authority, stakeholders, and other bodies within the frameworks provided by the law, customs, and business practices. Port governance has been extensively researched (see for example: Zhang et al., 2019; and Zhang et al., 2018) although not in relation to the energy transition.

The governance of the energy transition in ports can be defined as the set of rules and relations that define the priorities and efforts related to the energy transition, including responsibility for, funding, regulating and managing of energy transition initiatives. The energy transition governance in ports takes different forms and depends on factors such as:

- Legal and policy framework within which the port operates,
- Port governance laws and regulation and in particular, the allocation of responsibilities between port authority, city administration, local and regional authorities, and the central government,
- The relationship between the port authority and the other administrations and institutions,
- The relationship of the port authority with internal and external stakeholders,
- The local, regional, and national government strategies in relation to energy transition,
- The role of hinterland transport infrastructure providers and operators and their relationship with the port authority,
- The port cluster governance in general and in relation to energy transition.

Depending on the different circumstance different energy transition governance structures have emerged in ports. In some cases, the energy transition has developed organically within the port competences, and it is a function within the port management administration. All major ports have developed competencies in energy management and energy transition that they can draw upon as an organization to inform and guide the process (e.g. Port of Antwerp-Bruges, Port of Hamburg, Port of Rotterdam), sometimes with the support of academic institutions, external, or governmental expertise. In other cases, the energy transition is led outside of the port authority through a foundation or some other form of committee that coordinates efforts among stakeholders (e.g. Valenciaport). In some cases, the port energy transition is managed through collaboration between the port authority and national or regional utilities (e.g. Port of Vancouver, Port of Los Angeles/Long Beach). The focus of such entities is collaboration and/or communication with stakeholders. In some cases, the energy transition governance is driven by local or national institutions outside the port authority (e.g. Port of Sines), or is primarily in response to customer's demand (e.g. DeltaPort).

The choice among different governance structures depends on what is driving the energy transition in the port in addition to the general governance frameworks in which the port operates. The drivers for the energy transition fall into four categories and are explained in Table 10.

Table 10: Energy transition drivers and focus.

Driver Energy Transition		**Focus**
Alternative governance models	Within the port authority	Strategic: The port authority is in a position to drive the energy transition forward, within the limits set by resource-availability. This may be the result of a strategy that originated in the port business, e.g. as a result of a change in cargo mix or port technologies.
	Driven by the port authority's shareholders	Shareholder-driven: The port authority acts as a vehicle of its major shareholder, typically a government agency, to advance an energy transition strategy originating outside of the port business. The strategy will be determined by the willingness of the shareholders to provide resources to advance the energy transition.
	Driven by the port (external) stakeholders	Stakeholder-driven: The port authority responds to pressure from local or national stakeholders. The strategy for the energy transition is determined by what the port authority has to do to deal with the stakeholders.
	Driven by industry or customers (or internal stakeholders)	Customer-driven: The port authority responds to pressure from internal stakeholders (customers, port industry, energy stakeholders). The strategy is determined by the willingness of these stakeholders to provide resources to drive the energy transition.

A further issue, that impacts the energy transition is the extent to which stakeholders are involved. Port energy transition is clearly a collaborative effort and stakeholders play a critical role in terms of fast tracking the uptake of certain technologies, developing pilots, rationalising the use of energy, and providing incentives to their customers for energy management and energy efficiency, among other. The involvement of stakeholders can be driven by the port authority, by the stakeholders themselves, either internal or external, or by the city or other local, regional, or national authorities (see Section 10.4).

The energy transition is also impacted by policy at national, European, and international (e.g. IMO) level. On the national level, individual countries have their own regulations and procedures that must be taken into consideration, while on a higher, continental level, the European Union has established its own set of guidelines that have been developed to accelerate the energy transition of various sectors (including transport, shipping and energy). Furthermore, international organizations such as the IMO, have set forth regulations and standards that must be adhered to by port operators around the world. All of these policies, from the local to the international level, must be considered in order for the energy transition of ports to be successful. For example, financing of cold ironing would be easier if such measures were mandated and thus their costs could be transferred to port users.

As a matter of fact, one of the most critical aspects relating to governance concerns financing. The energy transition requires different sources of financing at different stages. The sources of financing, to which energy transition projects have access, depend on port laws, accounting rules, and financing practices, in addition to the specific characteristics of the energy transition project. While initial financing might be provided as subsidies for developing new technologies or energy transition concepts, the implementation of such concepts typically relies on a mix of public and private funding sources, and, at some stage, will entirely be developed privately. Within the limitations imposed by the national or local port governance frameworks, every party, e.g. port authority, government, city, internal stakeholders, etc. will have a role to play in providing or securing financing for the project. Of course, the funding framework differs depending on the energy transition initiative or project, the governance structure that prevails for the energy transition in the port, and the driving force promoting the project (internal or external stakeholders, government, mixed).

In the last few years, the concept of green corridors has been proposed to facilitate the uptake of low- and zero-carbon fuels. This concept aims also at facilitating port collaborations in the provision of infrastructure for the energy transition, most notably bunkering infrastructure. The Port of Rotterdam and the Port of Hamburg, for example, have joined the North Sea Green Corridor. These green corridors will also extend inland and include the major inland waterways in Germany and the Netherlands.

10.4 Actors

The energy transition governance depends on cooperation and the vision of port actors. Depending on the port every port actor can play a leading or supportive role. While, in general, the leading transition role is taken by the port authority, other actors might be behind this function, or multiple actors might be leading the transition, acting as drivers collectively. Within Port of Rotterdam, for example, the stakeholder field changed due to the energy transition (e.g. the gas network became part of the stakeholders' field with the hydrogen development).

Depending on the actors driving the energy transition in ports, we can distinguish between three types of drivers:

- Internal drive: Port authority or port authority and its shareholders (generally national or local governments)
- External drive: City, industrial cluster managers, other local or national authorities (not necessarily as major shareholder of the port authority), as well as firms, that are not direct port customers but are reliant on the port for their activities.
- Stakeholder's drive: Port customers (including ship owners and operators, terminal operators, and cargo owners) and other stakeholders, including citizen groups and non-government organisations, as well as hinterland transport service providers.

All the above actors can also be supporters of the energy transition by, for example, putting pressure, providing support, funding, developing policies that accelerate the energy transition. It should also be noted that the actors operate in a local environment that might show different degrees of innovativeness, for example thanks to the presence of research and academic institutions, a start-up ecosystem or other industrial clusters that can offer synergies for the energy transition.

Employment issues also need to be considered in the energy transition. This is because the energy transition can cause the need to requalify workers, can increase demand for skills and competences that were not traditionally part of the port domain, and can be substantially delayed because of conflict with workers' unions. The recruitment practices, wages and working conditions might need to be adapted in relation to the energy transition.

This highlights the inherently collaborative dimension of the energy transition, where all actors need to participate, either proactively or supportively, for success.

10.4.1 Internal drive

The energy transition can be driven by the port authority. This depends on the size and scale of operations at the port (e.g. small urban gateway port vs. large scale industrial port complex), and the role(s) which the port authority plays in the port. The port authority is usually the organisation responsible for managing the port and has a high degree of freedom of action and autonomy. The port authority facilitates the energy transition for example by:

- Providing incentives
- Setting standards
- Contracts and concession requirements
- Planning
- Coordination of initiatives and pilot projects
- Determining strategies for land allocation

The port authority can act as a leader in port energy transition even in response to pressure from external or internal stakeholders or from shareholders, in pursuit of a top-management vision, in response to pressure from customers, or a combination of these.

10.4.2 External drive

The external drive relates to a push for the energy transition that is driven by organisations outside the port, that are impacted by the port activity and that possess direct or indirect agency on the port. These include most notably the city, other local authorities, and the national government. Significant pressure can also be exerted by international organisations, such as the EU. This generally takes the form of legislation, regulations or financial incentives or penalties.

As most ports are situated in proximity of urbanised areas, the city administration is often concerned with the developments of the port cluster, both as a major beneficiary of port activities, by better connectivity and jobs, but also because of environmental external effects. Many ports are working closely with their municipalities and in some cases, they might be owned by them. In some cases, the city, is the main driver of the energy transition, even being able to push the port to act, even if the city is not the port's major shareholder.

Port cities, located in close proximity to a port, can play an integral role in the energy transition taking place within the port. By acting as an enabler for the energy transition, the city can provide the necessary tools and resources to drive the change taking place. This includes access to funding, which can be provided from the city itself. Additionally, the city can act as an advocate for the energy transition taking place in the port, helping to ensure its successful implementation. Furthermore, the city can facilitate the mobilization of resources and personnel, as well as providing a platform for the port to showcase its progress in the energy transition. Ultimately, the port city acts as a powerful ally in the energy transition taking place within the port (Mat et al., 2016).

The regional government can lead the energy transition, similarly to the city, in those contexts where the port is not near a large, urbanised area. This push can also happen through a port industrial cluster manager, that might include the port and can be controlled by the local government, a group of local authorities, including for example municipalities, or the national government. The national government can facilitate or mandate the energy transition through the development of laws and require ports to actively pursue energy transition, even when not directly under national government control. Among the many examples, the city of Helsinki is pressuring the port into meeting the city's environmental goals.

10.4.3 Stakeholder's drive

In some cases, the energy transition might be driven by the port's stakeholders, generally by putting pressure on the port authority. These stakeholders can be distinguished between internal and external stakeholders, with the former including among others: port customers, workers and unions, port and terminal operators, and transport service providers. The external stakeholder include citizen groups, non-governmental organisation, and hinterland transport service providers, such as railway companies.

Stakeholders play an important role in the social acceptability of the energy transition and, even when not actively petitioning for it, can act as facilitators or barriers for the energy transition.

10.5 Consequences of the energy transition governance choices

The energy transition governance model is an essential part of understanding the energy transition within a port. This model not only provides boundaries within which the port can operate, but it also identifies the areas where synergies can be leveraged and utilized. This is incredibly important in order to ensure that the energy transition within the port is as comprehensive and successful as possible. In this respect, the main issues that relate to governance, which can impact the energy transition are:

- Availability of finance: Governance structures define the resources that ports have at their disposals and how much can be invested in the energy transition. Port authorities that have resources deriving from public shareholders can invest in the energy transition, while those that do not have these funds available, have limited resources as they need access to other sources of capital, for example from the capital market.
- Relationships: Governance structures can favour or hinder relationships with local communities, internal and external stakeholders
- Knowledge sharing: The ability to share information among internal and external shareholders is a characteristic of governance structures, that are favourable to energy transition
- Skills: governance structure can make certain skills/competences available
- Overcoming trade-offs: the energy transition may result in conflicting objectives. Depending on the governance model adopted these trade-offs will be resolved in different ways (multi criteria decision with different interests)
- Competition: the governance structure might favour or hinder the development of new businesses (see also Section 10.6).

In general, during the interviews it emerged that the importance of the energy transition governance is often underestimated. It would be valuable if successful experiences on governance approaches and good practices on managing collaboration, as well as effective legal and regulatory regimes, could be documented to aid ports reform so the energy transition is supported.

10.6 Energy transition and competitiveness

During the discussions with port representatives, the issue of energy transition as a source of competitive advantage has been discussed. Ports seem to be aware of the role that the energy transition can play in reducing long term energy costs, improving relations with local communities, respond to client requirements and develop potential new business areas, such as the production and logistics of low and zero-carbon energy carriers.

With few exceptions, however, the energy transition for most ports in practice has been driven primarily by research and development and public relations, so that is its difficult to make a clear case for the economic benefits that can be associated with the energy transition. Energy transition developments often would not be financially viable without public support. Important investments are being carried out by energy majors and other private actors, but they often only marginally involve ports. This does not mean that ports are not affected by these developments, but their main role seems to be primarily that of supporting the energy transition.

At a policy level, however, ports have been identified as critical components of the energy transition of the transport sectors. Also at this level, it remains unclear whether their role will be primarily that of service providers (e.g. bunkering nodes, refuelling station, and cargo movement interfaces) or whether new types of business can emerge. The business case, albeit promising, remains unclear and most ports, as a result of limited resources or lack of expertise, seem to be waiting to see technological or demand uncertainty to be resolved. It might be too late to be able to secure a position in the low and zero-carbon energy commodities value chains, that would allow ports to capture the value generated by these new developments.

Large industrial and energy ports, in virtue of the nature of their traffics, will be forced to transition as their industrial cluster adapts. Similarly, the competitiveness of ports that have access to large amounts of renewable energy will depend on the energy transition. For other ports, however, it remains unclear how the energy transition will impact competitiveness. On the one hand, the transition from fossil to low and zero carbon alternatives, offers the possibility for energy value chains to be redefined. On the other hand, exiting infrastructures, such as pipelines, storage and power cables, as well as business knowledge, such as specific know-how, skills and industrial networks and synergies, may simply result in the reproduction of existing value-capturing dynamics, that will favour major energy producers and electricity providers over facilitators, such as ports and transport service providers.

Another aspect worth considering is that, as energy value chains are transformed, even within a single port, fuel suppliers, fuel producers, infrastructure providers, electricity suppliers, and producers of fuel feedstock and energy carriers will compete with each other to capture the value created in fuel and energy value chains. If this interaction occurs solely through arm-length transactions, there is a risk that the energy transition will be slowed. Novel approaches should be developed to improve collaboration between the parties involved.

10.7 Conclusions

Critical to the energy transition will be identifying adequate governance models able to support the transition, reconcile priorities among internal and external stakeholders and leverage on the skills and competences of the various actors involved in the energy transition. This chapter presented various forms of governance that have emerged in ports to advance the energy transition and respond to the needs of ports, their stakeholders, and industry. These governance structures have emerged either organically over time, finding the space to manoeuvre within policies and regulations often developed without sustainability in sight, or have been the result of top-down reform efforts. It remains clear, however, that there is an urgent need for clearer and more coherent models and governance frameworks that prioritise the energy transition in ports. The relationship between energy transition and port competitiveness is not yet fully understood and each port should assess how and if the energy transition strengthens the positions of the port in relation to its competitors.

11 A port typology for the energy transition

11.1 Introduction

This chapter will propose a port typology for the energy transition in the port sector. The information collected in the previous chapters was discussed with the MAGPIE consortium members in the September workshop. A categorisation of ports is proposed based on energy technologies and infrastructure, hinterland transport, and governance. This is the first time a comprehensive categorisation on the energy transition in ports has been developed, taking into account both literature, industry examples, and interviews. This categorisation can be used for providing recommendation on energy transition pathways that can help in the definition of an energy transition masterplan. This will be discussed in the port masterplan with a vision and roadmaps that will be developed later in the MAGPIE project.

In addition to Section 11.2, that explains how the topics developed in the rest of the report lead to three main themes, this chapter is structured in three more sections (Section 11.3, Section 11.4, and Section 11.5), dedicated to energy infrastructures & technologies, seagoing ships & hinterland transport, and governance. The port categories have been developed along these three themes. Section 11.6 brings the port typologies together and provides some additional considerations on their interpretation. Section 11.7 concludes the chapter.

11.2 Main themes relevant for the energy transition

In the previous chapters, the state of the art of the knowledge on the energy transition in ports has been presented. With the exception of governance and digital technologies that impact the port as a whole, the information discussed dealt with what happens within the port industrial activities and at the interfaces between the port and transport modes (including ships). Figure 7 below summarises the main elements in the port energy systems (governance and smart technologies are transversal to the energy system).

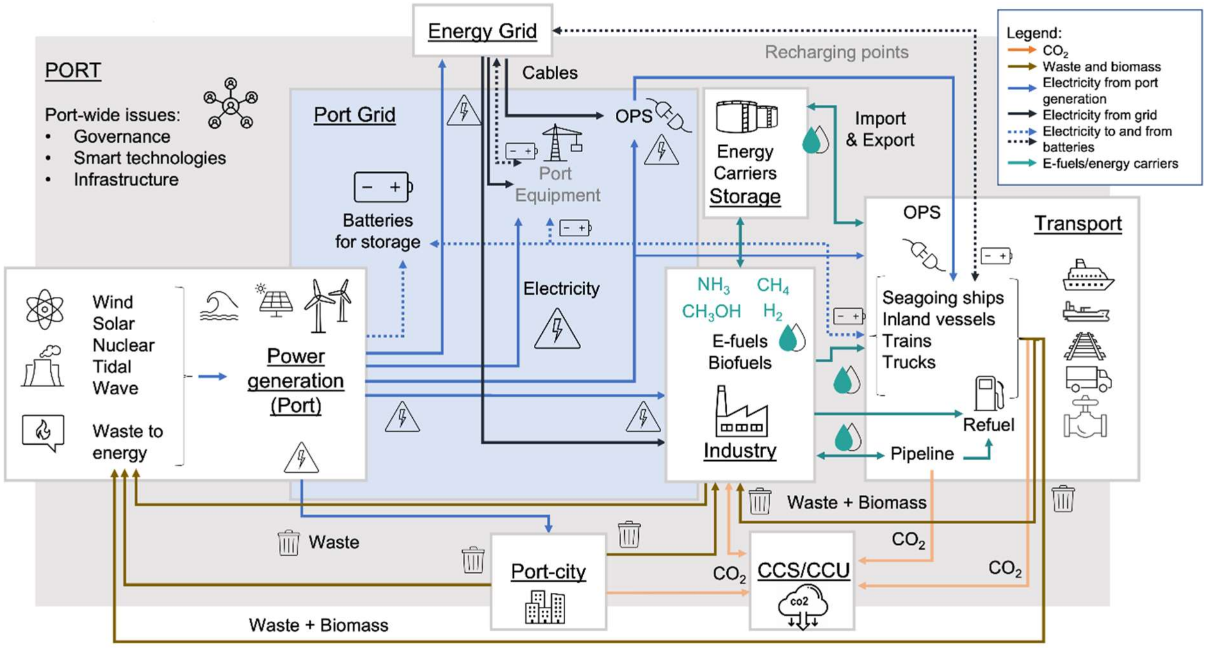

Figure 7: Port energy system. Blue shaded area indicates the port grid.

From the information collected, two main systems can be identified. One relates to power generation, on how energy is managed within the port and by extension how (renewable) energy is converted into e-fuels and other energy carriers. Another system relates to transportation systems, and specifically, on how electricity is used to power vessels and vehicles. The information collected through the MAGPIE project can then be grouped into three main themes that need to be considered when analysing the energy transition in ports:

- energy infrastructure & technology,
- seagoing ships & hinterland transport,
- and governance.

This structure was selected as infrastructure & technology, the impact of ports on the energy transition for seagoing ships and hinterland transport, and governance are the recurring general themes that are discussed when dealing with the energy transition in ports. The energy infrastructure & technology theme pertains to the processes and hardware involved in the production, storage, and distribution of renewable energy resources and low- and zero carbon energy carriers and e-fuels in ports. This includes the development of renewable energy sources, such as solar or wind, as well as the implementation of energy-efficient technologies, such as electric propulsion and energy storage systems.

The seagoing ships & hinterland transport theme relates on the one side on the uptake of low- and zero-carbon fuels, including electricity, and infrastructure for sea and hinterland transport, and on the other side to the optimization of transport processes, so that they become more energy-efficient and environmentally friendly. Lastly, the governance theme encompasses the legal and regulatory frameworks that are necessary for the energy transition to take place. This includes what forces drive the energy transition and how port stakeholders and actors can support or hinder it.

11.3 Energy infrastructure and technologies

The investigation of the current state of the art of energy transition in ports has looked extensively at energy infrastructure and technologies as one of the main determinants of the future energy transition pathways that the port can follow. The existence of certain technologies in the port, or economic and industrial activities or infrastructure, would be the first aspect that would need to be investigated to determine the future energy transition pathway for a port. However, only a limited number of ports have infrastructure that can be directly used for low- or zero-carbon fuels, and even in these cases, most infrastructure would need to be redeveloped or renovated to meet future demands and standards.

A first categorisation is proposed based on the existing economic and industrial activities present in the port. This assumes that ports that have advanced petrochemical industrial complexes or that are already important fossil fuel hubs (such as those in proximity of power generation infrastructure) would be in a better position to transform this infrastructure to supply and support the low- and zero-carbon economy of the future. Most of the ports that appear in the forefront of the energy transition are industrial hubs with a focus on petrochemical or power generation activities. While this is not a necessary condition for a port to develop these activities, this type of port clusters will have an advantage in terms of know-how, synergies, and competences as well as relations with industry players.

The extent and diversity of the industrial and power generation activities present in the port provides a measure of the extent of options available to the port. Ports without such activities would not be precluded to be the basis for new activities, but this would be less likely in view of the lack of existing infrastructure, business connections and pipeline/cable infrastructures. A categorisation on this basis is then proposed to account for the number of energy transition pathways available to ports, because of the existence of petrochemical and power generation activities. These categories are listed in the Table 11. Indicators on how to determine in which category a port falls can be developed on the basis of presence of the industrial activities or industry outputs.

Table 11: Energy-related activities in the port.

		Petrochemical industry	
		No	**Yes**
Power generation	**No**	(e1) No industrial or power activities	(e2) Petrochemical-dominated
	Yes	(e3) Power generation dominated	(e4) Both petrochemical and power generation

From the intersection of the two measures four categories can be obtained.

- No industrial or power activities (e1)
  Ports with no petrochemical or power generation activities: all pathways are possible depending on position on energy value chains and other external characteristics. Energy transition pathways will be constrained by know-how, industry relations, funding, and access to energy networks (grids, pipelines, etc.).
  These ports are likely to focus their energy transition pathways on a limited number of technologies and pilots, but they are also likely to be less impacted by the energy transition than those heavily reliant on petrochemical or power generation activities. Alternatively, they may focus more on sustainability technologies related to gateway activities such as energy efficiency, smart technologies, etc.
- Petrochemical-dominated (e2)
  Ports with petrochemical activities will benefit from developments that take advantage of existing infrastructure, for example hydrogen, ammonia, or biofuels. The energy transition pathways will be favoured by the existence of infrastructure such as pipeline and storage, but also industrial know-how and expertise.
  These ports are likely to focus on processes, that allows transition of the existing industry towards low carbon technologies. Probably attention will be paid also to carbon capture and storage or use.
- Power generation dominated (e3)
  Ports with no petrochemical activities but with power generation activities can rely on their position in the movement of raw materials for the supply of the power generation activities and on their position and connectivity to the electricity grid.
  In this case, the focus of the energy transition pathways might be related to renewable power generation and, eventually, on the provision of low and zero carbon fuels for exports on the basis of the use of renewable power generated in the port.
- Both petrochemical and power generation (e4)
  Ports in which both power generation and petrochemical industrial activities are present, have the possibility of combining the transition towards renewable and low and zero carbon fuels.
  These ports are those that are likely to have the possibility of exploring different avenues and technologies and will be able to pursue the energy transition on multiple pathways at the same time. In this case, circularity is likely to play a critical role by redeploying waste products generated through port activities.

Independently of the category each port falls in, they can also make use of organisational and operational measures, other energy efficiency measures or smart technologies.

A further categorisation is based on whether a port is primarily a user or producer of energy or both. The position of the port on production or use of energy will depend on geographical, economic, and infrastructural constrains (as well as governance but that will be addressed in Section 11.5) and is the result of the strategy that the port authority will pursue. For example, the extent to which the port authority wants to prioritize using land for energy over other activities. In some cases, these decisions are simply commercial. In other cases, they are the result of national policy decisions.

The energy pathways that can be pursued for the energy transition in a port, will depend on whether the future energy system in the port is primarily variable or stable, depending on the dominance of a certain (renewable) energy source. Based on the amount of energy available within a port, a categorisation can also be made on whether the amount of energy within a port is:

- Sufficient or balanced: This implies that local production of (renewable) power is adequate for the operations within its scope (scope meaning the activities for which it is destined or earmarked and differs per port).
- In excess or export-driven: This implies that the (renewable) power generated in the port can be used for activities outside the port. For example, transported as a product (out-of-scope of MAGPIE) or used as an energy source for transport to the hinterland (in scope of MAGPIE).
- In deficit or import reliant: This implies that the port needs to (partially) rely on imports, from outside the port area, to meet its energy needs.

For example, a port can generate electricity but has an industrial activity in which the used energy derives from burning oil. If the industrial activity is under pressure to decarbonise, the port would be balanced if the energy produced is sufficient to cover the needs of that industrial activity.

Sometimes, ports also operate as energy trading hubs, both importing energy to meet their energy needs, but also, at different times, exporting energy. This is different from the case where the port is generating an amount of energy sufficient for its uses. The difference is the focus the port places on energy trading. Trading of energy, whether in electricity or energy carriers, can be seen as instrumental to providing the energy the port needs similarly to a utility (reactive function based on needs, cost-centre) or as a business (proactive function, energy as a product, profit-centre). A possible route for a port to evolve from seeing energy as a utility to a business (e.g. Port of Sines), is to focus first on port operations and then to expand to its local network (city, industrial area and hinterland) and exporting it (e.g. hydrogen produced in Port of Sines is exported to Port of Rotterdam). The geographical location of a port affects its possibilities to obtain the required volume of energy to a certain price (depending also on optionality and availability).

On the basis of the distinction above, a further categorisation can be made along two dimensions: the degree of energy self-sufficiency and the degree to which energy is seen as a business activity. These categories are summarized in Table 12.

Table 12: Categorisation on ports on the basis of whether the port is able to meet its energy needs (self-sufficiency) and whether energy is seen as a utility or as an independent business area (business focus).

		Degree of self-sufficiency		
		Import-reliant	**Balanced**	**Export-driven**
Business focus	**Utility**	(f1) Import-reliant	(f2) Balanced utility-oriented	-
	Business	-	(f3) Balanced business-oriented	(f4) Export driven

The categories are described below:

- Import-reliant (f1): The port purchases energy to meet its need for users (including tenants, port customers, and transport service providers) within the port.
- Balanced utility-oriented (f2): The port produces energy to meet the needs of its users. It may also purchase from or provide energy back to the grid when power generation is in excess or short. Energy is produced primarily to meet the needs of the port.
- Balanced business-oriented (f3): The port acts as a hub in balancing energy flows. Energy trading is an integral part of the business of the port, that also sells energy and energy carriers to the city/region. Energy is produced with the objective of growing energy production as a core business for the port
- Export driven (f4): The port sells energy either as electricity or as energy carriers for uses outside the port region. This function can only be considered when other port uses have been fulfilled.

Depending on the position of the port in the previous tables (Tables 11 and 12), different pathways to energy transition can be developed. Strategic partnering influences possibilities of certain business models or changes the strategic position of importing energy. Moreover, it is important to consider possibilities of scaling up of certain energy production facilities and business models. In addition, the governmental steering affects the position of certain ports within an energy supply chain (especially if support of the government is needed, which is often the case). Sometimes a certain specific role within the energy system is part of a national strategy (e.g. Sines as a H2 hub). In some cases, certain (financial) means are available to specific ports because of their role (e.g. TEN-T) or because of the strategic position they have within a national strategy. This can accelerate the development of certain energy transition activities or infrastructures, especially if the government is a shareholder of the port. On the other side, ports that are not central in the country's energy transition strategy can find it harder to gather momentum or resources for the energy transition.

11.4 Seagoing ships and hinterland transport

Reducing emissions from sea-going ships and hinterland transport is critical for reaching decarbonisation and ports, as important nodes in (freight) hinterland transport networks, are important actors in facilitating and accelerating the energy transition in that region. Ports, however, rarely directly control any inland transport infrastructure and seldom actively participate in their operations. As far as ocean transport is concerned, ports also have a limited set of options to impact energy transition decision in the shipping industry. The impact that a port authority can exert on its hinterland is constrained by the typology of transport modes that serve the port. In this project, the transport modes to be investigated are rail, road, barge, pipeline, and electricity transmission cables.

In relation to hinterland transport, the first categorisation relates to the modes of transport that are available at the port. This needs to be effectively combined with the ability of the port authority to impact technology choices for the hinterland. Thus, a profile can be established for each port based on the modes of transportation and whether or not the port can influence hinterland infrastructure developments and energy efficiency measure uptake by hinterland transport service providers. It is recommended to develop pathways for each mode that consider the ability of the port operator to influence the choice of technology.

Table 13: Mode characteristics.

	Sea Shipping	Roads	Railways	Inland waterways	Pipelines	Electricity transmission cables
Presence	Always present for seaports	Always present	Present in larger ports	Always present in inland ports and sometimes in seaports	Always present in petrochemical industrial ports	Only relevant for power generation
Energy transition measures focus of ports	Alternative fuels, OPS, batteries, regulation, incentives	Batteries, biofuels, hydrogen, regulation, incentives	Electricity, hydrogen, batteries, regulation, incentives	Batteries, electricity, hydrogen, biofuels, regulation, incentives	Infrastructure, regulation, incentives	Infrastructure, regulation, incentives

Table 13 summarizes the hinterland modes and provides an indication of the focus of the energy transition measures for each mode of transport. This ability of a port authority to affect decision making in these modes is influenced by considerations such as geography, hinterland definition, the hinterland strategy the port authority is pursuing, time necessary to develop the infrastructure, use and user policy in terms of charging and access rights, infrastructure network capacity, and future technological developments. It should be noted that for seaports, how ports influence decision-making for ship-owners and operators is an important dimension, especially for transhipment ports.

In general, however, not all modes of transport will be available in the port. Hence, modal shift options will not always be available, or a set of actions will be needed to develop the necessary infrastructure or political goodwill to be able to diversify the port hinterland connectivity. Furthermore, certain measures, for example modal shift, will usually not be possible for all types of goods.

On the basis of the observed modality and the number of alternatives observed in the ports studied in the project, the following five categories (Table 14) can be considered exhaustive. These categories divide ports on the number of modalities available, depending on which different energy transition options will be available. Furthermore, the categories account for the ability of the port to influence these modalities. This could be assessed qualitatively by the port or specific key performance indicators could be developed.

Table 14: Hinterland transport categories.

Category	Description
Category 0 No connections (h0)	The port has limited hinterland connectivity (e.g. pure transshipment).
Category 1 No impact (h1)	The port is connected to one or more modes of hinterland transport (generally road or inland waterways) but has no influence on the energy transition of this mode(s).
Category 2 Limited alternatives (h2)	Port has only road and another mode of hinterland transport, and the mode of transport can be impacted by, for example, by developing refuelling stations, imposing standards, and facilitating vehicle improvements (for trucks) or OPS (for barges). Modal shift is not an option for example because of cargo differences.
Category 3 Transport hub some alternatives (h3)	Port has only road and another mode of hinterland transport and the port can impact the energy transition. Modal shift options are limited.
Category 4 Major hub (h4)	Port has more modes of hinterland transport and has the possibility to influence infrastructure and energy transition in more than one transport alternative. Modal shift is an option.

For each category the energy transition focus is described below.

- Category 0 - No connections (h0) In this case hinterland transportation should not be part of the energy transition strategy of the port. If any mode of transport (generally road or rail) could be developed, then see the following categories.
- Category 1 - No impact (h1) In this case, the main strategy for energy transition would entail developing the ability to influence the energy transition of the port through regulatory instruments, by, for example, imposing access

regulation to the port, or finding agreement with the responsible authorities. If so, see next categories.

- Category 2 - Limited alternatives (h2) In this case the strategy should focus on the energy transition of the mode on which the port has influence. For example, for road transport this could entail electrification, biofuels, or other low-carbon alternative fuels. If it would be possible to develop another mode for modal shift, see next category.
- Category 3 - Transport hub with some alternatives (h3) The port should identify which one of the modes is likely to provide a more rapid uptake of the energy transition technologies and provide reduction in emissions. If modal shift is possible, policies and measures should be developed to that end.
- Category 4 - Major hub (h4) The port should identify the most promising avenues for the energy transition, pursue cooperation with the transport service and infrastructure providers, develop pilot projects and leverage on cooperation.

11.5 Governance

Governance has an important impact on energy transition. Governance defines the relationships between the port and its internal and external stockholders, but also the boundaries within which the port authority can operate. We can structure the relationship with governance along two main dimensions that can be used to identify port typologies and provide a roadmap on how the port can advance the energy transition in its specific governance context.

As a first dimension, governance impacts the energy transition as it accounts for the drivers behind energy transition. Regulation, or public policy, has been identified ultimately as one of the main factors that accelerate energy transition in shipping and ports. Regulation and policy can drive the energy transition for the port authorities in three ways, that can be subsumed into three port typologies in relation to energy transition governance:

- Energy transition is driven by internal shareholders (that is the owner of the port, e.g. municipality, national government, or private company) or by top management of the port authorities (e.g. CEO's vision,). The energy transition is mandated by the shareholders or the decision to invest in the energy transition is the result of the vision pursued by top management. In this case, the port will advance the energy transition agenda within the boundaries of its resources (see 10.4.1).

- Energy transition is driven by external stakeholders (e.g. citizens, local authorities). In some cases, the energy transition is a necessary response for the port to maintain their license to operate or grow. In these cases, the energy transition might not fit with the overall strategy of the port, although it might get integrated later. In this case the port will meet the requirements of the external stakeholders doing what is necessary (see also 10.4.2).

- Energy transition is driven by customers. In ports, the main customers that have defined to advance their own energy or sustainability transition require the port authority to support them by providing services or infrastructure. The port will respond to such demands doing what is possible to satisfy customers demands (see 10.4.3).

As a second dimension, governance impacts the energy transition as it defines the boundaries within which the port may operate and contributes to identifying and leveraging on synergies, resulting from specific governance structures. An important aspect relates to the definition of the boundaries of action expected of the port. Is the port aiming at focusing only on the port authority, or the port jurisdiction, or beyond the port jurisdiction? Governance essentially relates to solving multiple trade-offs, and multi criteria decision approaches are key.

On the basis of the obstacles and synergies that can emerge from a specific energy transition governance approach (see also 10.5), three main governance structures can be defined that can impact the energy transition:

- A governance structure that is conducive to energy transition (e.g. access to funding, resources, expertise)
- A governance structure that is neutral (e.g. limited access to funding, limited resources, and knowledge)
- A governance structure that is of a more conflictual nature or a hindrance to energy transition (e.g. no funding, divergence of objectives, core port activities are already challenged by limited resources, infrastructure, etc.)

For each of these typologies, the main recommendation is to identify the key governance issues and address them before advancing in the energy transition. The categories are summarised in Table 15.

Table 15: Port governance in relation to conduciveness to promote energy transition.

	Customers	External stakeholders	(Internal) Shareholders
Conducive (funding, support, good relations, etc.)	(g1) Supported customer-oriented	(g2) Supported external-stakeholders-oriented	(g3) Supported shareholder-oriented
Neutral (moderate funding, moderate relationships)	(g4) Unsupported customer-oriented	(g5) Unsupported external-stakeholders -oriented	(g6) Unsupported shareholder-oriented
Hindrance (no funding, strained relationships)	(g7) Conflictual customer-oriented	(g8) Conflictual external-stakeholders -oriented	(g9) Conflictual shareholder-oriented

The nine categories are explained below:

- Supported customer-oriented (g1) Ports in this category are adopting an ambitious strategy for the energy transition, supported by a strong business case. The energy transition is driven by customers and the environment in which the port operates is supportive with good funding opportunities and good relations with stakeholders and regulators.

- Supported external-stakeholders-oriented (g2) For ports in this category, the energy transition is primarily a response to external stakeholders. The port has a good relation with external stakeholders, that strongly support the energy transition efforts of the port. In this case, ports prioritise dialogue with external stakeholders and then take actions that have positive impacts on local environment.
- Supported shareholder-oriented (g3) The internal shareholders of the port are the main driver in the energy transition. Stakeholders and customers are supportive of the transition. Ports in this category, focus on a long-term strategy, aiming at meeting future needs of customers, developing new business opportunities, and maintaining good relations with external stakeholders.
- Unsupported customer-oriented (g4) The energy transition for ports in this category is driven by customers. With the exception of customers, there is limited support from other stakeholders for the energy transition. In this case, ports have developed an ambitious strategy built on internal resources but more reliant on joint ventures and collaborative approaches than in g1.
- Unsupported external-stakeholders-oriented (g5) In this category, the port's energy transition is driven by external stakeholders, with limited or no support from customers or the main shareholders of the port. Pilots are used to foster dialogue with external stakeholders, and a mixed focus on effective transition and communication/public relations can be observed.
- Unsupported shareholder-oriented (g6) In this category, ports are capitalizing on existing resources and relationships, tailoring their approach to improving conditions for strategic development. The port top management, with the support of the port main shareholder, is the main actor of change in the port cluster or in the region and their efforts are neither supported no hindered by internal stakeholders and customers.
- Conflictual customer-oriented (g7) In this case, customers demand change in the port in relation to the energy transition, but these demands are met with resistance from the external stakeholders (e.g. city, workers). These ports are relying on customers, for driving initiatives for the energy transition, providing limited support.
- Conflictual external-stakeholders-oriented (g8) In this case, the energy transition is the result of pressure from external stakeholders, but the business case does not exist or there is no support from the port major shareholders. In this case, only limited resources can be invested in the energy transition, that may result in small pilots focussing on communication and public relations, and on joint projects with other ports (e.g. EU-funded projects).
- Conflictual shareholder-oriented (g9) The energy transition in ports in this category is driven by the desire of the port owners or top management to advance the energy transition, notwithstanding resistance from external shareholders or customers. In this case, the port focuses on pilots, aiming at creating momentum, leveraging on limited resources, and building on already available funds.

11.6 Port typologies for advancing the energy transition

Table 16 summarises the categories developed in the previous sections.

Table 16: Summary of categories that can be used to characterise ports in relation to the energy transition. The 30 attributes of ports in relation to the energy transition are grouped into six categories and three main themes (energy infrastructure & technologies, seagoing ships & hinterland transport, and governance). The attributes are all noted with a letter indicating the category. When categorising a port, an attribute from each category should be chosen.

THEME	CATEGORY	ATTRIBUTES
Energy infrastructure & technologies	Industrial and power generation activities (e)	• No industrial or power activities (e1) • Petrochemical dominated (e2) • Power generation dominated (e3) • Both petrochemical and power generation (e4)
	Energy self-sufficiency of a port (f)	• Import-reliant (f1) • Balanced utility-oriented (f2) • Balanced business-oriented (f3) • Export-driven (f4)
Seagoing ships & hinterland transport	Seaport / Inland port (p)	• Seaport (p1) • Inland port (p2)
	Hinterland transport (h)	• No connections (h0) • No impact (h1) • Limited alternatives (h2) • Minor transport hub (h3) • Major transport hub (h4)
	Dominant modality (m)	• Sea shipping (only for seaports) (m1) • Roads (m2) • Railways (m3) • Inland waterways (m4) • Pipelines (m5) • Electricity transmission cables (m6)
Governance	Governance (g)	• Supported customer-oriented (g1) • Supported external-stakeholders-oriented (g2) • Supported shareholder-oriented (g3) • Unsupported customer-oriented (g4) • Unsupported external-stakeholders-oriented (g5) • Unsupported shareholder-oriented (g6) • Conflictual customer-oriented (g7) • Conflictual external-stakeholders-oriented (g8) • Conflictual shareholder-oriented (g9)

Note: The energy transition strategy is related indirectly also to the digitalisation strategy, biodiversity and sustainability strategy, business strategy, port-city and external relations.

A port can be categorised using the six categories presented in Table 16. Given the number of categories and attributes, a port can be described with different combinations of attributes from each category. For example, Port of Rotterdam can be described as [e4, f3, p1, h4, m1, g3]. For different combinations of attributes[20], similar energy transition pathways could be developed. In the next years of the MAGPIE project, it should be considered what energy transition pathways should be associated with these profiles and whether some of these categories' combinations result in a more common constellation than others (MAGPIE D9.3). Information on the MAGPIE demonstrators, analysed in detail in the reports of WP8, will be used in future work of WP 9 for the definition of the port energy transition pathways and masterplan.

11.7 Conclusions

In this chapter, a categorisation for ports, in relation to the energy transition, has been proposed since no categorization existed previously. The categorisation is articulated into six categories, for a total of 30 attributes. The categories are grouped into the three main themes (energy infrastructure & technologies, seagoing ships & hinterland transport, and governance) that have emerged from the analysis carried out during this task (D9.1).

[20] There are 4x4x5x6x9=4,320 different possible combinations for seaports and 4x4x5x5x9 and 3,600 different possible combinations for inland ports.

12 Report conclusions

This work examined the state of the art of energy transition in ports in terms of technologies, infrastructure, and governance and provides a set of criteria for analysing ports and helping them develop energy transition pathways. It should be noted, that this work focuses on ports that are in some way leaders in the energy transition, rather than on the barriers to the deployment of energy transition technologies. These barriers, and what ports can do to overcome them, are addressed later in the MAGPIE project and in particular in the reports of WP7 and WP9. This overview should therefore be understood as a collection of best practices, rather than a description of the general development of the energy transition in the industry.

12.1 General conclusions

The following general conclusions can be drawn from the study, based on interviews with ten ports and the analysis of secondary data:

- Ports have made some advancements in energy efficiency and optimizing their operations. The gains from operational improvements, while important, will not be sufficient to accommodate the need for decarbonisation and reduction of energy consumption in the future (Chapter 4).
- Port authorities are aware of the challenges of adapting to a more hostile climate and of developing strategies for energy transition and climate change mitigation (Chapter 3).
- Ports are adopting different targets and priorities, in terms of decarbonisation, biodiversity preservation, and energy transition (Chapter 10).
- Most energy transition initiatives are at planning or pilot stage and would not be viable without government or external financial support (Chapter 7, Chapter 10)
- Except for fossil fuels, it resulted from the interviews that the amount of concrete tangible initiatives carried out in ports on alternative fuels are mostly limited to pilot projects (Chapter 7).

12.2 Conclusions on energy transition technologies and infrastructure

In terms of energy transition technologies and infrastructure, the following has been observed:

- Most ports seem to rely on transitioning towards renewable electricity for their activities and the use of low- and zero-carbon energy carriers for their energy transition (Chapter 6 and Chapter 7).
- Renewable electricity will be critical to decarbonizing ports and reducing their dependence on fossil fuels, but supply is limited for a large part of the European ports and industrial activities in ports will compete with other uses for renewable electricity (see also WP3) (Chapter 6).
- The mandated use of OPS, for some shipping segments for ocean-going vessels and barges, will further increase demand for low-carbon electricity at (some) ports (Section 5.4 and Section 6.4).

- The increased demand requires ports to reduce and rationalize their electricity consumption and expand renewable electricity generation in port areas or secure direct electricity supply from renewable energy plants near the ports (Chapter 4 and Section 6.4).
- Increased supply of renewable electricity to ports can be supported by peak shaving techniques, the development of virtual power plants, and microgrids that encompass all energy users and power generation activities at ports (Ahamad et al., 2018) (Chapter 5).
- Electrical infrastructure, in terms of grid connections within the port and to/from the port, distribution networks, and loading and spare capacity may need to be upgraded to avoid future congestion and power outages (Chapter 6).
- Wind and solar power seem to be the most promising renewable energy sources in ports. Although wind and sun are variable energy sources and power generation infrastructure still needs to be developed, those ports which have availability of either or both are in an advantageous position (Chapter 6).
- Carbon capture and storage/use is at its infancy and its potential for ports is yet difficult to establish (Chapter 7).

12.3 Conclusions on seagoing vessels and hinterland transport

The following conclusion can be made on the energy transition readiness at ports for seagoing vessels and hinterland transport modes:

- No single low-carbon fuel has been identified as the most promising for bunkering of sea-going vessels and barges, for port railways and for trucks. This implies that in the coming decades, a variety of low-carbon fuels will coexist (Chapter 7 and Chapter 8).
- There is no evidence that low- or zero-carbon fuels produced in proximity of a port are intended for primary use within the port. A better understanding on the import and export flows of low- and zero-carbon fuels is needed to see the port business potential of their production within the port (Chapter 7).
- There is potential for reducing emissions in port hinterland transport, but despite the central role of ports in inland transport networks, port authorities have limited ability to influence the technological choices of transport service providers (Chapter 8).
- The role of port authorities in the value chains of low- and zero-carbon energy carriers, such as ammonia, hydrogen, and biofuels, remains unclear (Chapter 7).
- Ports can use their existing pipeline networks for importing or exporting low- and zero-carbon energy carriers and e-fuels, but the scale of investment required and the complexity of converting such networks to use low and zero carbon renewable energy carriers is unclear (Chapter 8).

12.4 Conclusions on the energy transition governance

As far as the energy transition governance is concerned, the report concludes that:

- Energy transition governance requires more attention, in particular experiences and good practices on governance approaches that have successfully aided the energy transition should be identified (Chapter 10).
- Energy transition for a port authority is generally driven either by its top management vision, its customers and/or its external stakeholders (Chapter 10).
- Central governments and local authorities play a critical role in the energy transition governance (Chapter 10).
- Energy transition governance should be collaborative (Chapter 10).

12.5 Energy transition pathways

In particular, the report suggests that port energy transition pathways:

- Are influenced by and can benefit from the existence of power generation and petrochemical activities in the port,
- Are linked to the port energetic self-sufficiency and business focus,
- Depend on the degree of connectivity of the port and the opportunities offered by the energy transition of inland transport modes,
- Can be constrained by the ability of the port authority to impact the technological choices of inland transport service providers,
- Are influenced by which party is driving the energy transition for the port (i.e. customers, external stakeholders, or the port shareholders),
- Can be supported or hindered by other actors within the port (e.g. by shareholders or external stakeholders), depending on how the energy transition vision aligns the priorities of the port authority, its shareholders and customers, and other port stakeholders,
- Need to identify port-specific applications of smart technologies, that need to be connected to the energy transition needs of each port and its scale, resources, etc.

In terms of smart technologies, the report concludes that their use will follow from the clear definition of the port energy transition goals (e.g. whether the port has a masterplan for the energy transition with clear objectives; whether it has identified key areas to be prioritized that could help in choosing the smart technology). Their successful implementation will depend on data sharing conditions, the port innovation corporate culture, the existence of an innovation ecosystem (e.g. with local or international research institutions or innovation clusters).

Specifically for inland ports, the report concludes that their challenges, in relation to the energy transition, are consistent with those of seaports. Inland ports appear less ideally positioned to take advantage of renewable power generation but could benefit from integration into energy value chains given their generally high connectivity and logistics capabilities. The fact that few inland ports view themselves as energy hubs could offer a first-mover advantage for positioning themselves competitively in their region's energy value chains.

The report also elaborated six categories, with 30 attributes, that can be used in future work to develop an energy transition vision and roadmap for different typologies of ports. These categories are illustrated in Chapter 11, Table 16.

12.6 Recommendations for future work

Finally, the report recommends that:

- Pilots and tests are further developed to foster energy transition in the port context,
- Port authorities and port actors increasingly share experiences in relation to energy transition,
- Given the current biodiversity crisis and in the absence of biodiversity approaches to energy transition, energy transition strategies in ports explicitly account also for impacts on and potential loss of biodiversity,
- Energy transition governance is further explored to identify regulatory barriers and good practices,
- Best practices, in terms of innovation and communication, are identified.

D9.1 will be used for the development of a *Vision document for the future green European port with outlook to 2050* (D9.2) and for proposing a *Roadmap for implementation of sustainable solutions and to direct European ports to D9.2 vision document by 2030, 2040, 2050* (D9.3). The inputs from this document will also contribute to the preparation of the MAGPIE *Handbook* on how to become the future green European port with concrete guidance on planning, implementation, replication and scaling-up of MAGPIE demonstrators (D9.4).

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Annex 1: Glossary

5G: 5G is the fifth generation of mobile network technology, succeeding 4G. For ports, 5G can enhance real-time data transfer, automation, and other digital transitions crucial for efficient operations and the energy transition.

Accounting Rules: Standards in ports ensuring transparent reporting of sustainability efforts and achievements.

Actors: In the context of the energy transition in ports, actors refer to those who take or directly impact decisions on the development of the port. This includes stakeholders like government and local authorities, port users, and environmental groups. Port actors, such as port authorities, shareholders, and managers, play a pivotal role in driving and supporting the energy transition initiatives within ports.

Alternative Energy: Ports adopting non-traditional energy sources, such as wind or solar, to power their operations and reduce their environmental impact.

Alternative Fuels: Fuels other than traditional fossil fuels, including biofuels, e-fuels, and hydrogen. Ports are becoming increasingly involved in the production and distribution of these fuels to support sustainable shipping and transportation.

Ammonia: Ammonia is a promising low-carbon energy carrier. Ports can be involved in its production, storage, and distribution, similar to hydrogen. See also Green, Grey, Pink and Blue Fuels.

Artificial Intelligence (AI): AI-driven digitalisation could enable the automation of port operations, such as vessel tracking, berth scheduling, cargo handling, and route optimization. AI can also be used to monitor emissions from ships and identify potential sources of pollution. AI can be used to monitor and analyse data on port emissions, helping port authorities identify areas of improvement and develop strategies for reducing emissions. In addition, AI can be used to improve the safety of ports and reduce the risk of accidents, in this way facilitating the adoption of new energy transition technologies.

Barge Transport: Barge transport refers to the movement of goods on flat-bottomed boats, typically on rivers and canals. In the context of ports, LNG infrastructure is being developed for inland transport modes, including barges. Barges offer an energy-efficient means of transporting goods, especially in ports with access to inland waterways.

Batteries: Batteries, especially large-scale energy storage solutions, can be crucial for ports to store energy from renewable sources and release it when needed.

Biodiversity: While not directly linked to energy transition, ports can adopt multidisciplinary approaches to tackle biodiversity loss, ensuring sustainable and environmentally-friendly port operations. Biodiversity preservation is important when considering energy transition in ports.

Biofuels: Produced from renewable organic materials such as plant oils, animal fats, and agricultural waste. Ports play a role in the production and distribution of biofuels, leveraging their access to natural resources and international trade routes.

Biomass: Biomass can be used for both biofuel production and power generation in ports. However, its use for power generation in ports is limited.

Blue Fuels: see Blue Hydrogen.

Blue Hydrogen: Blue hydrogen is produced using natural gas through a process called steam methane reforming (SMR). In this process, methane from natural gas is combined with steam and heated to produce hydrogen and carbon dioxide (CO_2). What distinguishes blue hydrogen from other forms of hydrogen production is the capture and storage of the CO_2 byproduct, preventing its release into the atmosphere. This carbon capture and storage (CCS) process aims to make blue hydrogen a lower-carbon alternative to traditional hydrogen production methods. However, it's worth noting that while blue hydrogen reduces CO_2 emissions compared to traditional methods, it is not entirely carbon-free. The production process still requires significant energy, often derived from burning more natural gas, and there are concerns about the potential for methane leaks, which have a higher global warming potential than CO_2.

Bunkering: The process of supplying ships with fuel. In the context of ports as energy transition hubs, bunkering can involve supplying ships with alternative and more sustainable fuels, such as LNG, biofuels, or e-fuels, to reduce greenhouse gas emissions.

Carbon Capture and Storage (CCS): Carbon capture and storage (CCS) is a process that involves capturing carbon dioxide from large sources, such as power plants, industrial facilities, and other sources, or directly from the atmosphere. Once captured, the carbon dioxide is stored in the form of liquid or solid, deep underground or in disused gas or oil fields. CCS is considered an essential part of the global effort to reduce greenhouse gas emissions. Despite its potential, the technology is not yet available at a large scale. Seaports are increasingly being viewed as potential sites for CCS due to their strategic positioning to collect and store large amounts of CO_2 in empty gas fields in the seabed. Ports can also serve as transit points for carbon capture and use (CCU), a process that captures CO_2 and uses it for various industrial processes.

Carbon Capture and Use (CCU): CCU captures CO2 emissions and utilizes them for various industrial processes, turning the carbon into valuable products or materials.

Carbon Footprint: The total emissions a port is responsible for, emphasizing the need for sustainable practices in port operations.

Carbon Neutral: Ports achieving a balance between emitting and absorbing carbon, often through offsetting measures, to ensure sustainable operations.

Circularity: see Circular Economy.

Circular Economy: In the circular economy, resources used in production processes are recirculated back into the economy, allowing for greater efficiency and less waste. Ports play a key role in the circular economy due to their position in the transportation of goods, resources, and energy. They can support the circular economy by reducing waste and promoting the reuse and recycling of materials.

Cold Ironing: Ports providing shoreside electrical power to docked ships, allowing them to shut down engines and reduce emissions. See Onshore Power Supply.

Competition: In the context of ports, competition often refers to the rivalry between gateway ports, with factors like hinterland connections, nautical accessibility, and shipping connections being key success determinants. The energy transition can change the competition landscape among ports.

Compressed Natural Gas(CNG): CNG is a clean-burning fuel derived from natural gas and is considered an alternative to traditional diesel fuel. In the context of ports, CNG is seen as a potential fuel for drayage trucks. The Port of Vancouver, for instance, has demonstrated renewable CNG drayage trucks. CNG reduces CO2 emissions, making it a more environmentally friendly option, though its adoption in ports is still in the early stages.

Decarbonisation: The process of reducing or eliminating carbon dioxide emissions, crucial for ports aiming to minimize their environmental impact.

Digital Infrastructure: The digital systems and networks supporting port operations. This infrastructure is crucial for data collection, analysis, and decision-making.

Digitalisation in the Energy Transition in Ports: Digital technologies play a pivotal role in supporting the energy transition within ports. From monitoring energy consumption to optimizing operations, digitalisation offers tools and insights that drive efficiency and sustainability.

Distributed Energy Resources (DER): DER refers to a variety of small, modular power-generating sources that can be combined (or "distributed") to provide power necessary to meet regular demand.

Distributed Power Generation: Distributed power generation in ports is a concept that involves the generation of electricity closer to the point of use, rather than relying on large-scale, centralized power plants. This type of power generation is typically done with distributed renewable energy sources such as solar, wind, and biomass. By utilizing these sources of energy, ports are able to reduce their carbon footprint and become more sustainable. Additionally, distributed power generation in ports can provide a more reliable source of power, reduce the cost of energy, and help to protect the environment. Ultimately, distributed power generation in ports is a great way to reduce the environmental impact of energy production, while providing a more reliable and cost-effective source of energy.

E-fuels: Man-made fuels created from renewable energy sources. They can replace traditional fossil fuels and are produced by combining hydrogen with carbon dioxide. Ports can be pivotal in the production and distribution of e-fuels due to their access to renewable energy and infrastructure.

Electricity Providers: Companies supplying ports with green electricity, supporting their sustainability goals.

Electricity Transmission Cables: These are crucial for transmitting power, especially from renewable sources. The report indicates that as ports become more reliant on renewable electricity and power generation within the port increases, connecting lines to the port will need to be upgraded, emphasizing the role of ports in the broader energy transition.

Electrification of Port Equipment: Electrification in ports refers to the process of replacing traditional diesel-powered equipment with electric alternatives. This includes not only loading and unloading machinery, such as cranes and straddle carriers, but also transport equipment within the port like cars, trucks, and tugboats. By electrifying these machines, ports can reduce emissions, improve operational efficiency, and decrease energy consumption. Electric equipment also offers benefits like reduced maintenance costs, noise pollution reduction, and increased safety due to more precise operations.

Electrification: Transitioning port equipment and operations to run on electricity, reducing reliance on fossil fuels and decreasing emissions.

Emission Reduction: Ports actively working to decrease pollutants released into the environment.

Energy Carriers: Substances or systems that contain energy that can be converted to provide power. In the context of ports, energy carriers like e-fuels and hydrogen can be produced, stored, and transported to support the energy transition. See also Power to X.

Energy Infrastructure: The processes and hardware involved in the production, storage, and distribution of (renewable) energy resources and low- and zero-carbon energy carriers and e-fuels in ports. It includes the development of renewable energy sources, such as solar or wind, as well as the implementation of energy-management technologies, such as smart grids and energy storage systems.

Energy Majors: Large companies collaborating with ports to drive the energy transition, bringing expertise and resources.

Energy Management Systems: Energy management systems in ports are systems designed to improve the efficiency of energy use and reduce the environmental impact of port operations. The systems help identify and manage energy consumption, optimize energy use and reduce energy costs. They also help to monitor energy consumption and identify areas for improvement. The definition of an energy management system in a seaport is a set of tools, processes, and technologies used to monitor, measure, analyze, and control energy consumption and costs. The system can help to identify and prioritize energy-saving opportunities, reduce emissions, and improve operational efficiency. The system also provides data to help make more informed decisions about energy use and investments in energy-saving technologies.

Energy Producers: Entities partnering with ports to generate and supply renewable energy.

Energy Self-sufficiency: Energy self-sufficiency in the context of ports refers to the ability of a port to generate and use its own energy sources, reducing reliance on external energy providers. This is crucial for ports aiming to become sustainable and reduce their carbon footprint.

Energy Storage: Ports use energy storage systems, like batteries, to store energy from renewable sources such as solar and wind. These systems help reduce electricity costs, environmental impact, and ensure reliability. They can also store excess energy from renewable sources for later use, supporting the port's energy transition efforts.

Energy Supply Systems: These are the infrastructure and systems used to supply energy to various port operations. As ports electrify and integrate renewable energy sources, the energy supply systems need to be robust, flexible, and efficient.

Energy Transition Governance: Governance encompasses the legal and regulatory frameworks necessary for the energy transition to take place in ports. It addresses the driving forces behind the energy transition and how various port stakeholders and actors can either support or hinder the transition. Energy transition governance refers to the structures and processes used to manage and oversee the energy transition within ports. Effective governance ensures that sustainability goals are met and that all stakeholders are aligned in their effort.

Energy Transition Pathways: These are the strategies and routes that ports can adopt to achieve the energy transition. Different pathways might be suitable for different ports based on their size, location, and operational characteristics.

Energy Transition: The process of shifting from traditional energy sources, like fossil fuels, to renewable and sustainable energy sources. Ports play a pivotal role in this transition, serving as hubs for new energy solutions, from renewable fuel bunkering to hosting power generation infrastructure.

Energy Value Chains: Ports playing a role in the series of activities that produce and distribute energy, emphasizing their position in the global energy market.

ETS (Emissions Trading System): The ETS is a market-based measure for reducing greenhouse gas emissions by allowing companies to buy or sell emission allowances. Ports, as significant emission sources, can participate in ETS to achieve their sustainability goals.

External Expertise: Ports leveraging knowledge from outside experts to enhance their energy transition strategies.

Facilitators: Key players aiding ports in the energy transition, ensuring the adoption of best practices and technologies.

Finance: The energy transition in ports requires different sources of financing at different stages. The sources of financing depend on port laws, accounting rules, and financing practices. Both public and private funding sources are crucial, and every party, including the port authority, government, and stakeholders, play a role in providing or securing financing for energy transition projects.

Financing Practices: Strategies in ports for funding sustainable projects and operations.

Fuel production: Ports are increasing investing in the handling, storage, and production of low and zero-carbon energy carriers. These carriers, like hydrogen and biogas, support the reduction of emissions and meet sustainability goals, playing a crucial role in the energy transition of ports.

Gateway Port: Ports that primarily serve as logistics and transport nodes, providing connectivity for their hinterlands. Their role in the energy transition is central, especially in facilitating the movement of sustainable goods and energy sources.

Geothermal Power: The use of geothermal energy in ports is marginal. For instance, the Port of Hamburg uses geothermal energy for specific applications like maintaining the operability of rail switches.

Governance: This refers to the structures and processes used to manage and oversee activities in ports. It encompasses the legal and regulatory frameworks that are necessary for the energy transition to take place**.**

Green Finance: In the context of ports and energy transition, green finance typically refers to financial investments flowing into sustainable development projects and initiatives, including those related to renewable energy, which support the decarbonization of ports.

Green Fuels: Fuels produced using renewable energy sources, resulting in low or zero emissions. Ports can be centers for the production and distribution of green fuels, supporting the global energy transition.

Green Technologies: Ports implementing technologies that have minimal environmental impact.

Greenwashing: Greenwashing is the act of misleadingly portraying products or practices as environmentally friendly. In the context of ports and energy transition, it refers to ports exaggerating their sustainability efforts or green initiatives to appear more eco-friendly than they truly are, often to attract stakeholders or meet regulations.

Grey Ammonia: see Ammonia and Grey Fuels.

Grey Hydrogen: see Hydrogen and Grey Fuels.

Grey Fuels: Typically refers to fossil-based fuels or those produced without capturing and storing the carbon dioxide emitted during their production.

Grey Methanol: see Methanol and Grey Fuels.

Grid: See Port Grid.

H2SHIPS: Projects involving hydrogen-powered ships. The project, which includes HAROPA PORT, will develop a plan for the implementation of a pilot on the river Seine in Paris. The project aims to demonstrate the added value of hydrogen for inland water transport and develop a blueprint for its adoption across Europe.

Hinterland Transport Infrastructure: This refers to the infrastructure connecting ports to inland destinations. It includes roads, railways, and pipelines. Efficient hinterland transport is crucial for swift cargo movement and reducing bottlenecks.

Hydrogen: Hydrogen is a potential low-carbon energy carrier that can be produced using renewable electricity. Ports can play a role in the production, storage, and distribution of hydrogen, both for bunkering/refuelling ships and as a tradable commodity.

Hytruck: Refers to a project involving heavy hydrogen trucks and hydrogen filling stations, connecting ports like Duisport, Port of Rotterdam, and Port of Antwerp-Bruges. Such initiatives in ports underscore the move towards hydrogen as an alternative fuel, pushing the energy transition forward.

Industrial Port: Ports that serve as industrial zones where raw or semi-finished inputs are processed. Many of these ports are at the forefront of the energy transition, transforming their infrastructure to support the low- and zero-carbon economy, especially those with a focus on petrochemical or power generation activities.

Industrial Synergies: Ports collaborating with industries to enhance energy efficiency and sustainability.

Information and Communication Technology (ICT): In ports, ICT is increasingly being used to digitalize operations and processes, optimize resources and increase efficiency. Digital technologies are being used to reduce the environmental impact of port operations, increase safety and security, and enable the decarbonisation and energy transition of the port industry. For example, ICT is being used to monitor port operations, improve navigation and traffic, and manage cargo handling and storage. Additionally, ICT is being used to develop smart port systems that enable real-time monitoring and control of port operations, as well as facilitate data sharing and collaboration with stakeholders.

Infrastructure Development: Ports expanding and modernizing structures to support the energy transition, such as renewable energy installations.

Inland Shipping: Inland shipping refers to the transportation of goods via waterways that are located within a country's borders, such as rivers and canals. In the context of ports, inland waterway transport plays a significant role in moving goods to and from the port towards the hinterland. Given its high energy efficiency per tonne/km, its CO_2 emissions are comparable to those of rail transport and substantially lower than road transport. This makes it a sustainable alternative, especially in ports like Rotterdam and Antwerp-Bruges, where it constitutes a significant share of the goods movement.

Inland Waterways: see Inland Shipping and Barge Transport.

Intermodality: Intermodality refers to the use of multiple modes of transport within a single journey or transport chain. This concept is essential for efficient cargo movement, reducing emissions, and optimizing transport routes.

Internet of Things (IoT): The Internet of Things (IoT) is defined as a network of physical objects, such as port equipment, locks, bridges, traffic signals, connected to the internet and able to exchange data. IoT is often associated with digitalisation in ports as it could transform the way ports operate by automating and optimising processes. Digital technologies, such as sensors, devices, and software, are used to collect data on port operations, which can then be analysed and used to improve performance. IoT also enables decarbonisation and energy transition in ports by providing real-time data on energy consumption and enabling smart energy management.

Knowledge sharing: Knowledge sharing in the context of ports involves the dissemination and exchange of information, expertise, and best practices related to sustainable and energy-efficient port operations among stakeholders.

Land Use: Refers to how areas within and around ports are utilized. As ports transition to become energy hubs, land use decisions may prioritize infrastructure for renewable energy generation, storage, and distribution.

LNG (Liquified Natural Gas): Natural gas that has been cooled and liquified for transportation and storage. Ports equipped with LNG bunkering facilities can provide ships with a cleaner alternative to traditional marine fuels.

Low-Carbon Fuels: Fuels that result in lower carbon dioxide emissions compared to traditional fossil fuels. Ports can prioritize the use and distribution of low-carbon fuels to reduce their carbon footprint.

LPG (Liquified Petroleum Gas): A mixture of propane and butane that's used as fuel in heating appliances and vehicles. Ports can facilitate the storage and distribution of LPG as an alternative fuel.

Maritime Services: These are essential services provided within the port to ensure the safe and efficient movement of vessels. They play a crucial role in the energy transition by potentially adopting more sustainable practices and technologies. Specific services include: **Pilotage**: The act of navigating ships through potentially hazardous waters or congested ports using local experts familiar with the conditions; **Mooring**: The process of securing a ship to a berth using ropes, cables, or anchors; **Towing**: Using tugboats to guide ships in and out of ports, especially in tight spaces or when the ship is not under its own power.

Pink Fuels: see Pink Hydrogen.

Pink Hydrogen: Pink hydrogen is hydrogen produced using nuclear power. The process involves splitting water into hydrogen and oxygen using energy derived from nuclear reactions. Unlike green hydrogen, which relies on renewable energy sources for production, pink hydrogen leverages the constant and high-energy output of nuclear power plants. This method of production is considered low carbon, as nuclear power does not emit carbon dioxide during energy generation. Pink hydrogen offers a potential alternative to other forms of hydrogen production, especially in regions with established nuclear energy infrastructure. The emphasis on pink hydrogen has grown due to the global push for cleaner energy sources and the need to diversify energy production methods.

Methane Slip: Refers to the unintentional release of methane during the production, transportation, and use of natural gas. In ports, mitigating methane slip is crucial when using LNG as a transition fuel to ensure its environmental benefits.

Methanol: A potential alternative to diesel fuel. Ports can play a role in the production, storage, and distribution of methanol, including its sustainable versions like bio-methanol and e-methanol. See also Green, Grey, Pink and Blue Fuels.

Microgrids: A microgrid is a localized energy system that is connected to the main grid but can also operate independently. In ports, microgrids are used to provide reliable and resilient power to port operations and services. Microgrids can be used to reduce the cost of energy, enhance efficiency, and improve the reliability of energy supply. They can also help reduce emissions, increase the use of renewable energy sources, and provide a more secure and reliable source of power. By utilizing a combination of different sources of energy, microgrids can provide an efficient, reliable, and cost-effective way to power ports.

Modal Shift: Modal shift involves changing the mode of transportation, for instance, transitioning from road transport to rail. Such shifts can lead to reduced emissions, improved efficiency, and better utilization of transport infrastructure.

MRV (Monitoring, Reporting, and Verification): Refers to the European and IMO regulations for Monitoring, Reporting, and Verification of CO2 emissions from maritime transport. In the context of ports, MRV regulations ensure that ships operating within certain areas report their emissions, promoting transparency and driving efforts towards reducing greenhouse gas emissions in maritime transport.

Nuclear Power: Several ports are located near nuclear power plants, but active development of nuclear projects within ports is rare. Nuclear power generation is seen as a separate sector with limited interaction with ports. However, it's noted that nuclear power can be an attractive option for ports due to its reliability and low environmental impact.

Offshore Wind Farms: Offshore wind farms are clusters of wind turbines that are installed and operate in bodies of water, usually oceans or seas, to capture wind energy and convert it into electricity. They are distinct from onshore wind farms, which are located on land. Ports are central to the offshore wind industry, acting as logistical hubs for the construction and maintenance of wind farms. They handle key components like turbine blades and towers, driving economic growth and job creation in their regions. The rise of offshore wind also prompts ports to upgrade their infrastructure to meet industry needs. By harnessing the clean energy from these wind farms, ports advance their sustainability goals. Furthermore, collaborations between ports, wind developers, and energy companies underscore ports' crucial role in the renewable energy sector.

Oil-Based Fuels: Traditional fuels derived from petroleum, such as diesel and gasoline. While ports have historically relied on oil-based fuels, there's a shift towards more sustainable alternatives to reduce emissions.

Onshore Power Supply (OPS): OPS is an essential part of port electrification, providing power to ships while they are docked. This eliminates the need for ships to run their engines, leading to reduced emissions and noise pollution. The large-scale use of OPS can challenge current port grids, necessitating changes in grid structure, power management, and electricity supply.

Peak-load Reduction: Refers to strategies where a port installation reduces energy usage during high-demand periods, such as when a ship arrives at a terminal. By optimizing equipment operation and controlling electricity use, ports can manage peak energy demands, leading to improved energy management and cost savings.

Pipelines: Infrastructure critical for the logistics of low- and zero-carbon energy carriers. They play a role in the hinterland infrastructure, connecting ports to other regions and facilitating the movement of energy resources.

Port Energy Transition: The overarching shift in port operations to adopt sustainable energy sources and practices.

Port Grid: A port grid refers to the electrical infrastructure within a port that distributes and manages electricity for various port operations and services. In the context of the energy transition, the port grid plays a crucial role in integrating renewable energy sources, managing energy demand, and ensuring reliable power supply. As ports evolve to become more sustainable and reduce their carbon footprint, there's an increasing emphasis on upgrading and expanding port grids to accommodate new energy solutions like onshore power supply (OPS), renewable energy generation, and smart grid technologies. The port grid is essential for optimizing energy consumption, reducing costs, and enhancing the overall efficiency and sustainability of port operations.

Port Laws: Regulations guiding sustainable and environmentally-friendly operations within ports.

Port-city: Port cities are urban areas located in close proximity to a port. They play an integral role in the energy transition within the port, acting as enablers by providing necessary tools, resources, and funding. They can also advocate for the energy transition in the port and facilitate resource mobilization.

Porthos: Mentioned in relation to a CO2 pipeline in the Port of Rotterdam. Porthos stands as an example of infrastructure development in ports that aids in the capture and storage of CO2, thus promoting sustainable practices and energy transition.

Power Generation: Ports have traditionally relied on fossil fuels for power generation. However, there's a shift towards more sustainable energy sources, such as renewables and nuclear. Ports require a reliable source of power for their operations, and they are exploring various means, including renewable sources, to meet this need.

Power to X (P2X): A concept in the energy sector that refers to the conversion of electrical power, primarily from renewable sources, into various forms of energy or products. This conversion can lead to the production of gaseous energy carriers (Power to Gas), liquid fuels (Power to Liquid), direct heating (Power to Heat), or chemicals and raw materials (Power to Chemicals). In the context of ports, P2X can be applied to produce green fuels, store energy, reduce emissions, and create new economic opportunities, making port operations more sustainable and environmentally friendly.

Rail Transport: Rail transport involves the movement of goods via trains on railway tracks. Several ports are focusing on modal shift, which means moving cargo from trucks to trains. This is done either by building new tracks or by improving the capacity of existing tracks and trains. Rail transport is more energy-efficient than road modes, making it a preferred choice for long-haul freight transport. Ports like Rotterdam and Trieste have made significant investments in rail infrastructure to promote this shift.

Railways: see Rail Transport.

Re-fuelling: see Bunkering.

Re-skilling: In the context of ports and energy transition, re-skilling refers to training port workers in new skills required for the transition to more sustainable and technologically advanced port operations.

Renewable Energy Directive (RED): The RED is an EU policy that sets targets for the use of renewable energy sources in member states. Ports can align with RED by adopting renewable energy solutions.

Renewable Power Generation in Ports: Ports are increasingly focusing on renewable energy sources, such as wind, solar, and tidal energy. The integration of renewable energy can challenge the existing grid infrastructure, especially as the demand for electricity grows. Grid management tools, including peak shaving techniques and the use of batteries, become crucial as ports shift towards renewable energy.

Shareholders: Shareholders are individuals or entities that own shares in a company or organization. In the context of ports, they could be entities or individuals with ownership stakes in the port or related businesses.

Smart Grids: A smart grid in a seaport is an intelligent network of electricity distribution and usage that uses digital technology to monitor and control the flow of electricity. It is designed to be more efficient and reliable than traditional power grids, and can also provide real-time information on the energy consumption of individual users and businesses. Smart grids in ports can help to reduce energy costs and emissions, while also improving the overall efficiency of the port. Smart grids can also help to reduce the risk of blackouts, reduce the need for costly infrastructure upgrades, and enable the port to better manage its energy resources. Smart grids in ports can also help to improve the safety of the port and its environment, by providing real-time information on the energy.

Smart Ports: Smart ports are defined as ports that have embraced the digitalisation of their operations, integrating digital technologies such as automation, artificial intelligence, and the Internet of Things into their core operations. These technologies enable ports to reduce their environ

Smart Technologies: Advanced systems or devices in ports that optimize operations, reduce energy consumption, and enhance sustainability.

Smart Technologies: Advanced technologies that enhance port operations and contribute to the energy transition. They can include automation systems, AI-driven optimization tools, and IoT devices.

Solar Power: Solar power in ports is primarily through photovoltaic panels installed on structures like warehouses. Solar panels can provide a significant portion of a port's energy needs.

Stakeholder Collaboration: Ports working with various entities to drive the energy transition, ensuring a holistic approach.

Stakeholders: In the context of ports, stakeholders are individuals or groups with an interest in the port's operations and its impact on the environment, economy, and society. This includes port authorities, local communities, businesses, and environmental groups.

Sustainable Operations: Ports adopting practices that are environmentally-friendly and future-proof.

Syngas: A fuel gas mixture consisting mainly of hydrogen, carbon monoxide, and some carbon dioxide. It can be produced from many sources, including biomass and waste, and ports can facilitate its production and use.

Tidal Power Generation: Tidal power generation is a form of hydropower that harnesses the energy of tides to produce electricity. Unlike other forms of renewable energy like solar or wind, tidal energy is highly predictable because it's based on the gravitational interactions between the Earth, Moon, and Sun. Tidal energy generation in ports is not widely reported. Only a few ports, like Valenciaport, are exploring wave energy. The necessary infrastructure for tidal energy includes power cables and installations that leverage tidal differences.

Transhipment: The act of offloading cargo from one vessel and loading it onto another for further transportation. As ports evolve in the energy transition, the types of cargo being transshipped may also change, reflecting shifts in global energy consumption and production.

Trucks: Trucks are vehicles designed to transport cargo by road. In most ports, road transport, primarily through trucks, remains the dominant mode for cargo and passenger movement. Transitioning heavy-duty trucks to better engines or alternative fuels can significantly improve port performance. Ports like Los Angeles have implemented stricter rules and provided incentives for vehicle improvements to reduce emissions.

Virtual Power Plants (VPPs): VPPs in ports involve pooling together multiple generators and resources, such as storage systems, to provide reliable and cost-effective electricity. This decentralized system allows for the sharing of energy across multiple sources and the integration of more renewable energy sources into the grid.

Waste to Energy: While not directly mentioned in the context of ports, waste-to-energy typically involves converting non-recyclable waste materials into usable heat, electricity, or fuel through a variety of processes. This can be a sustainable way to produce energy and reduce the volume of waste.

Waste to Fuel: The process of converting waste materials into fuels. Ports can facilitate the transformation of waste, especially from ships and nearby industries, into valuable fuels, supporting a circular economy.

Wave Power Generation: Wave power generation, also known as wave energy conversion, harnesses the energy of ocean surface waves to produce electricity. Waves are generated by the wind as it blows across the surface of the ocean, and they contain both kinetic energy (from their movement) and potential energy (from their height). While wave power generation has potential, its direct application within ports is still limited. However, ports located near areas with strong wave activity could potentially harness wave energy as a supplementary power source. The integration of wave energy in ports can further their sustainability goals, reduce carbon emissions, and decrease reliance on traditional energy sources. Some ports might explore pilot projects or partnerships with wave energy companies to test the feasibility and benefits of this renewable energy source within their operations.

Wind Power: There's an increasing interest in using wind energy in ports. Wind installations are among the most often considered renewable power generation infrastructure in ports. See also Offshore Wind Farms.

Zero-Emission: Ports striving to produce no emissions, especially carbon dioxide, during operations, aligning with global sustainability goals.

ZES (Zero Emission Services): A consortium that developed the ZESPacks, which are portable battery systems. In the port context, these ZESPacks are used to electrify barges, offering a cleaner alternative to traditional fuel sources and supporting the energy transition within port operations.