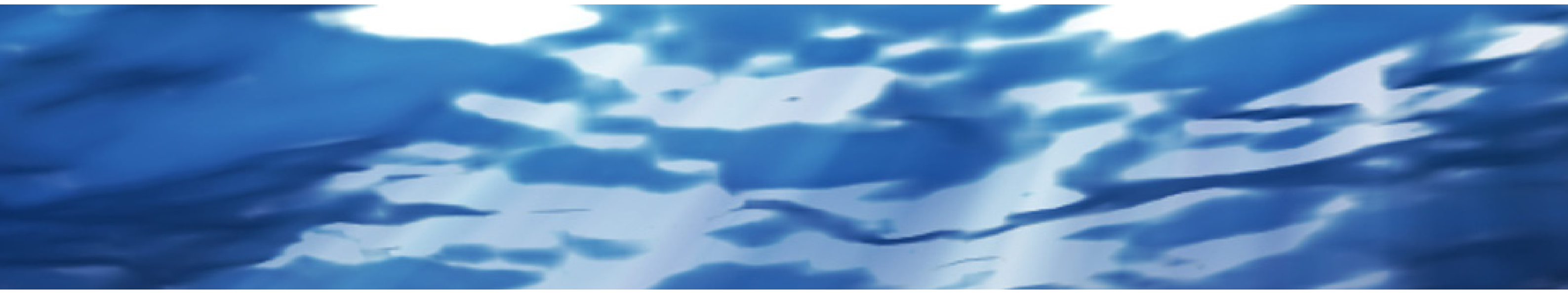
LIGHTHOUSE

SWEDISH MARITIME COMPETENCE CENTRE



LIGHTHOUSE REPORTS

The concept of the sustainable port – ports becoming enablers of sustainability in transports and logistics

En resultatrapport utförd inom Trafikverkets branschprogram Hållbar sjöfart som drivs av Lighthouse. Publicerad maj 2023

TRAFIKVERKET

LIGHTHOUSE
SWEDISH MARITIME COMPETENCE CENTRE

HÅLLBAR SJÖFART

The concept of the sustainable port
– ports becoming enablers of sustainability in transports and logistics

Illustration: Sandra Haraldson

Authors

Sandra Haraldson, Mikael Lind, Zeeshan Raza,
RISE, Research Institutes of Sweden

Johan Woxenius, University of Gothenburg

Fredrik Olindersson, Chalmers University of Technology

This effort was carried out by the innovation project I.Hamn within the Swedish Transport Administration's industry programme Sustainable shipping (Hållbar sjöfart), managed by Lighthouse.

Summary

Global transportation is one of the major contributors to greenhouse gas emissions. Ports play an important role for the leap towards a more sustainable transport ecosystem. Over the years, empowered by the Swedish innovation project I.Hamn, a concept for the sustainable port has been developed by the Swedish ports (see Appendix 1). This effort has been financed by the Swedish Transport Administration's industry programme Sustainable shipping managed by Lighthouse. The project is coordinated by the Research Institutes of Sweden (RISE), and University of Gothenburg and Chalmers University of Technology are project partners.

The result is a vision of the sustainable port, including a roadmap - developed together with Lighthouse Focus group for Ports - supporting Swedish ports, in which the three pillars of sustainability have been addressed, i.e., economic, social, and environmental sustainability. In this concept, the port as a transport node that acknowledges its interface to all traffic modes taken as the point of departure. A sustainable port addresses the means of sustainability in its own operations, in its services provided to users, and by being an active and integrated player in the sustainable development of the local and regional industries and communities. Building on the United Nation's Sustainable Development Goals, this report captures the concept of the sustainable port as a mean for becoming a proactive entity towards a more sustainable transport system, rather than a reactive one. The concept of the sustainable port also comes with the port as an energy node and as a digital node to address the opportunity for ports becoming a sustainable element as fully integrated in the transport and logistics ecosystem.

The vision for the Sustainable Port is based on the port as a sustainable transport node, which is able to leverage its role and capabilities both as a digital node and an energy node. The port is run on commercial grounds and as a transport node the port contributes to sustainable use of the transport system by being an integrated part of global, regional, and local transport systems where different types of traffic are included and interact.

Sammanfattning

Globala transporter är en av de största bidragsgivarna till utsläppen av växthusgaser. Hamnarna spelar en viktig roll för språnget mot ett mer hållbart transportekosystem. Genom insatser i innovationsprojektet I.Hamn har ett koncept för den hållbara hamnen tagits fram av de svenska hamnarna (se Appendix 1). Satsningen har finansierats av Trafikverkets branschprogram Hållbar sjöfart som förvaltas av Lighthouse. Projektet har koordinerats av Research Institutes of Sweden (RISE) tillsammans med Göteborgs universitet och Chalmers tekniska högskola.

Resultatet är en vision om den hållbara hamnen, inklusive en färdplan - framtagen tillsammans med Lighthouse Fokusgrupp Hamnar - som stödjer svenska hamnar, där de tre pelarna för hållbarhet har tagits upp, det vill säga ekonomisk, social och miljömässig hållbarhet. I detta koncept är hamnen som en transportnod med dess gränssnitt till alla trafikslag som tas som utgångspunkt. En hållbar hamn tar hänsyn till hållbarhetsaspekter i sin egen verksamhet, i de tjänster som tillhandahålls användarna och genom att vara en aktiv och integrerad aktör i den hållbara utvecklingen av det lokala och regionala näringslivet och det omgivande samhället. Med utgångspunkt i FN:s mål för hållbar utveckling fångar denna rapport begreppet hållbar hamn som ett medel för att bli en proaktiv aktör för ett mer hållbart transportsystem, snarare än en reaktiv aktör. Konceptet med den hållbara hamnen kommer också med hamnen som en energinod och som en digital nod för att ta itu med möjligheten för hamnar att bli ett hållbart element som är helt integrerat i transport- och logistikekosystemet.

Visionen för den hållbara hamnen bygger på hamnen som en hållbar transportnod, med förmågan att utnyttja sin roll och kapacitet både som en digital nod och en energinod. Hamnen drivs på kommersiella grunder och som transportnod bidrar hamnen till ett hållbart nyttjande av transportsystemet genom att vara en integrerad del av globala, regionala och lokala transportsystem där olika typer av trafik ingår och samverkar.

Table of contents

1 Introduction

Sweden, like other countries in the world, faces major challenges in ensuring that transport becomes more sustainable. The government of Sweden has set an ambition to make Sweden the world's first fossil-free welfare state and greening the transport sector is a key part of government's sustainability strategy. For the transport sector to play its part, the goal is that greenhouse gas (GHG) emissions from domestic transport, excluding domestic aviation, must be reduced by at least 70% by 2030 compared to 2010. The national climate goal of Sweden is zero GHG emissions by 2045 at the latest (Naturvårdsverket, 2023). In addition, in September 2015, the United Nation's General Assembly adopted Agenda 2030 and proposed 17 global goals for sustainable development also known as Sustainability Development Goals (SDGs). The agenda and goals must be implemented nationally as well as internationally and they concern sustainable transport systems, sustainable industry, innovations, and infrastructure and combating climate change by integrating climate measures into policy, strategies, and planning.

For Sweden to achieve the climate goals and to contribute to UN's SDGs, among other things, a greater proportion of goods need to be transported by rail and sea, and in the government's maritime strategy, as well as in the national freight transport strategy, shipping is singled out as an important part of achieving an efficient transport system and the seaports are important central nodes for transport and logistics system (Berglund and Andersson, 2021). Considering the modal shift from road to rail and sea, it is critical that seaports as nodes in the transport system become sustainable.

The quest for port sustainability has accelerated due to increased scrutiny of ports and pressure from actors such as regulators, customers, and cargo owners, to take actions and decrease externalities through sustainable and cleaner operations (UNCTAD, 2019). Such pressure motivates and stimulates ports not to merely focus on economic generation, but also to include resilient sustainable strategies. Put differently, ports are required to balance commercial and economic growth against environmental and social sustainability, and thus to achieve competitive advantage and boost service quality.

Sustainable and competitive Swedish small and medium-sized ports are an important part of enabling sustainable short sea shipping as part of a successful transfer of transport from land to sea and at the same time contribute to realising UN's SDGs.

1.1 Aim

To reach the emission targets and meet the domestic and global climate goals, ports need to enhance their innovation capabilities, increase the share of alternative fuels for own equipment, and collaborate with actors in the transport ecosystem for a transition to a more transport-efficient society.

The aim of this report is to develop and present a vision of how ports can become enablers of sustainability in transports and logistics as well as frameworks for ports as sustainable transport nodes, energy nodes and digital nodes are presented.

More details regarding Swedish ports' sustainability initiatives and contribution to SDGs can be found in the final report for the I.Hamn project (Haraldson et al. 2023). The aim of the I.Hamn final report is to raise awareness on ports' ongoing work on sustainability and to provide inspiration regarding various proactive measures ports can pursue to comply with regulations and to contribute to Agenda 2030. The practical examples cited in the I.Hamn final report can serve as inspiration for ports seeking to integrate UN's SDGs into their strategy and day-to-day business.

1.2 Scope

Although the project scope is limited to small and medium-sized ports, most of the rendering also apply to larger ports, at least in a Swedish context. After all, also the large Swedish ports can be considered medium-sized in a global comparison. The focus is, however, not limited to the port as a location or an organisation, but the scope includes its geographical, business, and societal context. Additionally, it is important to consider the difference between the terms port and port authority. A port is a facility where carriers visit to load and unload cargo and passengers. Often ports are to be seen as a multi-organisational practice engaging several (private and public) actors. It can refer to a specific location, such as a harbor or an anchorage, or a larger geographical area that includes several ports.

A port authority, on the other hand, is an organization responsible for the administration and management of a port or group of ports (Notteboom et al., 2022). This may include tasks such as maintaining the infrastructure of the port, regulating transport activities, ensuring compliance with safety and environmental standards, and collecting fees from visitors that use the port. Port authorities are typically established by government agencies or local municipalities to oversee the operation of ports within their jurisdiction.

Sweden's 52 ports vary significantly in terms of their characteristics such as the type of port, ownership/management, and geographic location, which impacts their investment opportunities, priorities, and role in the transition to a sustainable transport system. Business models suitable for each port depend on their specific strategy and conditions, including size, customer base, and location. These differences are important to consider when interpreting the relevance of the key findings of this report.

1.3 Structure of the report

The report starts with putting ports into a Swedish context elaborating on their role and importance. The following chapter presents a vision for a sustainable port, before more specifically scrutinising the role of ports as transport and logistics nodes, energy and digital nodes respectively. The next chapter presents a maturity framework for ports in their primary roles as transport and logistics nodes followed by a chapter on how ports can contribute to decarbonisation. Finally, conclusions are drawn.

2 Seaports' importance for Sweden

Ports play a central role in countries' economic growth: they are essential to the wellbeing of humankind including the provision of direct and indirect employment. Ports act as social caretakers for employees and communities, enhancing and supporting socioeconomic priorities.

Even in the worst shocks, particularly the recent COVID-19 pandemic, ports and shipping were at the global transport forefront, maintaining continuous delivery of the world's medical supplies, food, energy, and raw materials, as well as manufactured goods and components.

In Sweden ports are strategic logistics hubs for Sweden as a nation, for our neighbouring countries and partners, but they do also function as central transport and logistics nodes that many of the domestic and global companies depend on for their operations to be stable and can be used in both peace, crisis, and war. Sweden's great dependence on goods from other parts of the world with exports and imports means that already after about 10 days of stoppage of deliveries, certain daily goods will be handled as a shortage. To ensure Sweden's endurance, supply, and stability, it is crucial that the ports can operate in both peace, crisis, and war (Försvarsmakten, 2019). Trust in continuous supply of components and necessities also prevents firms and consumers from hoarding.

Most of Sweden's major ports are municipally owned, although individual terminals are increasingly operated by privately owned firms and have been established to support local and regional industry. Competitive ports make an important contribution to economic development and employment in Sweden. The logistics sector is rather dependent on goods being brought in via a port and then distributed further in Sweden – through land-based traffic modes or by sea along the coasts. Competitive ports are thus an important contributor to a more sustainable society (Sveriges Hamnar, 2011).

In Europe, **2200 port operators** employ more than **1.5 million workers** with the same amount again employed indirectly across the 22 EU maritime Member States. In Sweden about 30000 people work in the maritime industry including 4000 people who are associated with the port and logistics sectors. Considered as gateways to international trade, there exist thousands of seaports handling seaborne trade. As of 2018, some **98000 ships carried 11 billion tons** of seaborne trade, which is around 80% and 60–70% of world trade volume and value, respectively. Only in 2019, ships of more than 100 gross tons made **4.3 million port calls** (Alamoush *et al.,* 2021; EC, 2023b: Lighthouse, 2021).

Along Sweden's coast, which is one of Europe's longest coastlines, there are more than a hundred ports, of which a little more than fifty are designated as so-called public ports. The operations of the public ports are decisive for Sweden's imports and exports. The public ports account for nearly 80% of all traffic measured in transported goods and passengers across the Swedish ports.

Several Swedish ports act as gateways to neighbouring countries and handle transport of both goods and passengers. Many of the so-called bridge ports are passenger ports and serve RoPax and cruise ferry traffic which connects Sweden to the rest of Europe by transporting millions of passengers each year. These ports are mainly found in southern Sweden, western Sweden, and the Stockholm area.

An example of a bridge port is Port of Trelleborg and ports such as Stockholm and Gothenburg, serving cruise vessels and playing an important role in the regional development as cruise tourists spend billions in shopping and hoteling and thus directly or indirectly lead to an increased employment.

Port of Trelleborg is owned by Trelleborg's municipality and conducts port and terminal operations. It is Scandinavia's largest RoRo port and second largest ferry port and one of five Swedish core ports. The port has eight RoRo berths with different ramp systems and track connections and it is the largest railway port in the Baltic Sea with the ability to receive the largest railway ferries in the world (Bergdahl, 2019).

In addition, there are a number of industrial ports of varying size closely connected to nearby industry with a narrower scope of goods. In today's port structure, the majority of ports handle forest and steel products, which shows the importance of port operations for the Swedish base industry.

Nevertheless, many ports increasingly handle goods that never go over quays, for example intermodal terminals for transhipment between road and rail. Some ports in Sweden are energy ports such as the ports in Gothenburg and Gävle. Through the ports of Gothenburg and Brofjorden, for instance, crude oil is imported, and refineries produce oil products for distribution throughout Sweden and neighbouring countries. In addition, the port of Gävle states that two daily trains have replaced 55 daily tanker trucks that previously transported aviation fuel to Arlanda airport and moved through Stockholm's inner city (Bergdahl, 2019).

A total of **179 million tons of goods** were loaded and unloaded over quays and over **30 million passengers** boarded or disembarked ships in Swedish ports in 2018. According to the Port of Gothenburg, approximately 2,500 tanker vessels call each year and a total of **over 20 million tonnes** of crude oil, petrol, diesel and other energy products are handled in the port. Gävle Energihamn supplies Arlanda Airport with its aviation fuel needs through two daily train shuttles supporting the transport ecosystem.

3 A vision for a sustainable port

Considering the magnitude of port activities, ports as nodes in the global supply chains, as well as important gateways for passenger transport, always generate social and environmental external impacts (externalities). In general, ports generate environmental impacts through their various functions linked to cargo handling, connectivity to maritime and land transport networks, industrial and semi-industrial activities, logistics and distribution activities, and energy production and distribution (Notteboom *et al.,* 2020). Port operations and expansion, as well as shipping and land transport operation, have severe impacts on the environment and harms marine ecosystems (World Bank, 2017). Hence, ports need to play its part in improving sustainability of supply chains.

The vision for the Sustainable Port is based on the port as a sustainable transport node, able to leverage its role and capabilities both as a digital node (Lind *et al.*, 2021a) and an energy node (Bach *et al.*, 2022) (Figure 1). The port is run on commercial grounds and as a transport node the port contributes to sustainable use of the transport system by being an integrated part of global, regional and local transport systems where different types of traffic are included and interact (Lind *et al.,* 2021a).

Important starting point in the vision are UN's SDGs or Agenda 2030. To be a driving force in the transition towards a sustainable transport system, the strategy for transferring the traditional view of port operations needs to be challenged and the port's role in the transport system needs to be developed. Sustainable development goals, increased transport volumes and objectives relating to transport efficiency require increased utilisation of existing resources and infrastructure. To realise the vision, the port, in addition to functioning as a sustainable transport node, also needs to enhance and leverage their capabilities as a digital node and energy node (Berglund and Andersson, 2021). It is thus a need to re-frame the traditional viewpoint of what a port is

Figure 1. The sustainable port as a transport node, capable also of serving as an energy node and a digital node. Illustration: Sandra Haraldson.

The sustainable port is a transport and logistics node that by enhancing and leveraging its human and financial capabilities and using its role as an energy and digital/information node generates value for its customers, owners, employees and the wider society and concurrently considers environmental, social and economic sustainability in its operations and management.

The port as a transport node is not only a window to shipping, but a node for all types of transport modes in the sustainable transport system. Thus, the port has a critical role in relation to other transport nodes in the goods, passenger, and transport flow that is managed by the nodes jointly (see Figure 2 below).

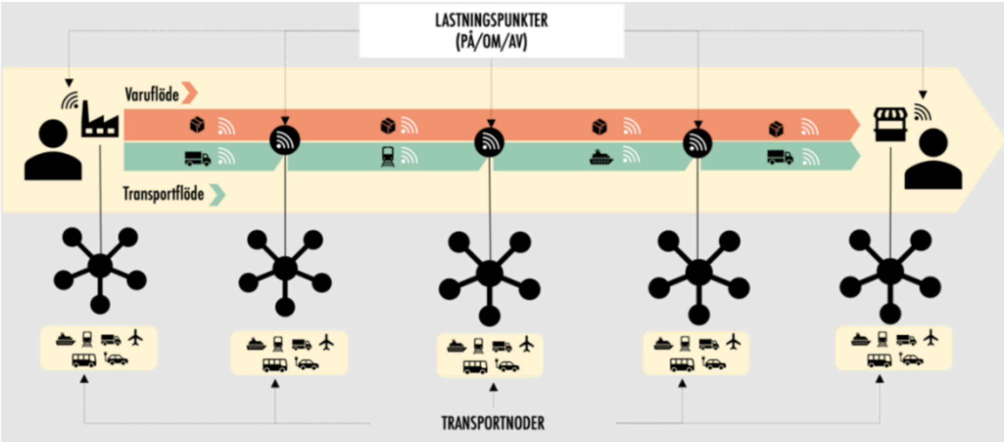


Figure 2. Goods and transport flow through different nodes (Source: Bach et al., 2022).

By considering the port as a transport node, conditions are thus created to identify the port's role in a larger energy supply context that goes beyond offering shore power to visiting ships. The port as an energy node addresses the acquisition, storage, and supply of sustainable energy for the port's own operations, and to users in connection with their bunkering regardless transport mode. Additionally, ports play a central role as energy hubs by providing land and infrastructure, developing safety regulations, and enabling the production, storage, and transportation of sustainable energy for the communities and industries. As such it is crucial in the transition from fossil fuels to fossil-free energy carriers. To ensure sustainable port operations and in the role of the port in the transport ecosystem, the port's characteristics as both a transport node and an energy node need to be supported through various digitalisation initiatives that establish the port as a digital node.

To ensure that the port as a transport node can function efficiently with lowest possible negative impact on the natural environment and effectively serve its customers with interface between all modes of transport, it is important that the port is established as a sustainable port which capitalises on the opportunities provided by digitalisation, energy transition and contributes to UN's SDGs. A sustainable port that is a transport and logistics node, energy node and digital node. The port as a digital node is an expression of the aggregated digital capability required for the sustainable port, while the port as an energy node expresses the aggregated energy supply capability of the sustainable port. The port as a transport node is the collective logistics capability required for the sustainable port (Lind *et al.,* 2021a).

The concepts of port as a transport node, digital node and energy node (Figure 3) are explained in detail in the following.

Figure 3. Illustration of a port as a transport node, digital node, and energy node. Illustration: Sandra Haraldson.

The basis for the elaboration of the different node roles is taken from different components building the capability of the port (Figure 4). Those components are digital infrastructure, processes, physical infrastructure, innovation capacity/ability, rules/regulations, employees, and business models.

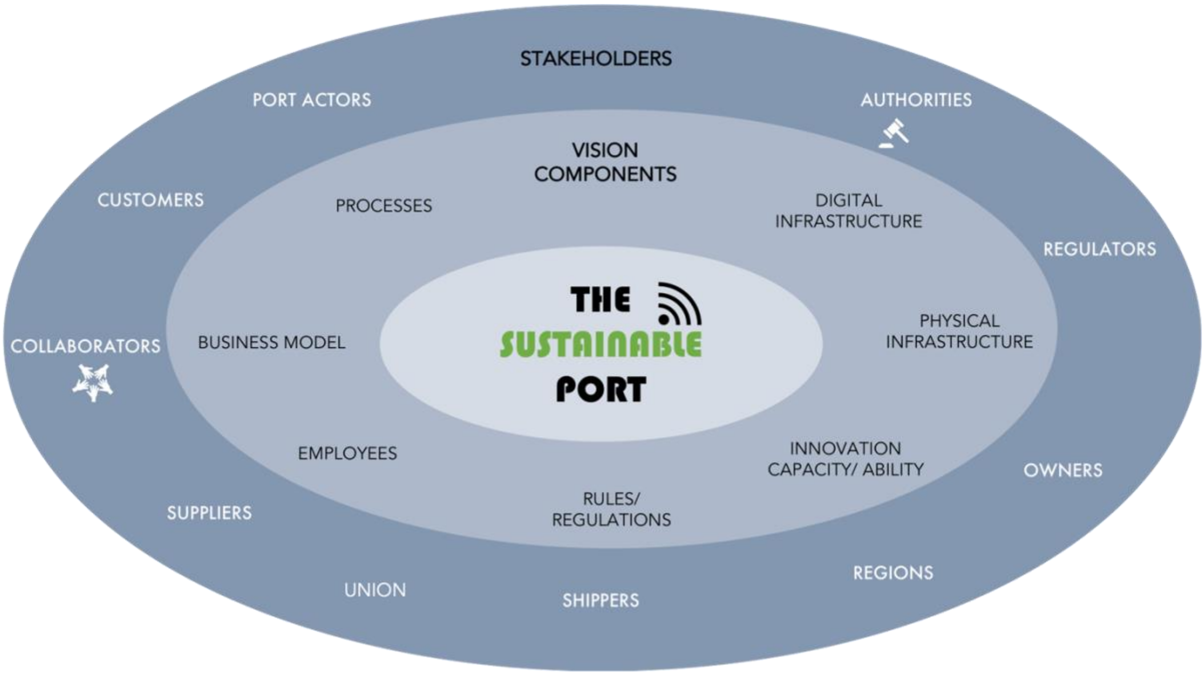


Figure 4. Components constituting the sustainable ports and stakeholders affecting those. Illustration: Sandra Haraldson.

4 Ports' nodal functions

This chapter elaborates on ports' different nodal functions. Starting with the fundamental and original role as interface between traffic modes, continuing with the role in the provision of energy carriers and, finally, how they contribute to digitalisation of transport flows.

4.1 Ports as Transport and Logistics nodes

The seaport has a long history going back to the early days of human endeavours. As soon as civilisations emerged across the world, trade networks supported by ports emerged as well. Most really large cities have access to maritime transport as they grew based on their location at the coastline, along a river or ideally with a combination of the two. Although maritime transport technology has evolved substantially, the role and function of ports remain relatively similar. Conventionally, a port is defined as a transit area, a gateway through which goods and people move from and to the sea. It is a place of contact between the land and maritime space, a node where ocean and inland transport systems interact, and a place of convergence for different transportation modes. Since maritime and inland transportation modes have different capacities, the port assumes the role of a point of load break where cargo is consolidated or deconsolidated (Notteboom *et al.*, 2022). Over the years the role of seaports has evolved, and contemporary ports also function as inland terminals or transhipment centres which connect systems of freight circulation through the same mode (e.g., rail to rail) or through intermodalism, (e.g., between rail and road) without even involving sea transport.

According to Notteboom *et. al.,* (2022) even if the term port appears generic, it expresses a substantial diversity of sizes and functions. Ports also have a geographical diversity in terms of the sites being used for port activities, which can range from rivers, bays to offshore locations. They are complex and multi-faceted and can be approached primarily from a supply chain perspective. Thus, a seaport is a logistics and industrial node in global supply chains with a strong maritime character and a functional and spatial clustering of activities directly or indirectly linked to transportation, transformation, and information processes within global supply chains (Figure 5). A modern day's port is not regarded solely as a load breakpoint in various supply chains but should be considered a value-adding transit point. As nodes within transportation and logistics networks, ports have a location, which relative importance can fluctuate given economic, technical, and political changes. This location tries to capitalise on the advantages of a port site characterised by fundamental physical features influencing the nautical profile, such as water depth, access channels, and the available land.

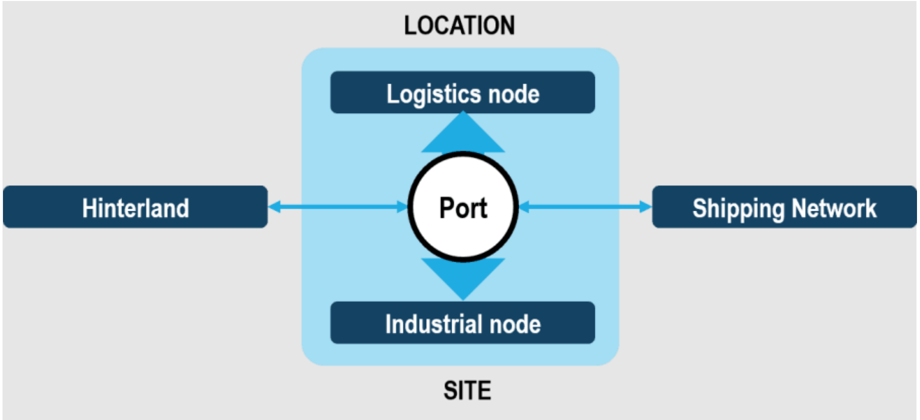


Figure 5. What a seaport is (Source: Notteboom et. al., 2022)

Ports perform a variety of operations such as the construction and operation of quays, buildings, and other facilities within the port area as well as services related to handling of ships, passengers, crew, and cargo in connection with the arrival, departure and stay of ships in port. In addition to access and provision of fixed connections such as the port and port entrance as well as quays, warehouses, storage in the port, a range of different services are included in the operation of ports. This concerns, for example, planning and communication systems, services for pilotage and towing at the arrival and departure of ships, terminals, and terminal services for passengers and for various types of goods, stevedoring services for loading and unloading ships, services in connection with passenger transport, access, and connection to various forms of land service such as electricity, water and sewage, waste reception and more (Bergdahl, 2019).

Over the decades port functions have changed and expanded, responding to technical, economical, and social developments. From the traffic being generated, functions such as trade, distribution, and industry have emerged in seaports, broadening, and deepening their functions. UNCTAD (1992) defines three port generations based on port development policy, strategy, and attitude; the scope and extension of port activities and the integration of port activities and organisation. These port generations are briefly described in the following.

The *First generation* port is seen as merely a cargo interface between land and sea transport. UNCTAD points out that the classification is most suitable for general cargo ports since many bulk ports fulfil their purpose well by being just an intermodal interface. World Bank (2017) denotes this a *Land-sea interface.*

The *Second generation* port offers industrial or commercial services beyond transhipment and are viewed as industrial and commercial service centres. Examples of services beside transhipment are packing, labelling and cargo transformation. Metal works, refineries, manufacturing of paper and pulp, fertilisers, sugar and starch, flour milling, and other food-related activities can establish in a second generation port. The scope and land use of the maritime cluster then expands. World Bank (2017) accordingly terms it *Expanding industrial and commercial centre.*

In the view of UNCTAD (1992), the *Third generation port* appeared in the 1980's as a result of developments in global trade, rapid containerisation and focus on intermodal conections. Activities and services are specialised, variable and integrated. Like the Second generation port, it is characterised as a service centre, but the services are more developed. It is here called a *Logistics node* highlighting that logistics takes the port beyond being a freight terminal and location of freight-intensive process industry.

Later, UNCTAD (1999) added the *Fourth generation* port which is physically separated but linked through common operators or through a common administration. UNCTAD's description pointed into the future, and now almost 25 years later captures the current port situation quite well. UNCTAD illustrates with Copenhagen Malmö Port, being a merger in 2001 between a Swedish and a Danish port on either side of the Öresund Strait. UNCTAD also points out the interplay with the Öresund Connection between the two countries in line with cross-border region enlargement ambitions. The World Bank (2017) calls this type of port *Distributed terminals*.

During the last 50 years, the main driving forces include containerisation, diversification of cargo types and equipment, intermodal transport, and information technologies. Port functions are extended to trade, logistics, and production centres with an extensive portfolio of operations, including production, trade, and service industries. Some seaports have grown to become industrial complexes comprising a large number of industrial activities.

Successive stages in port development in part coordinated by different economic opportunities have favoured the setting of a hierarchy of ports, ranging from small ports servicing a niche market to large gateways servicing a vast area composed of an extensive range of economic activities. Like most hierarchies, there are a small number of very large ports accounting for a significant share of the total traffic and many small ports that account for limited traffic.

In 2019, **the 20 largest container ports** accounted for **44% of the total global traffic**, reflecting a well-established hierarchy. This does not imply that small ports are of limited importance for the economies they serve. Small islands and nation-states have a high dependence on their ports to access global markets (Notteboom *et al.*, 2022). Additionally, on average **400 million passengers** embark and disembark in European ports every year.

From a supply chain perspective, seaports are increasingly functioning not as individual places that handle ships but as turntables within global supply chains and global transportation networks. The contemporary port (by UNCTAD, 1999, labelled a fourth-generation port) is characterised as a platform commanding freight flows and requiring knowledge-intensive coordination activities. A port's organisational role varies depending on whether it is regarded from the inside or outside. Externally, a port is a hub acting on behalf of all port actors. Internally, each port actor is an agent acting on behalf of the port and its interests. The involvement of multiple actors in port ecosystem requires collaboration to enable the optimal realisation of port visits by flexibly balancing capacity utilisation and turn-around time to minimise port disruptions. A seaport is not self-contained as port activities contribute to the industrial and logistics development in the port areas and its hinterland. Thus, ports act as service centres and logistics platforms for international trade and transport. In recent decades ports have been subject to a wave of reforms that reflects the increasing business and market-oriented approach to port management. From governance and institutional perspectives, many ports have become independent commercial organisations aiming at profitability, cost recovery, and customer service (Notteboom *et al.*, 2022; Alamoush *et al.,* 2021).

4.2 Ports as Energy Nodes

The reduction of GHG emissions has become a greater societal responsibility and the transport sector is undoubtedly one of the largest GHG emitters. According to the estimates of the International Energy Agency (IEA, 2023) this sector is responsible for about 21% of global CO_2 emissions. Ports face pressure from customers requiring cleaner energy and a plethora of existing/forthcoming global and regional regulations. Ports are mini energy systems themselves similar to other industrial hubs.

A port is not only a transport and digital node but also an energy hub in the global energy ecosystem (Lind *et al.*, 2020; Lind *et al.*, 2021a; Lind *et al.*, 2023; Bach *et al.*, 2022). On average 40% of goods going through ports are energy related. Ports are generally connected to economic activity, as industrial clusters are often located in and near ports, which points to potential synergies and co-creation opportunities. Ports are central nodes for sector coupling and energy system integration as they host and serve multiple industries including oil and gas facilities, maritime supply chains, road haulage, rail transports, cruise-tourism, manufacturing sites, heat and power stations, and electricity grid and offshore wind operators.

Decarbonisation of transport requires all stakeholders to collaborate and act including shippers, transport operators, freight forwarders, ports, vehicle makers, engine manufacturers, energy producers and policy makers. Ports could play an important model role at the intersection of marine fuel, shipbuilding (including ship repair and supplies), and operational value chains in their capacity of providing energy to seaborne users, i.e., wet and dry bulk, container, car carriers, and land borne trucks and trains (Lind *et al.*, 2022b). Ports help synchronisation along the transportation value chain which requires data sharing and large-scale end-to-end digitalisation as well as the adoption of any possibly available enabler of transport decarbonisation. Ports are often located close to cities and industrial centres pointing to potential synergies. More details regarding the role of ports as energy nodes and description of various initiatives port can adopt are provided in chapter 6.

4.3 Ports as Digital Nodes

By gathering and providing information, using digital means, about the respective state of inbound and outbound consignments moved by different means of transport, transport nodes play an essential role in forecasting and prescribing actions on use of capabilities and providing services to episodic visitors. Ports as transport nodes could thus lead the way into a more synchronised future of maritime supply chains. This however requires that the ports develop their digital maturity, both for performing efficiently and sustainably as well as for providing data streams for more reliable planning to their clients, allowing for such things as elastic time slot management (Lind *et al.*, 2021b).

The pressure and needs from transport buyers, shipping companies, freight forwarders and even end consumers for accurate and reliable information in real time and transparency will increase in the future. More connected sensors and smart applications open up new opportunities and services. The requirements are therefore primarily placed on the ports that handle containerised or rolling goods in the form of trailers or passenger cars, but also basic and input goods will have increased requirements for information sharing when more and more industries upgrade their logistics and manufacturing systems to an increased degree of digitalisation and timely deliveries. With accurate and reliable information, goods in transit can form liquid inventory and reduce the need for intermediate and buffer stock. With transparent information about the current situation in different nodes and with different transport lines, goods can be redirected more quickly to alternative routes to avoid getting stuck in congestion in ports or if there are disruptions to a route. In this way, transport flows can be smoothed out and peak loads can be steered away. At the same time, resilience is achieved in the transport system when more transport options can be used seamlessly.

The port's role as a digital node is a prerequisite for efficient and sustainable transport networks. The port as a digital node exchanges up-to-date information with the transport system's stakeholders for well-founded decisions about planning and coordination based on information about transport, infrastructure utilisation, the status of the transport object and the needs of the transport buyer. To this end, Lind and Lehmacher (2023) in a recent article elaborate that in the world of moving goods, the weakest link can greatly impact the entire supply chain. A delay at one point can cause problems in subsequent steps, resulting in losses for everyone involved, including the consignees and cargo owners. However, there is also the potential for winners. Ports that gather and provide accurate information to all actors can improve the performance of the entire chain, empowering subsequent actors and participants to prepare for any delays. Additionally, this can increase the value of ports for shippers and consignees. Analyzing this data can also help ports to assess their own performance and make necessary improvements. Cargo owners now have access to more information, allowing them to take action when needed. Ports can develop new data-based analytical services and offer them to all stakeholders across the maritime ecosystem, positioning themselves as leading players in the digital age. The anticipated disruption involves using digitalization to communicate and collaborate not only with direct stakeholders of the port, such as carriers, but also with indirect stakeholders like transport buyers. This will soon become standard in fully connected and networked supply chains.

With a greater degree of digitalisation, ports can be better integrated into the entire transport system and increase the possibilities for greater coordination between the transport modes and other transport nodes. Ports are often required to have greater accessibility by providing services around the clock, while the costs of port fees and cargo handling must also be kept down. Through better and more reliable exchange of information in real time, better and safer planning of resources can be performed. This streamlining could lead to lower costs. These are aspects that are also highlighted in the Swedish Transport Administration's report (Berglund and Andersson, 2021) as enablers for the sustainable port.

The port as a digital node means that a port acts both as a consumer and a provider of digital information / services, to be efficient, sustainable, and resilient in its complementary roles as a transport, energy, and digital node. The digitalisation "trend" is encouraging solutions that are characterised by:

- Interoperability allowing for multiple information sharing environments to become connected and data to be gathered from, and sourced to, different types of systems within and outside the port
- Modularisation allowing for diverse use cases to be supported by different applications avoiding large systems requiring substantial maintenance costs
- Standardisation allowing for reduced investment costs to become connected
- Data harvesting, data aggregation, and data analytics populated by the increasing number of connected devices providing foundations for fact-based decision-making

The port as a digital node directs attention to the efficient generation and sharing of data from connected infrastructure, resources, and actors being used for enhanced business intelligence, synchronisation of activities, and new business opportunities. In this way the port becomes an enabler for exchanges for well-founded decisions on planning and coordination based on information about transport and infrastructure utilisation and based on the transport object's status and the transport buyer's needs. The port as a digital node allows for enhancing its capabilities as transport (logistic), energy, but also as a digital node providing vital information to the outside world. The digital concept addresses the following needs:

- Enhanced possibilities to coordinate and synchronise the use of vehicles and means of transport by minimising idle time and empty miles - for carrier companies (shipping companies, truck operators, rail companies)
- Maximised utilisation of storage capacity, to provide up-to-date track-and-trace information to their clients - for cargo owners
- Maximised utilisation of infrastructure and resources – for port actors
- Keeping track of whereabouts of cargo units for repositioning and distribution - for cargo unit owners (i.e. carriers with own cargo units and also container or trailer leasing companies)

Importantly, an information-node port can also fulfil a key role in the context of the introduction of the maritime single window, which requires much more information to be shared digitally, providing cargo owners, and transport buyers with a basis to report to authorities. In order to understand port digital maturity and to guide ports towards a more sustainable future a digital maturity framework is developed, which is detailed in Chapter 7.

5 A maturity framework for ports as sustainable transport nodes

In this study we provide a framework for guiding ports on how to fully develop and enhance their capabilities as sustainable transport and logistics nodes by leveraging the opportunities provided by energy transition and digitalisation. This framework builds upon

- the port's strategy and vision to become a sustainable port (Level 1)
- pointing at the need for important measures including digital and energy transformations to take into account for its own operations, equipment, assets and financial and human resources (Level 2),
- providing for instance sustainable energy, charging lower fees for sustainable operations, and digitalised and automated services to the users of the port (Level 3),
- and its role associated with being part of the local, regional, and global energy and transport ecosystem (Level 4).

Figure depicts this four-level maturity framework which is discussed in more detail below. The framework should not be seen as a one-direction/step-by-step framework but needs to be understood as a self-improving circular system, where ports move back and forth between the levels.

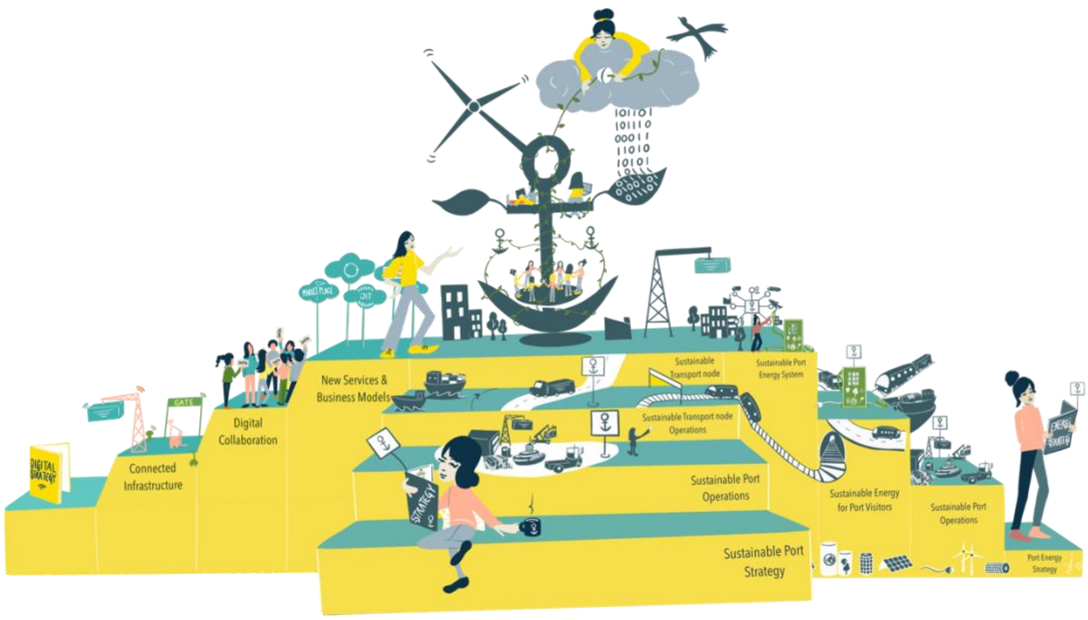


Figure 6. The Port as a Transport Node. Illustration: Sandra Haraldson.

5.1 Level 1: Strategy formulation for a port as a sustainable transport node

The journey towards establishing a port as a sustainable transport node starts with the creation of a new strategy and a vision which should also consider the port's role as the energy node and use digitalisation as a key enabler to optimise port functions as transport and energy nodes. A strategy should focus on finding new ways for creating value for the economy, society, and the environment using digital technologies, upskilled and reskilled talents, and sustainable energy. Strategy formulation process for a sustainable port should engage all stakeholders involved in a port ecosystem including port management/owners, port users and land users (road, rail and vessels, warehousing firms, terminal operators), policy makers, regional authorities, industry organisations (such as ESPO - the European Sea Ports Organisation, Ports of Sweden, FEPORT – The Federation of European Private Port Companies and Terminals), energy companies as well as industrial actors located in the hinterland. As a key element of strategy, ports should identify the key challenges and opportunities related to the ports' function as a transport node for both cargo and passengers which should be addressed by relevant initiatives and by benefitting from digitalisation and energy transition. It is important that measures taken by ports should be intended to increase the effectiveness and efficiency of port operations as a transport node, fulfil customers' service quality and environmental requirements, promote business growth through innovations, increase diversity at workplace, protect employees' rights and health, and reduce negative environmental and social externalities caused by ports own activities as well as by ports users, and hence contribute to the UN's SDGs.

To this end, leadership commitment in a port plays an indispensable role as a fundamental driver for a successful strategy creation for a sustainable port. Top leadership can play an important role to increase the pace of change through developing a strategy and vision, allocating investments, setting clear aspirations and by acquiring infrastructures and capabilities to support the sustainable operations across entire port business.

> Sustainable ports need to take not only the reactive measures to address the challenges and comply with regulations but also proactive measures to take advantage of the opportunities created by digitalisation, energy transition and innovations.

To enhance the port competitiveness, ports need to engage in planning and development of port operations which is comprised of short-, medium- and long-term planning (Notteboom *et al.*, 2022). Short term planning involves the current allocation of the port's resources and services. The resulting decisions aim to solve practical problems related to efficient cargo handling at the port, increasing energy efficiency and optimal utilisation of the port's assets and equipment.

The medium-term planning involves both financial and strategic planning, often reported through business plans. The budgeting for the annual allocation of the port's resources to specific activities is part of the financial planning process. Strategic plans, which are usually prepared every three to five years, aim to allocate port resources to different activities and meet specific marketing and financial objectives. This assumes a competitive environment in which the allocation of resources will affect the structure and level of demand.

Finally, the long-term planning demands a more fundamental and visionary approach, in most cases embodied in the development of port master plans or strategic port plans. The output is a physical plan (including capital budgeting) for the future development of port infrastructure and other capabilities and capacities with a ten to 30 years planning horizon. Port management is challenged to maximise consistency between the different types of port planning.

Ports should design a strategy that makes the most effective use of their core resources and capabilities. In the framework of strategy formulation, a port has to define specific objectives or goals to pursue. The objectives must be dynamic and permit changing external and internal factors. Objectives must be specific in terms of time span and figures and must refer to defined departments or units of the organisation. Objectives and targets should cover marketing, operation, finance, workforce, and the environment. The ability of a port authority to design and select strategies can be increased by improving communications the relevant stakeholder involved in a port ecosystem and the relevant public authorities. After formulation, ports should continuously evaluate their strategy. The strategic evaluation involves a constant adaptation of the objectives and goals to respond adequately to relevant changes in the resources and capabilities of the port (internal appraisal) and its competitive environment (external appraisal) (Notteboom *et al.,* 2022; Bach *et al.*, 2022). In this whole process, ports need to consider levels 2-4 of the framework, by holding stakeholder dialogues, and initiating collaborations.

5.2 Level 2: Sustainable initiatives within a port

Ports generally have small environmental footprints of their own, but ports are nonetheless a place where a lot of emissions and pollution come together – both for the internal operations of the port and for providing visitors, independent of transport mean, with sustainable fuel. Therefore, a sustainable port needs to reduce negative environmental externalities generated by both the port activities, as well as all transport and industry players in the port area. While the port is fully responsible for the reduction of emissions and other externalities related to its own infrastructure, equipment and activities, transport and industry players in the port must set their own agendas, goals, and plans for greening their operations. However, ports need to support and encourage these efforts, creating a joint pathway to a more sustainable future and contribute to SDGs (ESPO, 2021).

To integrate SDGs in their own business operations, ports can take various initiatives. Our findings show that a vast majority of ports in Sweden do not measure and report the CO_2 emissions, so ports need to allocate resources for CO_2 measurement and collaborate with other ports and stakeholders to develop CO_2 measurement criteria and standards for the entire port industry.

Advancement in alternative fuels and fossil free energy solutions have unlocked new opportunities to reduce air and noise pollution, and ports can take advantage of such opportunities and repower the machines and cargo handling equipment with green electricity and alternative fuels such as HVO (Hydrotreated vegetable oil) and hydrogen. To increase energy efficiency, ports can encourage eco-driving of port vehicle and machines, replace fluorescent lamps with LED lighting and install motion detectors in port buildings and warehouses, which automatically turn the lights on and off and all such measures can substantially save energy, costs, and emissions.

Compared to many other industries, shipping and the port industry in general is behind the digitalisation curve. So, the role of ports as transport nodes for different traffic modes requires that ports investigate the potential of improving port operations through digitalisation. Ports can invest in autonomous trucks and machines as well as introducing autonomous gate check-ins for port users, upgrading the terminal systems with optimised yard planning functions which can as result minimise the number of lifts, shorten driving routes and the movements of containers in the port area and eventually lead to increased efficiency, safety, and lower emissions for ports as well as for port users.

Moreover, when making purchase decisions regarding materials, services and equipment, ports need to choose sustainable and energy efficient products and require that its suppliers are sustainable and trustworthy to avoid unacceptable working conditions, child labour and contribute to relevant SDGs.

Case example: The port is traditionally a male dominated workplace. To support gender equality at workplace the Port of Helsingborg made the organizational changes, and the management team has changed to four men and four women in 2021.

Ports need to develop and upgrade workforce policies and make sure that the port is a workplace for everyone, regardless of gender, gender identity or expression, ethnic affiliation, religion or other belief, disability, sexual orientation, or age and hence contribute to SDG 5 (Gender equality) and SDG 10 (Reduce inequalities).

Ports need to pay serious attention to climate adaptation and biodiversity considerations when modifying existing infrastructure and when planning new infrastructure. To support biodiversity (SDG 15) a major Swedish port for instance chose tiles with different structures and patterns that are placed in the quay walls. This creates better conditions for marine organisms, such as mussels and crabs, which can settle in the nooks and crannies of the slab. It benefits biodiversity and creates a more sustainable ocean. Ports should make policies and allocate resources for biological and chemical treatment of the wastewater and the waste generated at port should be sorted for recycling, biological or thermal treatment.

Additionally, to meet the rapidly evolving customer requirements regarding environmental sustainability, end-to-end visibility, and to comply with the ever-changing regulatory landscape a new set of capabilities, behaviours and reskilling or upskilling of port employees is required. Port managers should be equipped with a crucial capability of transformation or change management. To drive change in ports and drive towards sustainable and efficient port operations, managers must be provided with substantial decision-making power, sufficient budget, and support by senior leaders from different business functions.

5.3 Level 3: Sustainable initiatives for port users

Ports as transport and logistics nodes can play pivotal role to enhance efficiency across the entire supply chains and support the ambitious climate goals of port users (rail, road haulage and vessels) and industrial tenants. Ports can offer charging stations to heavy vehicles and shore-side electricity to vessels while berthed and facilitate the supply of alternative fuels (e.g., liqufied biogas (LBG), liqufied natural gas (LNG), ammonia, methanol and hydrogen) required by all different transport modes.

Case example: The Gothenburg Port Authority, which operates the largest port in Sweden, has developed world´s first concept of the innovative shore power system for oil tankers in the explosive areas at the energy port under the project Green Cable. Annual reduction of the ships' CO_2 emissions as a result of the shore side electricity connection is estimated at 1815 tons.

Beyond provision of clean energy, ports can support just-in-time arrivals and slot management practices which can optimise the use of port infrastructure and resources, and hence have a significant impact on the level of emissions of the port area, including terminals, and which provide prerequisites for significant emissions reductions in the entire end-to-end cargo flow (Lind et al, 2022a). Additionally, ports need to benefit from digitalisation and invest in Track and Trace (T&T) solutions to enhance customer benefit through digitalised freight tracking. Port Optimizer, a T&T solution deployed by Port of Gothenburg, is an example of such digitalised solution which makes it easier for freight owners and rail and terminal operators to track their freight in real time from quayside to inland destination. Traditionally customers devote a great deal of time searching through a whole host of sources to determine where their freight is at any given time, while still facing challenges confirming accuracy. Ports have hundreds of different players in the network that need to communicate with each other, resulting in an inordinate number of phone calls and emails, generating stress and uncertainty, and taking up a great deal of time unnecessarily.

Port Optimizer T&T easily filters information about the freight moving through the port. It sees which vessel carried the freight, when it was loaded, and when it left the terminal for the onward journey by rail. The system is linked to scanning sensors along the rail tracks, using data collected from the Swedish Transport Administration and various rail companies and organisations. Regular updates on the location of the freight ensure secure, traceable transport movements with a clearly stated time of arrival. Innovative solutions such as Port Optimizer can facilitate the planning and decision-making process for shippers and reduce emissions.

To support the EU goals of shifting goods from road to sea, serve larger vessels, to support intermodal transport operations and to increase capacity, ports need to investigate the need for new infrastructures projects in collaboration with stakeholders and port users. Ports can build larger warehouses, bigger berths and quays, and initiate dredging projects of the harbour basin to reach a sufficient depth so larger vessels with increased capacity can be berthed. Larger volumes mean better turnover and thus there are conditions for port operations to be a good partner for industry and business.

Case example: Malmporten is the largest dredging project in Sweden of modern times, aiming for the port of Luleå to be able to accept vessels that can carry up to 160,000 tonnes, compared to the current maximum of 50,000 tonnes (during ice-free period). Due to lower fuel consumption and emissions per transported tonne of goods, larger vessels are beneficial for the environment. Malmporten dredging project can reduce sea transport's fuel consumption, environmental emissions and shipping costs by up to 40% on its way to and from Port of Luleå. The project therefore fits within the vision of a climate-neutral Sweden in 2045 (Sjöfartsverket, 2022).

However, sustainability requirements must be followed for all construction projects. The case of a construction project carried out by port of Trelleborg illustrates how ports can adopt environmental aspects for new and existing infrastructure projects.

Case example: To build two new ferry berths including ramps as well as a side ramp to an existing ferry berth the Port of Trelleborg and the builder PEAB are working together to minimize environmental impact through PEABs own products ECO-Betong and ECO-Asfalt. ECO-Asfalt, for example, reduces CO_2 emissions by around 63% compared to traditional asphalt. PEAB states that large part of the vehicles that will be used in transportation run on HVO diesel which is renewable and sustainable. Steel deliveries, which are a substantial part of the project, will mainly be transported on trains and ships which have lower emissions and congestion problems compared to trucking.

Ports need to develop and upgrade policies and disposal stations to receive waste generated by ships such as plastic, paper, glass, and organic waste as well as oily waste such as engine room oil (sludge) and sewage. Ports can adopt a "No special fee principle", i.e. and make sure that no extra fee is charged for waste, as it is included in the port fee regardless of quantity or type. To avoid the discharge of untreated grey and black water from ships in harbour areas, ports must be able to receive black and grey water, i.e., toilet water as well as shower and dish water.

To encourage green practices, ports can introduce environmentally differentiated port fees for vessels, for example some ports in Sweden offer up to 30% discount on port charges for vessels which have good environmental rating.

5.4 Level 4: Sustainable initiatives for broader society and industry

Driven by the stringent environmental regulations and end consumers' requirements regarding sustainable products and services, the demand for renewable and fossil free energy has escalated in various industries. Ports can support this development by providing land, and by investing co investing in the required infrastructure for the production, storage and transportation of alternative fuels needed for sustainable industries and communities. Ports are more than consumers of energy and focal points of pollution. They are also well-placed to become important producers and providers of clean energy solutions for a transitioning economy, providing the location for green businesses and sustainable solutions for the surrounding community or city. In these ways, ports contribute in a positive way to greening Europe's economy and society as a whole.

Ports in addition to providing terminal and stevedoring services for passengers and cargo owners also provide access and connection to various forms of land service, such as hosting various industries and energy companies. Furthermore, as a supplier of jobs ports do not only serve as an economical but also a social function. Industries require a safe, inexpensive and competitive means of exporting finished goods and importing raw materials which is enabled by efficient and optimised port operations. However, over the years the demand for port services has evolved and amplified, creating new challenges for ports. As noted by Rodrigue (2020), the city and the port are now competing for the same land, which can create prioritisation problems. Ports thus have a complex set of relationships, sometimes conflicting, with the cities they service, often a function of the port and city size. While ports are sources of employment and commercial interactions, they also generate externalities such as noise and congestion near their access points. The pressure of many ports on their sites is even more demanding than those of airports because they must be adjacent to deep water. Such sites are very limited and may give rise to conflicts with the city that sees waterfront land as potential high-value residential and commercial areas, park space, or as environmentally sensitive. Many ports are now constrained by urban and environmental pressures, which did not exist when their initial facilities were developed. This requires cross functional and cross organisational collaboration involving all stakeholders in port infrastructure planning.

According to estimates of the European Commission (EC) (EC, 2023) European ports on average serve over 400 million passengers each year. Advancements in technology and digitalisation have revolutionised various industries, hence, ports need to benefit from such opportunities and update passenger terminals to achieve safety standards, optimise embarking and disembarking operations and enhance customer experience. Ports need to consider all types of passengers from pedestrians to vehicles, people with disabilities, to public transit, to cyclists in their future infrastructure planning.

Moreover, both the IPCC and the EU have identified CO_2 capture as necessary to reach the climate goals. Ports can leverage this business opportunity and provide the necessary infrastructure for the storage and transportation of captured CO_2 to facilitate the entire logistics chain required for the CCS projects and thus play their role to make the industries and surrounding communities sustainable and concurrently increase their business revenues.

Ports can take measures to reduce the climate impact of the entire transport ecosystem. Ports can develop partnerships to support the actors involved in a transport ecosystem by changing policies or investing in alternative solutions. This is evidenced by the case of Port of Helsingborg and Höganäs in Sweden as detailed in the box.

Case example: Höganäs is the world's leading manufacturer of iron, metal and ceramic powders based in Sweden. Höganäs previously executed approximately 9,000 transport trips of iron and metal powder between the plant in Höganäs and the port of Helsingborg. But since five years ago, Höganäs, together with the haulier GDL, Volvo Trucks and Parator, have worked intensively to try to make transport more efficient using High Capacity Transport (HCT) road vehicles that can load two containers instead of one with a total weight of 74 tons instead of 64 tons. This has reduced the number of trips from Höganäs AB to the Port of Helsingborg from 9000 to around 5250 a year. Fuel consumption and thus CO_2 emissions are reduced by approx. 35% per transported container. In addition, GDL and Höganäs use a renewable fuel, HVO100, with approximately 90% lower CO_2 emissions than traditional diesel.

Figure 7. High Capacity Transport vehicles (Source Höganäs).

6 Detailing a maturity framework for ports as energy nodes

In recent years, we have seen the efforts of some of the world's ports to establish themselves as key energy hubs. The ports of Antwerp-Bruges, Hamburg, Rotterdam, and Singapore are examples of ports that aim to position themselves as multi-fuel bunkering hubs to support transport carriers by acquiring, storing, and supplying low and zero-carbon fuels including biofuels, methanol, ammonia, and potentially hydrogen as well as electricity.

Ports can facilitate decarbonisation, energy efficiency and energy transition in multiple ways. As landlords and investors, ports can optimise the spatial planning ensuring that land and basic relevant infrastructure are available to facilitate energy projects (as e.g. in Hamburg and Antwerp-Bruges), while proactively investing and coinvesting in sustainable alternative energy solutions to meet their own energy needs as well as to support energy needs of customers, industrial clusters located in the vicinity, and the wider society. As "regulators", port authorities can develop and leverage tariffs and incentives to support low carbon measures, and upgrade environmental and safety standards to facilitate production, storage, bunkering and transportation of alternative fuels. Ports can create (digitally supported) processes that help other stakeholders to become more (energy) efficient, not necessarily changing to low/zero carbon energy sources. Ports as "enablers/collaboration partners" can initiate collaboration, partnerships, and business consortia with a broad spectrum of players involved in the transport and energy ecosystem to align climate goals, predict energy needs, develop energy related projects for production, storage, and transportation of low/zero carbon fuels. Energy-empowered ports can expand the port community by inviting "energy" actors and tracking/tracing energy generation/consumption flows through big data intelligence and blockchain technologies etc. Such ports can drive new revenue streams, and this can be achieved through climbing up the four levels of the maturity framework (DHV, 2022).

Based on a larger Swedish study, Bach *et al.* (2022) provide a framework for guiding ports on how to fully develop their energy node capabilities and play a role as energy model nodes demonstrating and influencing the pace of decarbonisation globally. This framework builds upon

- the port's energy strategy (Level 1)
- pointing at the need for proactive actions to take into account its own operations (Level 2),
- the provision of sustainable energy to users of the port (Level 3),
- and its role associated with being part of the transport ecosystem - which also includes the global energy system (Level 4).

Figure 8 depicts this four-level maturity framework which is discussed in more detail below.

Figure 8. Maturity framework for the port as energy node (Lind et al., 2023) (Illustration: Sandra Haraldson)

6.1 Level 1: The need for an energy strategy

Ports need to be proactive to contribute to a sustainable transport ecosystem to capitalise on the opportunities presented by the energy transition and to measure and quantify energy efficiency for energy strategy decision-support. Ports can generate new lease earnings or incomes through the sale of energy. Port authorities are advised to start by devising an energy strategy for their own energy needs and for their energy supply capacity in their role as a transport provider (first level of the maturity framework depicted in Figure 8). Such an energy strategy should encompass all port operations and work as a guide for the entire port community including customers who use ports as transport, digital, and energy nodes. This implies that the port authority's energy strategy is not only a guide for the port authority itself but also influences, to varying degrees the actors that operate within the port and those that visit the port. All energy-related investment and partnership decisions should be aligned with the port authority's overall strategy. In the process, ports need to consider levels 2-4 of the framework, by holding stakeholder dialogues, initiating collaborations etc. The framework should not be seen as a one-direction/step-by-step framework but needs to be understood as a self-improving circular system, where ports move back and forth between the levels.

6.2 Level 2: Sustainable operations within the port

At the next level (Figure 8), and after defining the port authority's energy strategy, ports should evaluate their current energy needs and emissions from their own assets and operations within the port area and develop measures to reduce the port area's carbon footprint. One of the promising measures for ports is to improve energy efficiency and make sure that their own needs within the port area are met sustainably through a shift from fossil-fuels to sustainable energy solutions. Electrification can help through powering e.g., cranes, reach-stackers, prime-movers, tugboats, forklifts, and the port's vehicle fleet.

Many ports already also pay attention towards the use of LED and smart lighting in port premises. They acquire green electricity from energy companies, and some produce their own renewable energy through investments in solar and wind power. Evidence from Swedish ports suggests that adoption of such measures can result in substantial OPEX savings, next to several other benefits for ports including reduced emissions, and less noise pollution helping ports to contribute to UN's SDGs. Most ports are landlords with multiple independent operators, leases, and terminals within the port areas. Port authorities need to create collaborative platforms, regulative incentives, and partnerships together with their stakeholders to achieve effective reduction of the emissions. They can, for example, initiate joint roadmaps with terminals, other operators and logistics services providers, secure infrastructure by planning for and investing in grid capacity for terminals, and develop shared port processes for efficient traffic management between terminals.

6.3 Level 3: Provision of sustainable energy to port users

Recently, a growing number of operators of vessels, railways, and heavy vehicles have set ambitious CO_2 reduction targets and need to comply with various regional and global environmental regulations. Carriers will need to further optimise their operations while reducing their reliance on fossil fuels by switching to low/no carbon energy sources, like electricity generated from renewable sources. Increasingly, ports are expected to supply and facilitate sustainable energy consumption by carriers (level 3 of the maturity framework in Figure 8). Port authorities can for instance facilitate the bunkering of low carbon fuels (e.g., ammonia, hydrogen, and methanol) and offer shore-side electricity to vessels while berthed, charging stations and alternative fuel stations (e.g., LBG and hydrogen) for heavy vehicles transporting goods to and from ports and electrification of rail in the port area.

6.4 Level 4: Broader industry role in the energy transition

Countries and industries across the globe have ambitions to reduce GHG emissions by the middle of this century propelled by legislations such as EU Green Deal, EU energy efficiency target of at least 32.5% for 2030 (EC, 2018) and REPowerEU plan (EC, 2022) which aims to replace Russian natural gas with imported (10 million tons) and locally produced (5 million tons) renewable hydrogen. Industries will increasingly rely on low to zero carbon fuels. Ports can, for example, provide land to energy companies for new production sites. Ports can support the development of productions facilities by directly investing or coinvesting in energy production facilities. These are aspects depicted at level 4 in the maturity framework captured in Figure 8. Large-scale electrification of different industries, including transportation, triggers the need for capacity upgrades for the production and distribution of low/zero carbon fuels. Like other industries, ports will need to assess and estimate their potential need for such energy sources, both for their own operations, users, and in relation to the needs of other nearby industries and societies. This can be supported digitally by solutions such as digital twins which can utilise complex modelling to provide insights into energy demand and enable testing of future scenarios, optimal siting of energy infrastructure to reduce transmission losses, and applicability of power transfer within the port estate during periods of peak demand. Finally, ports can reconsider the types of cargo handled by entering partnerships and strategically planning for terminals that handle goods which enable regional transitions to net zero; ports can also be testbeds or enablers for new technologies such as Carbon Capture and Storage/Usage (CCS/U).

The clean energy landscape consists of a plethora of alternatives. As reflected by the maritime industry, there are several complementary enablers that can be put in place to decarbonise operations pursued by the sector. Many of these enablers are also relevant for other transport segments, which consequently affect ports in their investments, but also highlights the need for prioritising of the use of the scarce sources of sustainable energy (Lind *et al.* 2022c).

The community required to be aligned to decarbonise the maritime industry alone is already huge. The port can play a model role in aligning supply and demand of sustainable alternative energy sources by deeper engagement with the energy value chain. This requires that the port enhances its scope of activity by adding energy production, storage, and provision to its business portfolio. With this also comes the need to raise the knowledge and skill-base of the people working in the port and elsewhere along the maritime value chain.

7 Detailing a maturity framework for ports as digital nodes

Ports are at different starting positions and will adopt different degrees of digitalisation. Some ports have taken pioneering steps to become first-movers in the adoption of advanced technologies for collaboration, synchronisation, automation, and analytics. But, at many smaller ports, much of the information is not managed by digital means.

For most ports digitalisation skills are only a small part of their capability set. Few smaller and medium-sized ports can run larger digitalisation projects themselves. However, there is movement towards simplifying technological solutions, less complex and for specific use cases. Ports can also pool together and share development costs.

Based on the experiences from Swedish ports, a digital three-step maturity model (Figure 9) has been defined and validated, that accommodates the different situations for individual ports (Lind *et al.*, 2021ab). The maturity model takes a formal digitalisation strategy / plan as the basis for informing actions on subsequent steps. The first step is achieved with a digitally connected infrastructure, the second is the achievement of digital collaboration (both between the port actors as well as becoming established as a communication party to the outside world) and the final step is to have in place defined services and business models for digital business activity. The proposed three step model is therefore in line with several models emphasising the collaborative capabilities within and outside the port.

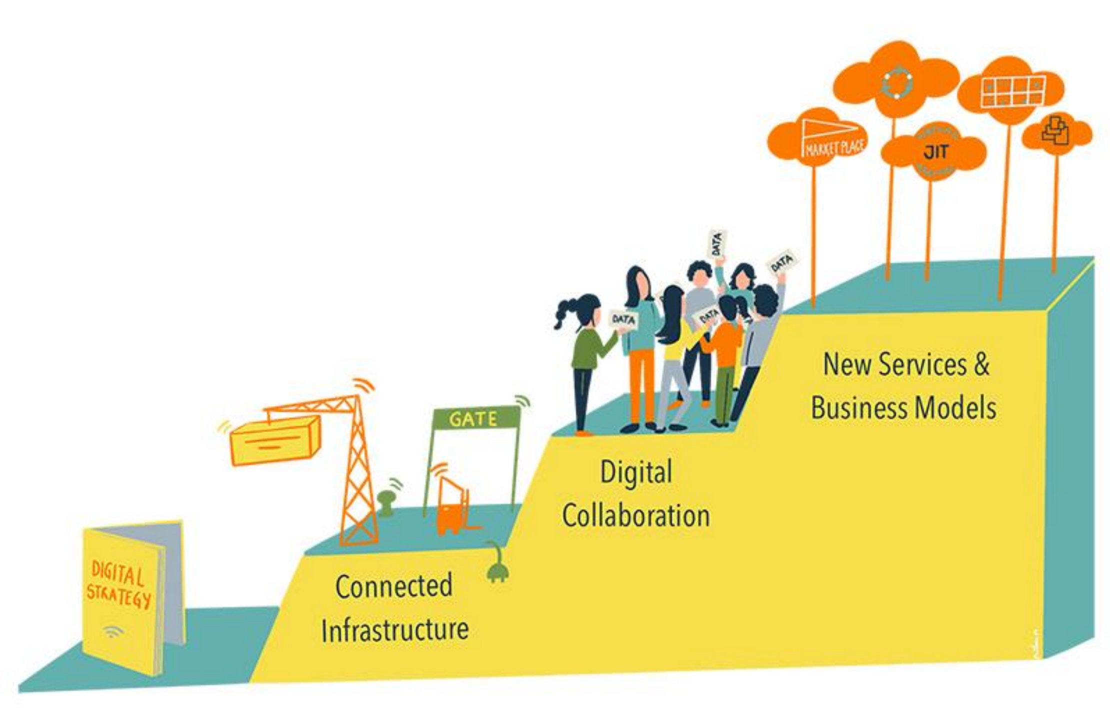


Figure 9. Maturity model for developing port digital maturity (Lind et al., 2021b) (Illustration Sandra Haraldson)

This maturity model has been defined and validated by Swedish ports with the purpose to raise their digital maturity and establish capabilities to become digital nodes. Guided by the digital maturity model, the aim is to assure that the ports become digitally integrated to support Sweden's national aims of efficient and sustainable transport services.

Only 20% of the 4,900 ports (Lind et al., 2021b) in the world have established, or plan to establish, digital capabilities to assure transport chain connectivity. It is assumed that the situation is the same for other transport nodes, such as dry ports, combi terminals, and logistic centres. This is a major digital divide in the way of efficient, environmentally friendly, and resilient transport chains.

7.1 Level 1: The need for a digitalization strategy

This model allows a port to adopt a gradual approach to developing its digital maturity. The model takes the port's digital strategy as the point of departure and then pinpoints different use cases, digital capabilities, and digital services on the three levels of maturity. In the case that the port has not established a digital strategy, the model encourages its establishment as the framework for the port to support its digital capability development. A digital strategy includes the goals and the action plans required to achieve those goals. It is based on an inventory of which parts of the infrastructure can be connected and reviews what the needs are.

7.2 Level 2: The need for connecting infrastructures

The first step in the model is connected infrastructure, which means that the infrastructure and resources available in the port can be monitored and controlled in the original sense of the internet of things. These can be, for example, connected physical objects (quays, bridges, storage areas, bollards, etc.), work vehicles and load carriers. A connected infrastructure is a basic digital capability that can streamline port operations and reduce costs. It can also give port players the opportunity to increase control over their infrastructure and resources regarding its status and current utilisation to improve efficiency and future capacity needs as an input to planning.

7.3 Level 3: Building the capability of digital collaboration

When connected infrastructure is in place, it is possible to share data within an organisation, but also between port actors, and between different transport nodes (regardless of traffic mode). Such ability is called Digital Collaboration in the maturity model. This means that port actors are empowered by enhanced collaboration, based on data sharing, creating better planning conditions throughout an overall situation, enabling improved supply chain visibility, and communicating status of goods and transport. For an effective digital collaboration, standards are required for compatibility between current systems, both technically and semantically.

7.4 Level 4: Identifying new services and business models

Once the infrastructure is connected and digital collaboration is established between relevant actors, new services and business models can be designed. These can be offered by the port itself, by other actors on behalf of the port or by third-party providers. Examples of such services could be to establish / be part of (digital) marketplaces for empty load carriers, energy supply, storage areas, and slot times for episodic visits.

8 Challenges

Our report has identified several challenges that hinder Swedish small and medium sized ports from achieving the vision of becoming sustainable. The results of the report, which are supported by survey responses and interviews, reveal that the biggest obstacles to progress towards sustainability include insufficient financial resources, high costs and taxes, immature technology, inadequate infrastructure, environmental impact, lack of standardization and competence, and political ambiguity (Bach et al, 2022). It is important to note that ports in Sweden vary greatly in terms of size, available resources, geography, customer types, and management and ownership structures, which can significantly affect their ability to undertake sustainability projects.

Creating economically sustainable projects is a prerequisite for implementing measures to reduce carbon dioxide emissions in ports. However, limited funds mean that investment decisions require careful prioritization and balancing, regardless of whether the port authorities, terminal operators or other actors are making the investment.

For ports to become driving forces in the transition to a sustainable transport system, they require tools in the form of clear policy instruments and financial support for infrastructure projects. Becoming a sustainable port often requires large investments and a long-term view of returns. For example, providing shore power from renewable electricity can cost anywhere from 1-25 million euros, depending on available connections and distances. This includes installation of grid connection, cable to berths, converter station, and onshore power plants on quays and ships. It is important to consider that ship owners also need to invest approximately 0.5 - 1 million euros and must weigh the profitability of electrification and alternative fuels based on various factors.

Insufficient financial means and profitability requirements pose significant challenges for ports, particularly small and medium-sized ones with low traffic volumes, making it difficult for them to justify large investments in infrastructure projects. High taxes on biofuels like HVO also increase costs for ports. Even when port customers demand environmentally friendly measures, they are often unwilling to pay the increased costs, resulting in withdrawn demands. Additionally, electrification faces obstacles such as immature technology, limited electricity output, and uncertainty about future fuels for port visitors, particularly in some regions. Standardization issues further hinder green infrastructure investments, especially regarding shore power connection for ships as well as digitalization, and this can negatively impact profitability and investments in such initiatives. Ultimately, the transition to sustainability requires someone to bear the cost.

9 Conclusions

The essence of the rendering above is concluded here as lists of actions.

9.1 Develop the port as a transport and logistics node

The list contains activities required for developing the key role of ports in the sustainable transport system.

9.1.1 Level 1: Strategy formulation for a port as a sustainable transport node

- Creation of a new strategy and a vision for the port's role as an energy node and use of digitalisation as a key enabler to optimise port functions as a transport and energy node.
- Focus on finding new ways for creating value for the economy, society, and the environment using digital technologies, upskilled and reskilled talents, and sustainable energy.
- Identify the key challenges and new opportunities related to the ports' function as a transport node for both cargo and passengers which should be addressed by relevant initiatives and by benefitting from digitalisation and energy transition.
- Engage in planning and development of port operations:
  - short term planning involves the current allocation of the port's resources and services,
  - medium-term planning involves both financial and strategic planning, often reported through business plans and,
  - long-term planning demands a more fundamental and visionary approach, in most cases embodied in the development of port master plans or strategic port plans.
- Ports should design a strategy that makes the most effective use of their core resources and capabilities.
- Leadership commitment in a port plays an indispensable role as a fundamental driver for a successful strategy creation for a sustainable port.

9.1.2 Level 2: Sustainable initiatives within a port

- Reduce negative environmental externalities generated by the port activities as well as all transport and industry players in the port area.
- Take various initiatives:
  - allocate resources for CO_2 measurement,
  - repower the machines and cargo handling equipment with green electricity and alternative fuels,
  - eco-driving of port vehicle and machines,
  - replace fluorescent lamps with LED and smart lighting
- Investigate the potential of improving port operations through digitalisation
  - invest in autonomous trucks and machines,
  - introduce autonomous gate check-ins for port users and,
  - upgrade the terminal systems with optimised yard planning functions.
- Develop and upgrade workforce policies and make sure that the port is a workplace for everyone.

- Pay serious attention to climate adaptation and biodiversity considerations when modifying existing infrastructure and when planning new infrastructure.

9.1.3 Level 3: Sustainable initiatives for port users

- Offer charging stations to heavy vehicles and shore-side electricity to vessels while berthed and facilitate the supply of alternative fuels.
- Support just-in-time arrivals and slot management practices.
- Invest in Track and Trace (T&T) solutions to enhance customer benefit through digitalised freight tracking.
- Investigate the need for new infrastructures projects in collaboration with stakeholders and port users.
- Develop and upgrade policies and disposal stations to receive waste generated by ships.
- Introduce environmentally differentiated port fees for vessels.

9.1.4 Level 4: Sustainable initiatives for broader society and industry

- Support renewable and fossil free energy:
  - providing land and,
  - investing or coinvesting and developing safety regulations for the production, storage and transportation of alternative fuels.
- Become important producers and providers of clean energy solutions for a transitioning economy, providing the location for green businesses and sustainable solutions for the surrounding community or city.
- Access and connection to various forms of land service such as hosting various industries and energy companies.
- Serve as a social function in society.
- Cross functional and cross organisational collaboration involving all stakeholders in port infrastructure planning.
- Need to consider all types of passengers from pedestrians to vehicles, people with disabilities, to public transit, to cyclists in the future infrastructure planning.
- Provide the necessary infrastructure for the storage and transportation of captured CO_2 from surrounding industries.
- Develop partnerships to support the actors involved in a transport ecosystem by changing policies or investing in alternative solutions.

9.2 Develop the port as an energy node

9.2.1 Level 1: The need for an energy strategy

- Devising an energy strategy for the port authority's own energy needs and for the energy supply capacity in their role as a transport provider:
  - encompass all port operations,
  - work as a guide for the entire port community including customers who use ports as transport, digital, and energy nodes and,
  - All energy-related investment and partnership decisions should be aligned with the port authority's overall strategy.

9.2.2 Level 2: Sustainable operations within the port

- Evaluate port authority's current energy needs and emissions from their own assets and operations within the port area.
- Develop measures to reduce the port area's carbon footprint.
- Shift from fossil-fuels to sustainable energy solutions.
- Acquire green electricity from energy companies or produce own renewable energy
- Create collaborative platforms, regulative incentives, and partnerships together with their stakeholders to achieve effective reduction of the emissions.

9.2.3 Level 3: Provision of sustainable energy to port users

- Port authorities are expected to supply and facilitate potential sustainable energy needed by different transport modes such as shipping and trucking.
- Facilitate the bunkering of low carbon fuels.
- Offer shore-side electricity to vessels.
- Charging stations and alternative fuel stations (e.g., LBG and hydrogen) for heavy vehicles.
- Electrification of rail in the port area.

9.2.4 Level 4: Broader industry role in the energy transition

- Provide land to energy companies for new production sites.
- Support the development of productions facilities by directly investing or coinvesting in energy production facilities.
- Support digitally by solutions such as digital twins which can utilise complex modelling to provide insights into energy demand and enable testing of future scenarios, optimal siting of energy infrastructure to reduce transmission losses, and applicability of power transfer within the port estate during periods of peak demand.
- Reconsider the types of cargo handled by entering partnerships and strategically planning for terminals that handle goods which enable regional transitions to net zero.
- Be testbeds or enablers for new technologies.

9.3 Develop the port as a digital node

Finally, a set of activities to develop the port in its role as a digital node.

- Transparent information about the current situation in different nodes and with different transport lines, goods can be redirected more quickly to alternative routes to avoid getting stuck in congestion in ports or if there are disruptions to a route.
- Exchanges up-to-date information with the transport system's stakeholders for well-founded decisions about planning and coordination based on information about transport, infrastructure utilisation, the status of the transport object and the needs of the transport buyer.
- Better integrated into the entire transport system and increase the possibilities for greater coordination between the transport modes and other transport nodes.
- Better and more reliable exchange of information in real time, better and safer planning of resources can be performed.
- Directs attention to the efficient generation and sharing of data from connected infrastructure, resources, and actors being used for enhanced business intelligence, synchronisation of activities, and new business opportunities.

- Maturity model:
  1. Digitally connected infrastructure:
     - infrastructure and resources available in the port can be monitored and controlled in the original sense of the internet of things and,
     - increases control over port authority's infrastructure and resources regarding its status and current utilisation to improve efficiency and future capacity needs as an input to planning
  2. Achievement of digital collaboration (both between the port actors as well as becoming established as a communication party to the outside world):
     - port actors can, based on data sharing, create better planning conditions throughout an overall situation, enable improved supply chain visibility, and communicate information regarding the status of goods and transport and,
     - standards for compatibility between current systems both technically and semantically.
  3. Defined services and business models for digital business activity:
     - establish / be part of (digital) marketplaces for empty load carriers, energy supply, storage areas, and slot times for episodic visits.

10 References

Alamoush A.S., Ballini, F. and Ölçer, A.I. (2021) "Revisiting port sustainability as a foundation for the implementation of the United Nations Sustainable Development Goals (UN SDGs)," Journal of Shipping and Trade, 6(1). (https://doi.org/10.1186/s41072-021-00101-6)

Bach A., Forsström E., Haraldson S., Holmgren K., Lind K., Lind M., Piehl H., Raza Z., Rydbergh T. (2022) Hamnen som energinod – ett koncept för hamnens roll i omställningen mot ett hållbart transportsystem, RISE Rapport 2022:125 (http://ri.diva-portal.org/smash/record.jsf?pid=diva2%3A1707500&dswid=-7796)

Bergdahl P. (2019) Hamnar i fokus (https://www.trafa.se/globalassets/pm/2019/pm2019_7-hamnar-i-fokus.pdf)

Berglund P., Andersson G. (2021) Tilläggsuppdrag hamnar. Inom ramen för regeringsuppdraget Nationell samordnare för inrikes och närsjöfart, publikation 2021:172, Trafikverket.

DHV (2022) The new energy landscape Impact on and implications for European ports, European Sea Ports Organisation (ESPO) and European Federation of Inland Ports (EFIP)

Haraldson, S., Lind, M., Raza, Z. (2023) The Sustainable Development Goals: An opportunity for seaports to drive business value - A practical guide, Lighthouse.

EC (2018), Energy efficiency targets (https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-targets_en)

EC (2022), REPowerEU: affordable, secure and sustainable energy for Europe (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en)

EC (2023a), Maritime passenger statistics https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_passenger_statistics&oldid=530161

EC (2023b), Mobility and Transport, https://transport.ec.europa.eu/transport-modes/maritime/ports_en#:~:text=400%20million%20passengers%20embark%20and,22%20EU%20maritime%20Member%20States

ESPO (2021) ESPO green guide 2021 a manual for european ports towards a green future (https://www.espo.be/media/ESPO%20Green%20Guide%202021%20-%20FINAL.pdf)

Försvarsmakten (2019) Västkusten - ett av flera viktiga områden för Sverige (https://www.forsvarsmakten.se/sv/aktuellt/2019/02/vastkusten-ett-av-flera-viktiga-omraden-forsverige/#:~:text=M%C3%A5nga%20av%20de%20varor%20vi,h%C3%A4ndelser%20av%20kris% 20eller%20krig)

IEA (2023) Data and statistics, International Energy Agency, (https://portal.idata.se/Dispatcher/DocumentViewer?ts=1678296165242), Accessed 2023-03-08.

Lighthouse mfl 2021. Nationell agenda för sjöfartsforskning och innovation (NRIA Sjöfart 2021)

Lind M., Pettersson S., Karlsson J., Steijaert B., Hermansson P., Haraldson S., Axell M., Zerem A. (2020) Sustainable Ports as Energy Hubs, The Maritime Executive, 27/11-2020 (https://www.maritime-executive.com/editorials/sustainable-ports-as-energy-hubs)

Lind M., Haraldsson S., Lind K., Lundman J., Karlsson M., Olsson E., Bach A. (2021a) Hamnen som digital nod – förstudie, TRV 2050/50902, Trafikverket (https://fudinfo.trafikverket.se/fudinfoexternwebb/Publikationer/Publikationer_005701_005800/Publikation_005764/Hamnen%20som%20digital%20nod_slutrapport%20(2021-09-30)%20TRV%202020%2050902.pdf)

Lind M., Haraldson S., K Lind., Lehmacher W., Svan M., Renz M., Gardeitchik J., Singh S., Zuesongdham P. (2021b) Ports of tomorrow: Measuring digital maturity to empower sustainable port operations and business ecosystems (https://unctad.org/news/ports-tomorrow-measuring-digital-maturity-empower-sustainable-port-operations-and-business)

Lind M., Lehmacher W., Hoffmann J., Jensen L., Notteboom T., Rydbergh T., Sand P., Haraldson S., White R., Becha H., Berglund P. (2022a) An expanded JIT approach: Improving synchronization across maritime value chains, Marine Technology, January 2022, pp. 60-65, The society of Naval Architects & Marine Engineers (https://maritimeinformatics.org/wp-content/uploads/2022/01/An-Expanded-JIT-Approach.pdf)

Lind M., Lehmacher W., Doepel T., Heinimaa J., Hoffmann J., Laurilehto M., Lebmeier M., Petersen M., Rytkölä I., Saari J., Singh S., Walls R., Watson R.T. (2022b) The Benefits of a Clusters of Value Chains perspective in Decarbonising Shipping: Decarbonisation Playbook Part 2, 22/8-2022, The Maritime Executive (https://maritime-executive.com/editorials/the-three-maritime-value-chains-decarbonization-playbook-part-2)

Lind M., Lehmacher W., De Tremerie L., Dubielzig F., Forsström E., Holthus P., Morgante A., Singh S., Tenenbaum L. (2022c) Enablers for Decarbonising the Maritime Industry: Decarbonisation Playbook Part 3, 25/9-2022, The Maritime Executive (https://www.maritime-executive.com/editorials/enablers-for-decarbonizing-the-maritime-industry-part-3)

Lind M., Haraldson S., Lehmacher W., Raza Z., Forsström E., Astner L., Bentham J., Fu X., Suroto J., Zuesongdham P. (2023) Thinking the future energy model nodes of the world - a reflection framework for port development, under consideration for publication in UNCTAD Transport and Trade Facilitation Newsletter

Lind M., Lehmacher W. (2023) The port as a digital node: A connector well-positioned not only amidst carriers, pp. 58-61, edition 131, Port Technology International (https://maritimeinformatics.org/wp-content/uploads/2023/05/Smart-Digital-Ports-of-the-future.pdf)

Naturvårdsverket, (2023) Sveriges klimatmål och klimatpolitiska ramverk, (https://www.naturvardsverket.se/amnesomraden/klimatomstallningen/sveriges-klimatarbete/sveriges-klimatmal-och-klimatpolitiska-ramverk/#:~:text=Sveriges%20klimatm%C3%A5l-,Det%20l%C3%A5ngsiktiga%20m%C3%A5let,2045%20%C3%A4n%20utsl%C3%A4ppen%20%C3%A5r%201990)

Notteboom T, Van Der Lugt L, Van Saase N, Sel S, Neyens K (2020) The role of seaports in green supply chain management: initiatives, attitudes, and perspectives in Rotterdam, Antwerp, North Sea Port, and Zeebrugge. Sustainability. https://doi.org/10.3390/su12041688

Notteboom T., Pallis T., Rodrigue J.P. (2022) Port Economics, Management and Policy, New York: Routledge, 690 pages / 218 illustrations. ISBN 9780367331559.

Rodrigue J.P. (2020) The Geography of Transport Systems, Fifth edition, New York: Routledge, 456 pages. ISBN 978-0-367-36463-2

Sjöfartsverket (2022) Malmporten in Luleå (https://www.sjofartsverket.se/en/dredging-projects/welcome-to-the-market-dialogue/malmporten-in-lulea/)

Sveriges Hamnar (2011) Hamnen i det svenska samhället (https://www.transportforetagen.se/globalassets/rapporter/hamn/hamnen-i-det-svenska-samhallet-final.pdf?ts=8d7a638182a0180)

UNCTAD (1992) Port marketing and the third generation port, UNCTAD Trade and Development Board, Geneva. 60 pages. (http://unctad.org/en/PublicationsLibrary/tdc4ac7_d14_en.pdf).

UNCTAD (1999) Technical note: Fourth generation port. UNCTAD Ports newsletter 19. UNCTAD, Geneva pp. 9–12.(http://unctad.org/en/Docs/posdtetibm15.en.pdf).

UNCTAD (2019) Review of maritime transport 2019. United Nation Conference on Trade and Development, Geneva, Switzerland

World Bank (2017) Mombasa: options for the port city interface – final report, COWI, Johan Woxenius, Syagga & Associates, Washington D.C., 134 pages.

11 Appendix 1: List of ports that have been part of contributing to / formulating the vision of the sustainable port

Ports
• Falkenbergs terminal • Gävle hamn • Göteborgs hamn • Hallands hamnar (*representing Halmstad hamn and Varberg hamn*) • Hargs hamn • Helsingborgs hamn • Kalix Industrihotell AB/Kalix hamn • Karlshamns hamn • Karlskrona Hamn • Kvarkenhamnar • Landskrona Hamn • Luleå hamn • Lysekils hamn • Malmö hamn, (*owned by Malmö stad/City of Malmö*) • Oxelösunds hamn • PetroPort • Piteå hamn • Port of Skellefteå • Södertälje Hamn • Sölvesborg hamn • Stockholms Hamnar (*representing* Stockholm, Kapellskär, Norvik, Nynäshamn) • Trelleborgs hamn • Uddevalla hamnterminal • Wallhamn AB • Ystad hamn • Åhus hamn & stuveri • Örnsköldsviks hamn & Logistik • Vänerhamn AB (*representing* Karlstad, Kristinehamn, Lidköping, Otterbäcken, Vänersborg)