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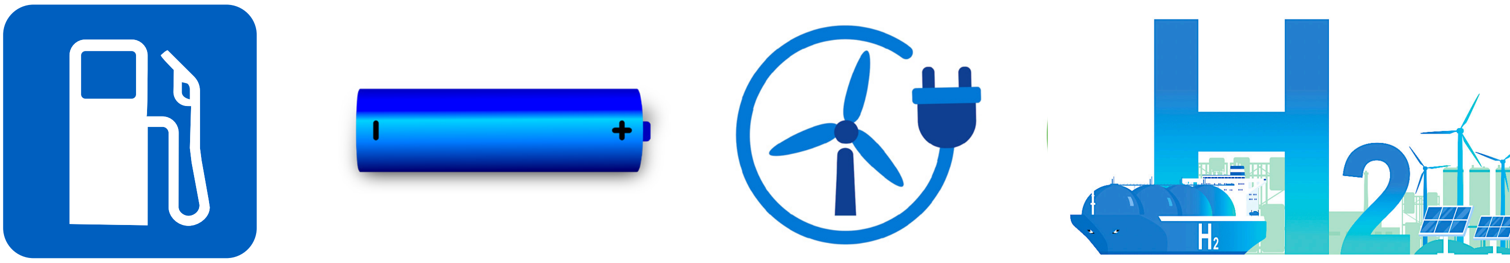

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Port as an energy hub

A pre-study on estimating electricity demand

Authors
Jessica Wehner, VTI
David Daniels, VTI
Vendela Santén, RISE Research Institutes of Sweden
Sara Rogerson, RISE Research Institutes of Sweden
Andreas Bach, RISE Research Institutes of Sweden

In cooperation with
Linus Olsson at Landskrona Hamn AB
Sandra Sönnerberg at Landskrona Hamn AB

Summary

Ports are key hubs in the maritime transport system and are pivotal to the sector's transition to fossil-freedom. As port operations and vessels shift from fossil fuels to electricity and alternative fuels, ports can evolve into energy hubs, supplying power to their internal operations (e.g., cranes, forklifts) and external users like road vehicles and ships. Ports also have potential for renewable energy production, such as offshore wind and solar power, as well as storage.

However, insufficient data on future energy consumption and production limits ports' ability to plan infrastructure upgrades or investments in electricity production and grid connections. This pre-study aims to create a structure to assess ports' current and future energy demands and production. By identifying the necessary data for a quantitative energy model, it seeks to help ports transition into fossil-free energy hubs by addressing information gaps.

The study focused on the Port of Landskrona, including input from its energy supplier. The developed framework evaluates five areas: port operations, surrounding transport systems, the port's role as an energy node, additional energy activities, and the port's future energy plans. A combined top-down and bottom-up approach tracks energy consumption from both electricity and fuel, aiding decision-making around energy production, storage, and decarbonization.

The results show that the port has a fair overview of energy consumption of their own operations in terms of electricity and diesel for the full year (based on today's data availability). However, for specific activities, like energy consumption for the electric conveyor belts, no such data is available today and further measurements are required for such details. Further, for the surrounding transport system (i.e., trucks visiting the port), the port is dependent on external parties to share data of their energy usage. Challenges include limited data availability on current energy consumption. The pre-study also highlights the importance of managing the timing of energy demand and offers insights into how ports can manage demand and electrification while preparing to transition to fossil-free operations in the future.

Sammanfattning

Hamnar är viktiga hubbar i det maritima transportsystemet och spelar en avgörande roll i sektorns arbete mot fossilfrihet. När hamnverksamheter och fartyg övergår från fossila bränslen till el och alternativa bränslen kan hamnar utvecklas till energihubbar, som förser både sina egna interna system (t.ex. kranar, gaffeltruckar) och externa användare som vägfordon och fartyg med energi. Hamnar har också potential för produktion av förnybar energi, såsom vindkraft till havs och solenergi, samt lagring.

Brist på tillräcklig data om framtida energiförbrukning och produktion begränsar dock hamnarnas förmåga att planera infrastrukturuppgraderingar eller investeringar i elproduktion och nätanslutningar. Denna förstudie syftar till att skapa en struktur för att bedöma hamnarnas nuvarande och framtida energibehov och produktion. Genom att identifiera den nödvändiga datan för en kvantitativ energimodell strävar studien efter att hjälpa hamnar att övergå till fossilfria energihubbar genom att ta itu med informationsluckor.

Studien fokuserade på Landskrona hamn, inklusive input från hamnens energileverantör. Den utvecklade strukturen utvärderar fem områden: hamnverksamheter, omgivande transportsystem, hamnens roll som energinod, ytterligare energiaktiviteter samt hamnens framtida energiplaner. En kombinerad top-down och bottom-up-ansats spårar energiförbrukningen från både el och bränsle, vilket stödjer beslutsfattande kring energiproduktion, lagring och minskning av koldioxidutsläpp.

Resultaten visar att hamnen har en god överblick över den egna verksamhetens energiförbrukning vad gäller el och diesel på årsbasis (baserat på dagens datatillgänglighet). Men för specifika aktiviteter, som energiförbrukningen för de elektriska transportbanden, finns inga sådana data tillgängliga idag och ytterligare mätningar krävs för den detaljnivån. För det omgivande transportsystemet (såsom lastbilar som besöker hamnen) är hamnen beroende av att externa parter delar data om sin energianvändning. Utmaningar inkluderar begränsad datatillgång om nuvarande energiförbrukning. Förstudien belyser också vikten av att hantera tidpunkten för energibehov och ger insikter i hur hamnar kan hantera efterfrågan och elektrifiering samtidigt som de förbereder sig för övergången till fossilfri verksamhet i framtiden.

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1 Introduction

1.1 Background

Ports are the principal nodes in the maritime transport system. As the transport sector as a whole moves away fossil fuels, so has also the discussion started on how the martitime transport sector, including vessels and port operations, can transition to fossil-free fuels. Already hubs for transport activities, ports can in the future also become the providers of fossil-free energy to internal port operations (i.e., forklifts, cranes), road vehicles that enter and leave the port (i.e., drayage trucks) as well as vessels. In addition, the location of ports offers the opportunity for production of renewable energy (e.g., offshore wind power, rooftop solar energy). However, available data is generally insufficient to estimate the potential of either energy consumption or production in a future fossil-free port, and this limits ports' ability to make informed plans about future infrastructure. To plan ahead, ports need answers to questions such as how to manage operations to maximize energy efficiency, whether and how much to invest in electricity production, how much and when to strengthen existing connections to the power grid, etc. This pre-study evaluates the data needed to develop a quantitative model of future energy demand at ports.

This pre-study takes its starting point from the road map of sustainable ports from 2025 to 2050 (Haraldson, 2023; Haraldson et al., 2023). It builds on that road map by identifying what data is needed to estimate ports' energy and especially electricity demand in the future, both for their own fossil-free operations, in servicing/fuelling transiting vessels and in interacting with the local sustainable ecosystem. The pre-study's idea also connects to the EU's Fit for 55 deal on cleaner maritime fuels (DNV, 2021; European Parliament, 2023), for example by studying the possibility of increasing onshore electrical power supply.

So far, research in Sweden focusing on "Ports as energy hubs" has foremost focused on qualitative studies, identifying the ports' roles in this new ecosystem (Bach et al., 2022). In a study carried out by the Swedish Confederation of Transport Enterprises, the electricity demand for Swedish ports was estimated for the year 2030 (Transportföretagen, 2023). In collaboration with several Swedish ports, an increase of 230% in port electrical power consumption is projected by 2030. However, there is currently no method in place to allocate future energy consumption across different port equipment, activities, and processes. Additionally, a tool to compare energy demand with sources of energy production at ports and delivery to ports is lacking.

Other work that highlights ports' important role as the principal node in the maritime transport system was conducted by Lind et al. (2021) regarding digital nodes and by Von Wieding et al. (2023) regarding logistics nodes. They emphasize the role of ports as energy hubs in the future, but do not go into more detail.

1.2 Goal and purpose

The *goal* of this pre-study is to support ports in the transition to becoming fossil-free energy hubs by identifying information gaps that hinder the port's transition.

The *purpose* is to develop a structure to assess ports' current and future energy demand and production.

This work sets out to evaluate the data needed to develop a quantitative model of future energy demand at ports. This pre-study is the first step towards creating a digital twin of a port's energy systems that has the ability to simulate future energy demand and production.

2 Method

2.1 Literature review and framework selection

The work started with a review of different frameworks within the field of maritime freight transport providing an overview of energy-related activities at ports; firstly, on water, such as through ships that are transiting and service boats that are associated with the ports, and secondly, on land, through terminals (equipment, lighting, building, refrigeration) and mobile equipment.

For this work, frameworks from over 30 references were reviewed to gain knowledge regarding measures, standards and categories of activities/clustering approaches for measuring the energy demand at ports as well as to collect benchmark data and estimate future demands. All references came from the field of maritime freight transport and were either publications in academic journals or reports by industry organisations or research institutes related to the field.

This review of frameworks was conducted as a comparative literature review, as it aimed to gain an initial impression of the topic (Bell et al., 2022). It started with a wide scope and inclusive selection criteria but focused down on methods and data measures as the review proceeded.

During the review process, 19 frameworks were selected providing a contribution to this work on ports as an energy hub. All 19 frameworks come from in total eleven different references and were sorted into the six following categories (see **Fel! Hittar inte referenskälla.**) that emerged during the review process:

i. Ports becoming energy nodes: Listing frameworks that describe ports in a transition process and generally depict ports in a greater ecosystem.
ii. Categorization of energy types: Providing different categories for equipment at ports and their type of energy.
iii. Categorization of emission types: Providing different categories for equipment at ports and their type of emission.
iv. Method to categorization: Providing examples of approaches to port categorization.
v. Benchmark: Providing examples of energy demand for different terminals, types of ships and equipment that can be used to benchmark own results.
vi. Quantitative predictions of future energy need: Providing forecasts of future energy needs for different examples.

The selected frameworks are presented in more detail and discussed in section 3.1.

2.2 Mapping energy activities and processes at the case port

The pre-study focused on identifying which data should be included in a model (to be developed in a subsequent project) to estimate ports' energy demand. This has been done by studying a single port in more detail, including the port's energy supplier for additional information. The selected port was the Port of Landskrona, with additional information provided by Landskrona Energi, both of whom are also partner organizations in this pre-study.

In a first step, the port of Landskrona was studied in detail to identify existing energy consumption in and around the port (i.e. internal operations, trucks, ships). A site visit and several interviews were conducted between representatives of the port and researchers from the pre-study.

A detailed compilation of the port's energy-consuming activities and processes was developed. The data was collected through several meetings (on site and through online meetings) with the project partners and were validated through presenting the results back to the port and energy provider and discussing them in detail.

The work was conducted foremost by: (1) mapping of data to describe the current energy demand at a port, (2) identifying sources of missing data, and (3) identifying barriers for collecting data, such as converting existing energy demands to electric load equivalents and estimating future energy demands and load profiles.

2.3 Brief description of the case

Port of Landskrona is a small port in the South of Sweden offering stevedoring services to customers both within and outside the port area. The port focuses primarily on bulk goods and offers unloading and loading of ships, warehousing and terminal operations (Landskrona Hamn, 2024). The port has four mobile cranes that operate along the 1100-metre-long quay, a conveyor belt system for dust-free unloading to silos and a ship loader (see Figure 1 and Figure 2).

The port is partly owned by the municipality of Landskrona and comprises a central part of Landskrona's transportation infrastructure by functioning as an important node for shipping and freight transport in the region.

Within the port area, several other companies participate in energy-intensive processes; these include, among others, grinding of quicklime, storing and distributing of slag (Thomas Cement, 2024), and production and processing of fertilizer (Yara, 2024).

Landskrona Energi is responsible not only for providing energy to the residents of Landskrona and its vicinity, but also to companies, including the Port of Landskrona. It is a municipality-owned company and delivers electricity, district heating, broadband and other services to its customers (Landskrona Energi, 2024). Landskrona Energi supplies the port with electricity for its daily operations. The energy provider and the port are in a dialogue about the port's development of sustainable energy solutions.

Figure 1. Bird view on the Port of Landskrona [Source: Port of Landskrona].

Figure 2. Equipment at the port [Source: Port of Landskrona].

3 Findings

This chapter presents the identified frameworks involving ports' connection to energy. It also describes and presents a structure to assess ports' current and future energy demand and production.

3.1 Review of frameworks

This section provides an overview of 19 frameworks that collectively address the complex landscape of ports in the transition to becoming energy hubs. Table 1 provides and overview of these frameworks, summarizing their contribution to the pre-study.

Table 1. Identified frameworks for ports in connection to energy.

Nr.	Reference	Title of framework	Contribution to pre-study
i. Ports becoming energy nodes			
1.	Bach et al. (2022)	Maturity framework for the port as energy node	Describes ports' four maturity levels for becoming an energy node: 1) energy strategy, 2) need for proactive actions, accounting for its own operations, 3) provision of sustainable energy to port visitors, 4) role as part of the transport-energy ecosystem
2.	Bach et al. (2022)	The port part of the energy ecosystem	Illustration of how the port's ecosystem is connected to the transport ecosystem and their surrounding society with respect to the energy ecosystem
3.	Bach et al. (2022)	Swedish ports' ongoing efforts regarding energy consumption	Breakdown of ports' ongoing efforts regarding the energy consumption into 1) the port's own energy needs, 2) the visitor's energy needs, 3) the port in the energy ecosystem
4.	Royal HaskoningDHV (2022)	Areas of change for ports due to energy transition	Lists the six areas of change (space, facilities, infrastructure, cargo flows, industry and hubs) and their impacts
5.	Spengler & Wilmsmeier (2019)	Energy activity clusters in a container terminal	Illustrating container port operations split into process clusters: quay cranes, lighting, buildings, cooling (reefer), horizontal operations in container handling, and other
6.	DNV (2020)	Ten Green transitions towards decarbonization of ports	Mapping ten transitions, such as electrification of port-connected activities, fuel switching for maritime transports, electrification of industry, offshore wind, energy system integration, hydrogen, phase-out of fossil-fuelled power plants, carbon capture and storage, new regulations and the circular and bio-based economy
ii. Categorization of energy types			
7.	Iris & Lam (2019)	Emission assessment, energy consumption for ports	Review of eleven different studies, mapping the source of energy demand at each port, which are sorted into two categories: (1) cargo handling, canes, vehicles, purchased electricity etc., (2) ship arrival and departure, ocean going vessels, hotelling, manoeuvring
8.	Iris & Lam (2019)	Energy sources for different equipment	Overview of which equipment uses which fuel (e.g., diesel, electricity, LNG, hydrogen)
iii. Categorization of emission types			
9.	IMO (2018)	Port-related emission sources, categorized by energy type	Categorization of emission sources (distinguishing mobile and stationary sources) and energy types (fuel oil, diesel, natural gas, methanol, propane, electricity and renewable)
10.	Gibbs et al. (2014)	GHG Protocol	Categorization of emissions from ports into scope 1, 2 or 3 according to the GHG Protocol
iv. Method to categorization			
11.	IMO (2018)	Three ways to inventory port energy consumption	Presenting approaches taken to develop the port emission inventory: (1) scaled, (2), screening, and (3) comprehensive

12.	Sifakis & Tsoutsos (2020)	Port categories	Presenting an approach to categorize ports based on number of passengers, number of ships, actual size/type of ships (i.e. cruise, cargo, transportation, etc.), region (in most cases, the port town), and services
13.	Winnes et al. (2015)	Overview of port emissions data sources	Presenting an approach to calculate emissions of each ship call
v. Benchmarks			
14.	Costa et al. (2022)	Existing onshore power supply in Swedish ports	Overview of terminal, voltage, frequency (Hz) and vessel type at nine different ports in Sweden
15.	Costa et al. (2022)	Power demand indicator per vessel type	Providing the power demand for onshore power (kW) of seven different kinds of vessels, such as commuter vessel, feeder container ships, container ships, ro-ro ships, tankers, and cruise ships
16.	Spengler & Wilmsmeier (2019)	Container handling equipment energy consumption values	Providing energy consumption values for different handling equipment at ports
17.	DNV (2020)	Definition and dimensioning of building blocks for Industrial Port 1.0	Examples of the size of different units at ports
vi. Quantitative predictions of future energy need			
18.	Transportföretagen (2023)	Gothenburg port's energy demand	Predicts a 550 %-increase of energy need from 2022 to 2040
19.	Sifakis & Tsoutsos (2020)	Ports' yearly energy consumption from 2010 to 2030	Provides ports' yearly energy consumption from 2010 to 2018 and forecasts it then up until 2030, showing almost a doubling of the energy consumption until 2030 compared to 2010

The contributions of those frameworks on the work in the pre-study differs. The first six frameworks (category i. "Ports becoming energy nodes" in Table 1) had a direct impact on how the structure to assess ports' current and future energy demand and production should look, while frameworks 7-10 influenced the categories within this structure, e.g., energy and emission types. Frameworks 11-19 helped to form an understanding of the work carried out in the pre-study but will be more relevant in subsequent work. Methods to categorize and calculate emissions and energy consumption are presented in frameworks 11-13 (category iv. "Method to categorization" in Table 1). Examples of energy demand for different terminals and types of ships and equipment are found in framework 14-17 (category v. "Benchmarks" in Table 1) and can be used to benchmark own results. Forecasts of future energy needs for different examples are provided by frameworks 18-19 (category vi. "Quantitative predictions of future energy need" in Table 1).

The four-level maturity model by Bach et al. (2022) had an important impact on the pre-study's structure and is therefore described in detail below (see Figure 3). This framework (Nr. 1 in Table 1) illustrates in four levels the journey ports have to become energy hubs.

Figure 3. Maturity framework for the port as energy node [Source: Bach et al. (2022)].

According to the maturity model, the port begins by developing an energy strategy to guide its development towards establishing capabilities as an energy hub (level 1 of the maturity model in Bach et al. (2022)). This strategy should not be seen as static but as evolving over time as the port and its surroundings co-develop at each level.

Level 2 in the maturity model focuses on ensuring that the port's ongoing energy needs are met with sustainable energy. This may involve energy for operating equipment, heating facilities, and its own vehicles, as well as port employees' needs for charging infrastructure while at work. It also includes the energy provided to in-port independent commercial and industrial facilities. This level could include the consideration of opportunities to invest in energy production or storage infrastructure, for example, solar panels, batteries or alternative fuel storage facilities. Thus, level 2 addresses the role of the port as an energy consumer, potential energy producer or storage provider, and energy supplier to the actors forming part of the port cluster.

Level 3 expands this role outward from the port to include the surrounding transport system of visitors to the port, such as to trucks, trains, and ships, which will increasingly require sustainable energy during their visits to the port. Offering sustainable energy to visitors by, e.g., ensuring that ships can connect to onshore power, that trucks waiting to load or unload at the port can charge their batteries and that the rail system can be powered by the port if needed, is part of this maturity level. It may also be necessary to provide energy for equipment and cargo transported by visiting infrastructure, such as carriers, for purposes like cooling. This level includes an emphasis on managing peak electric power demands, considering the port's ability to generate or store electricity, or manage loads. While the port's energy supply, consumption, and storage activities remain qualitatively similar to those in level 2, level 3 considerably expands the port's energy coordination and management role with the inclusion of a broader community of transportation actors.

The highest level in the maturity model, level 4, allows the port to leverage its role as a coordinator of energy activities within the greater transport system, to become a hub in the broader energy system. This could involve coordinating the energy needs of the port's ecosystem with other energy consumers, such as across the city or region where the port is geographically located. Level 4 in the maturity model also involves identifying new business opportunities for the port to serve as a transport hub for emerging fuels, such as being the first stop and storage depot for liquid biofuels, hydrogen or synthetic fuels before further distribution (e.g., to fuel stations, airports, industrial facilities). At this level, there is also the potential for the port to serve as a logistics hub for raw materials for energy production, such as food waste or bioenergy crops. Thus, level 4 in the maturity model primarily addresses the port as a mediator of energy supply and demand, acting primarily as a storage and distribution hub.

The framework "The port part of the energy ecosystem" (nr. 2 in Table 1) by Bach et al. (2022) provides further support to mapping energy-consuming activities with the port as a starting point (see Figure 4). The framework distinguishes the port's own ecosystem from the greater transport ecosystem and the energy ecosystem of the surrounding society.

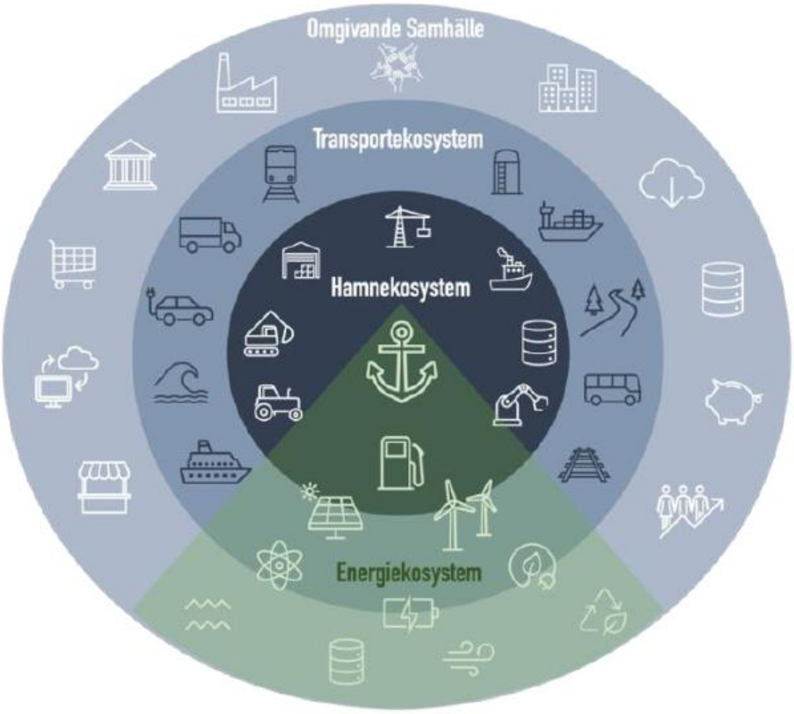

Figure 4. The port part of the energy ecosystem [Source: Bach et al. (2022)].

The structure to assess ports' current and future energy demand and production was also significantly influenced by the framework "Areas of change for ports due to energy transition" by Royal HaskoningDHV (2022) (nr. 3 in Table 1) that highlights space, facilities, infrastructure, cargo flows, industry and hubs as areas of change (see Figure 5).

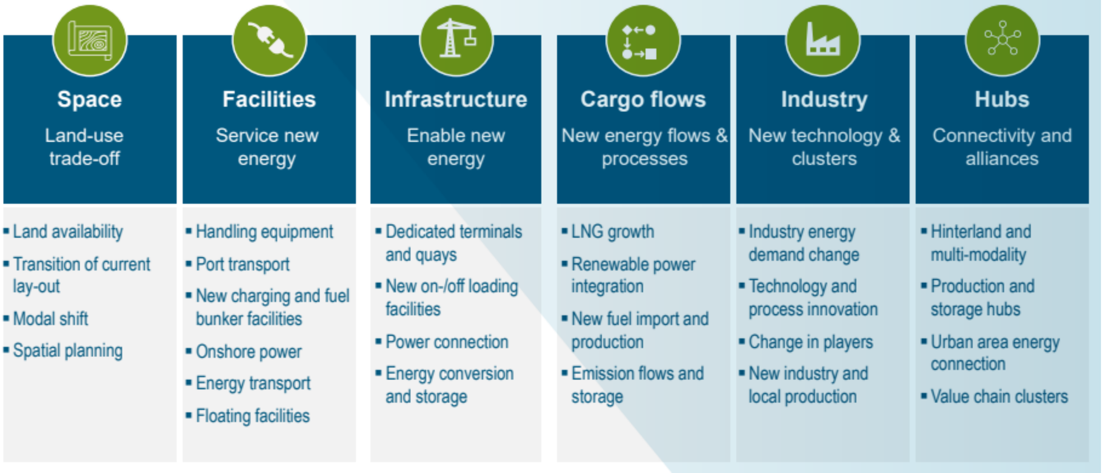

Figure 5. Areas of change for ports due to energy transition [Source: Royal HaskoningDHV (2022)].

3.2 Structure to map energy activities and processes

Drawing on the frameworks from section 3.1, a structure to assess ports' current and future energy demand and production was developed (see Figure 6). It pinpoints energy needs in three areas:

1. the port itself,
2. the surrounding transport system, i.e. visitors to the port, and
3. the port as a hub in the surrounding energy system.

To complement this list of areas, the following two were added, making it possible to collect additional data:

4. other port-related energy activities, and
5. the port energy plan.

For each of these areas more detail is added, outlining the total energy consumption and its more detailed components. For the port (1) this consists of the following:

(a) in-port vehicles and equipment, including cargo handling (e.g., cranes),
(b) in-port facilities, including buildings such as offices, warehouse, depot,
(c) car parks,
(d) service vessels, such as tug or pilot boats, and
(e) energy production, such as solar panels.

With regards to visitors to the port this includes vessels, trains and trucks, and focuses on the amount of energy that they might need while in port. This includes, for example, charging while in port (i.e., cold ironing, megawatt charging) and refuelling.

Regarding the port as a hub in the energy system, this considers the port alongside other industries located in the port area, as well as the local municipality. Under “other,” additional energy-consuming or producing activities and processes are collected, such as lighthouse and fairway maintenance operations. Information on future energy plans or strategies can be collected in the fifth area, which includes plans for decarbonization of the port and is in line with the maturity level framework of Bach et al. (2022).

The developed structure to assess ports' current and future energy demands and production is available as an appendix to this report.

A list of energy activities and processes of the case port is presented in Table 2, in which the availability of energy data is also described (based on the experience with the case port – Port of Landskrona).

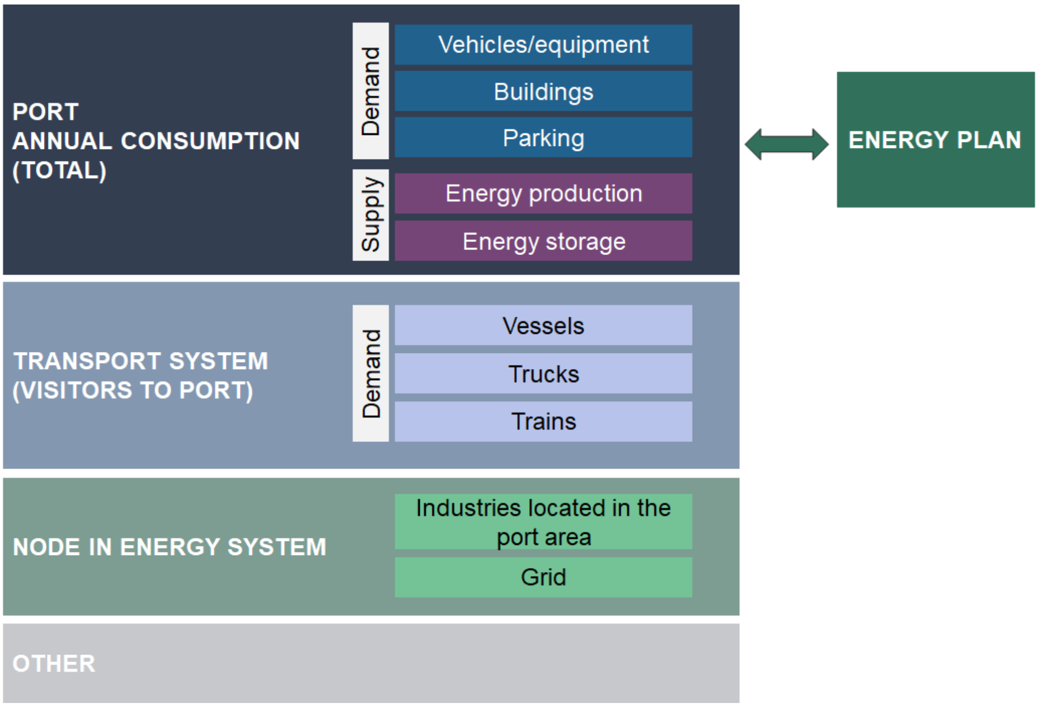

Figure 6. Overview of structure to map energy activities and processes.

3.3 Assessment of availability of energy data

The data mapping to describe the current energy demand at the port of Landskrona is presented in relation to the structure in Table 2. The mapping was done through several meetings with Port of Landskrona where data was shared and discussed during the project period (see section 2.2). It should be mentioned that the mapping was based on the availability of data during this period and data was collected for 2023. A need for additional data was identified to complete the full mapping. The case shows which data is easily available by the port itself, and which data would require data sharing between two or more parties, or where another level of detail would be required to fulfil the data need. In Table 2, a summary of the availability of energy data at the end of the project period is provided.

For the total energy consumed, there are figures available for a full year, based on electricity and diesel consumption. For electricity, there are six measurement points in the port, which all provide data for the specific consumption related to each measurement point. For example, one measurement point was related to “Storage” and one for “Office”. For diesel consumption, refuelling of cranes and the diesel tank was done by an external partner, which provided the data to the port. The diesel tank was used to refuel the equipment and vehicles in the port. Since the diesel tank was installed during 2023, it was also necessary to collect figures from the previous fuel provider.

A summary of all in-port vehicles and equipment is provided in Table 2, which includes both electric and diesel-driven vehicles and equipment. In total, there are four cranes driven by diesel and also a number of trucks. For the diesel-driven equipment figures are available for the full year through the refuelling statistics from the external partner. It is possible to derive the refuelling statistics for each crane, but not for a single vehicle or piece of equipment (since those are refuelled from the diesel tank). Also, there are additional data available from the modern crane system (which applies to two of the cranes), and such data includes diesel consumed per hour and hours of utilisation. For the electric vehicles and equipment, data based on the measurement points are available, but to map the electricity consumption for each piece of equipment, more detailed data is needed. Installations of additional measurement applications would be required. Finally, the rented equipment is mostly fuelled by the diesel tank and then included in that overall statistics, but sometimes the rental firm does the refuelling, and such data has not been available at this stage.

The in-port facilities include one office and one storage building. The electricity figures provide data from the measurement points “Office” and “Storage” on a yearly basis. These figures also include the charging of the electric in-port car, but there is no separate charging data.

There is limited data related to the car park outside the office building, and the specific consumption when charging cars (visitors and employees). It is unclear if the electricity used for charging cars is part of the aggregated electricity consumption figures or if it is separated. Most likely it is outside of the overall statistics.

There is no energy production at the port today. However, there is an ongoing discussion related to installing solar panels on one of the buildings.

Energy storage is not available today at the port.

The transport system – i.e. visitors to the port, relate to vessels and trucks visiting the port. No train connection is available today. The number of ship calls per year is available internally, as well as their cargo types. Ship types can be derived from their cargo types, but it would be helpful to have the specific ship types logged separately. Amounts of fuel transferred to these vessels are available from an external partner (bunkering is made from trucks). When it comes to truck movements in the port area and related energy consumption, such statistics are not available from the port alone. Data need to be extracted from the port’s contracted haulier as well as from the industrial partners that contract hauliers separately.

Looking at data related to the port as a node in the energy system, it is of relevance to map other industries’ energy consumption – industries that are located in or close to the port area. There are several industries in the port area, but energy data has not been retrieved at this stage.

Finally, there are other energy-consuming activities/facilities/equipment, such as electric gates, lighthouse and navigation lights as well as operations related to fairway maintenance. For the lighthouse and navigation lights, there is aggregated data available for the full year, derived from two of the electric measurement points. However, there is no data available at this stage related to the energy consumption of the electric gate and maintenance of fairway operations.

Table 2. Map of energy activities and processes at port including data availability (Data = data available at port, Extern = data available through external parties, New = data is missing and new data/collection is required).

ACTIVITY/PROCESS	DATA AVAILABILITY IN CASE	Data	Extern	New
THE PORT				
Total energy consumed by the port per year	Summary: The port consumes energy from electricity and diesel.			
Electricity	Figures are available for the full year. It is divided between six different measurement points in the port.	X		
Diesel	Figures are available for the full year, based on external partners' refuelling statistics. It covers refuelling of the four cranes and a diesel tank used for other equipment (in place from Sep 2023). Jan-Aug 2023 another partner refuelled the other equipment (instead of the diesel tank).	X	X	
In-port vehicles and equipment e.g., yard truck, forklift, car, quay crane, automated guided vehicle, yard crane, automated stacking crane, straddle carrier, rail-mounted gantry crane, rubber-tired gantry crane.	Summary: 2 diesel L30, 1 diesel L90, 1 electric truck, 1 Mantsinen diesel crane and 3 Caterpillar diesel cranes, 1 electric vessel loader, 2 electric conveyor belts for quicklime and manure, 1 electric quicklime vacuum pocket, 2 cars (one electric and one diesel), and various rental diesel equipment			
Energy consumption/year and per energy type (electricity, diesel, etc.) for that vehicle/equipment	Summary: For the diesel-driven equipment and cranes, the full year coverage could be derived from refuelling diesel statistics. Data for each crane is available. Additional crane data are available for two of the cranes, including fuel consumed per hour and hours used. For the other diesel equipment, it is not possible to derive figures for each one. For electric driven equipment, yearly aggregated data based on measurement points are available. Further details are needed to map electricity consumption for each equipment. The rented equipment is mostly refuelled from the diesel tank and then included in the refuelling aggregated statistics. Otherwise figures from the rental firm are required.	X	X	X
In-port facilities List each facility followed by type of energy.	Summary: 1 office and 1 workshop building			
Electricity	Electricity figures from aggregated yearly statistics in the measurement points "Office" and "Storage". These figures include charging of the electric in-port car.	X		X

Car park connected to the port	Summary: There is a car park for visitors outside of the office building.			
No. of cars parked per year	No data available.			X
Duration of time cars are parked	No data available.			X
Energy consumption by cars	No data available. Unclear if the electricity used for charging cars is in the aggregated electricity figures. Most likely this consumption is outside of the overall statistics.			X
Energy production connected to the port	Summary: There is no energy production in the port today.			
Amount of external energy (e.g., purchased fuels, energy from the port or the grid), consumed/year?	See total energy consumed.	X		
Plans for energy production in the future? What and when?	A strategy is under development. Solar panels are discussed as part of the strategy.	X		
Energy storage (e.g., liquid fuels, battery storage) connected to the port	Summary: There is no energy storage in the port today.			
TRANSPORT SYSTEM - VISITORS TO THE PORT				
Ships	Summary: Ships calls the port in the general cargo segment (bulk).			
No. of ship calls per year	Available data from internal reports.	X		
Type of vessels	Available data from internal reports related to cargo type. Ship type can be derived based on cargo type.	X		X
Amount of fuel transferred to these vessels	Not available internally. Data from external partners needed (bunkering trucks).		X	
Percentage of vessels using cold ironing while at berth	Not available.	–	–	–
Amount of onshore energy transferred for cold ironing	Not available.	–	–	–
Trains	Summary: No train connection to the port today.			
Drayage trucks	Summary: Trucking companies visit the port daily, either contracted from the port itself or from the industries in the port area.			
No. of trucks arriving at the port per year	Data need to be extracted from own haulier and industries in the port area. Estimates have been made.		X	X
Energy consumption for these trucks	Data need to be extracted from own haulier and industries in the port area. Estimates have been made.		X	X
Amount of energy transferred to them by the port	Not available.	–	–	–

NODE IN ENERGY SYSTEM				
Co-located industries (port area)	Summary: There are a number of industries in the port area, but energy data has not been retrieved at this stage.			
OTHER				
Other energy-consuming activities/facilities/equipment	Summary: Electric gates, lighthouse/navigation lights, fairway maintenance operations.			
Energy consumption/year and per energy type (electricity, diesel…) for that activity/facility//equipment	For the lighthouse and navigation lights there are aggregated data available for the full year derived from two measurement points, which include only those consumptions. The other activities listed has no data availability.	X	X	X

4 Discussion and conclusion

4.1 Discussion of structure

A structure for categorizing energy consumption in ports by activity has been developed. The starting point was the work by Bach et al. (2022) showing that the port ecosystem is connected to the transport ecosystem and surrounding society. The structure categorises energy consumption related to (1) activities/equipment controlled by the port itself, (2) activities related to the surrounding transport system connected to the port, i.e. visitors to the port, as well as (3) the port as a node in the energy system (including for example provision of electrical onshore power for vessels, fuel to vessels, energy production through solar or wind power), also for co-located industries. In this way, the structure shows that ports need to consider more than simply the equipment and activities under their direct control, such as for example cranes and vehicles.

The categorization includes aggregated energy consumption (a top-down approach) but also its constituent parts, providing more details and understanding regarding sources of energy demand (a bottom-up approach). Overall energy consumption may be the most relevant information in some situations. However, breaking it down into specific vehicles, for example, helps to identify if there are particular sources of energy demand that could be changed or replaced. Here, ports may find it interesting to identify which are their most energy-consuming activities or processes. Total energy consumption could also be calculated based on the more detailed information if totals are not readily available. The structure aims to cover a broad number of sources of energy demand and, therefore, suggests what these may be, such as cranes. However, the structure will need to be adapted, and specifics added for a particular port, e.g., crane type. This is because ports have a varying array of equipment, depending, for example, on the type of cargo that is handled in the port.

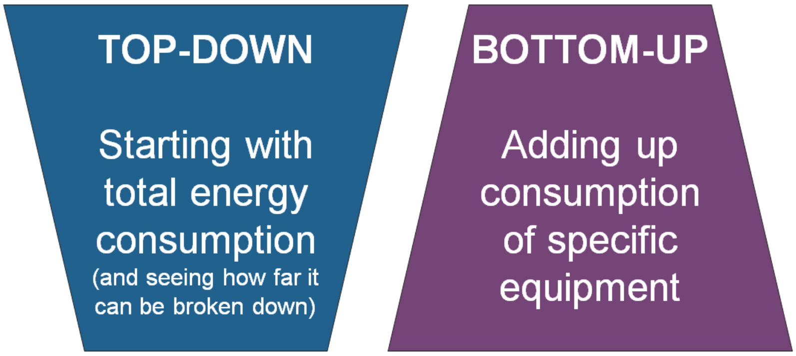

Figure 7: Difference between top-down and bottom-up approach

In addition to sources of energy demand, the structure includes energy production and energy storage. In this way, it anticipates plans for ports to take a greater role in the supply of energy. Here, the port can see how its energy demands match with potential generation resources, which may inform decisions regarding development of energy production and storage.

The activities and equipment controlled by the port itself are easiest for ports to address first. The port generally has data on their own energy consumption, for example, through invoices. Also, the port generally controls decisions related to their own equipment, for example the specification when purchasing a new crane or the utilization of equipment.

For the activities and equipment controlled by the port, the structure differentiates between equipment and facilities. An alternative mentioned in literature is to differentiate between mobile and stationary sources (e.g., IMO, 2018), i.e. vehicles versus offices, which makes a similar differentiation. However, after consultation with the case port, the equipment/facilities distinction was deemed more intuitive for a port user, for example, detailing office building and warehouse.

The structure further takes into account that the energy needs of a port include a mix of liquid fuels and electricity, such as marine fuel oil for ships, gasoline and diesel fuel for in-port vehicles and equipment and electricity for heating and lighting. It is important to note that ports are in transition. While historically liquid fossil fuels are commodities that can be bought in bulk and stored at a depot, local and regional electricity networks have only needed to support relatively modest and predictable port electricity loads. With increased electrification, for example, onshore power supply and cranes that run on electricity, this changes.

The structure can help to identify such changes to the electricity demand and can be used in discussions with energy providers. While much focus is on electrification, the port also needs to consider how to manage a demand for decarbonized fuels, such as biofuels, hydrogen, ammonia, or synthetic fuels, all of which require electricity for their synthesis. There is great uncertainty about the energy transition in both the maritime and other demand sectors; e.g., which fossil-free fuels will be used by ships in the future, and how non-port electricity consumers will use electric power in the future. The structure will not help with this uncertainty, but it can help provide an overview of the current situation and help identify areas that are more or less likely to change. As such, it can be used to facilitate planning discussions and help in decision-making.

Since the average and, especially, the peak power consumption both are expected to increase as a port electrifies, estimating the amount and, especially, the timing of energy consumption are important. This could still be emphasised more strongly in the structure. Electricity load profile (when energy is used, e.g., weekly, on weekdays, on weekends, day or nighttime, or even hourly during a day) is increasingly important given electrification, compared to the use of, for example, diesel. New demands, such as fast charging vehicles or onshore power supply, are likely to represent intermittent, high-power loads to the electric power system. Unmanaged, these high-power loads could present challenges to the local and regional electricity grids, such as overloaded circuits, voltage deviations and even frequency instabilities. Thus, the timing of ports' energy consumption as well as possibilities to even out peaks in the load profile are likely to become much more important in an electrified future than it has been. This needs to be studied further.

During this pre-study, data availability was investigated in the case port, and it was found that different sources of data were needed. For example, energy consumption in one type of crane was logged, while not as easily accessible for another. There were challenges in structuring the data, for example, some data was available for a group of activities/processes without detailing individual use, meaning a diesel tank was used for several vehicles but it was not tracked the specific diesel usage per vehcile. This meant that some simplifications and assumptions had to be made.

Data availability when considering activities outside of the port's control, such as the number of trucks going through the port and how long they stay in the port area, the amount of fuel transferred to vessels, or a shipping line's plans regarding its need for onshore power supply, required data from other actors. The case port contacted companies located in the port area regarding the traffic of trucks and contacted shipping lines regarding the vessels calling the port. Relying on information from other actors makes the compilation of data more challenging. Some information may be easier for the port to capture, such as the number of port calls, or the number of trucks entering the port, while other information, such as the duration of stay in the port, was not as readily available.

4.2 Implication for ports' energy transition

Energy consumption is central to any port's transition plan. This pre-study has validated the earlier observation that these plans can include concrete short- and long-term strategies to electrify and/or switch to fossil-fuels for equipment and vehicles at a port while maintaining service levels required to serve expected future port operations. The results from this pre-study also demonstrate that much of the activity-related energy consumption data needed to measure emissions reductions is either available or can be obtained by port authorities; thus, a lack of data should not prevent a port from beginning to execute its transition plan. However, there are still several gaps in available data, which could hinder a port's ability to measure its own progress or to adapt its plan as the future becomes clearer. Future research efforts could explore options for addressing these information gaps, giving ports a more complete picture of their own energy usage. This should enable ports both to evaluate their efforts to using fossil-free fuels in future more accurately and support them in becoming enery hubs providing fossil-free fuels in the future.

As expected, the case port had limited data on the energy consumption and transition plans of nearby and associated energy-consuming entities (i.e., outside the port). As a port progresses along its transition journey, it could be in a position to support the concurrent energy transition activities of adjacent actors: vessels that visit the port (i.e., supplying various low-carbon bunkering fuels, providing onshore power), land transportation vehicles (i.e., providing electric charging opportunities and/or other low-carbon transportation fuels), nearby industrial facilities and the local community (i.e., energy supply and/or load management). In return, greater coordination of the transition activities among these actors could increase the speed and efficiency of their transitions, as well as contributing to greater resilience of the decarbonized energy sector. Future research will explore the potential benefits of expanding transition activities to include cooperation among communities of energy actors aligned with the port.

These preliminary implications rely primarily on observations from the case port, and they have not been fully validated against the experience from other ports. It is not yet known how representative these initial findings are, but this is a clear aim for future research.

4.3 Next step

While this pre-study provides a structure that helps ports outline their current and future energy demand and production, several areas for improvement were also found. To continue the work, a follow-on project is granted from the Swedish Transport Administration's industry program Sustainable shipping that is operated by Lighthouse. In this project, the structure outlined in this pre-study will be further developed into a spreadsheet tool that Swedish ports can use to analyse their energy consumption and efforts to transition to fossil-free fuels and becoming energy hubs. It will be important to test the applicability and usability of the spreadsheet tool.

Another area needing further attention is collaboration between various actors, particularly cooperation between ports and their energy suppliers to accelerate the transition to an electrified future. Demand-side solutions will need collaboration regarding efficiency and load shifting, for example, which is of interest to maintain grid stability. The capability of the port to provide grid stability transcends the port's own energy demand. As new, higher-power loads from industrial, commercial, and residential electrification meet variable supply from increasing renewable generation, ports could be able to play a balancing role in the local or regional energy system.

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Appendix

Structure to assess ports' current and future energy demand and production (version 1.0)

ACTIVITY/PROCESS	ENERGY CONSUMPTION
THE PORT	
Total energy consumed by the port per year (in total here and below per energy type).	
electricity	
diesel	
bunker	
LNG	
petrol	
… [add more lines as required]	
Electricity load profile (e.g., hourly) of the port	
In-port vehicles and equipment e.g., yard truck, forklift, car, quay crane, automated guided vehicle, yard crane, automated stacking crane, straddle carrier, rail-mounted gantry crane, rubber-tired gantry crane. List one at a time.	
… [add type of vehicle/equipment]	
Energy consumption/year and per energy type (electricity, diesel…) for that vehicle/equipment	
No. of this type of equipment	
… [add type of vehicle/equipment]	
Energy consumption/year and per energy type (electricity, diesel…) for that vehicle/equipment	
No. of this type of equipment	
… [add type of vehicle/equipment]	
Energy consumption/year and per energy type (electricity, diesel…) for that vehicle/equipment	
No. of this type of equipment	
… [add more lines as required for more equipment]	
… [add also rented equipment]	
In-port facilities List each facility followed by type of energy. List one at a time.	
Warehouse energy consumption	
Warehouse consumption electricity	
Warehouse consumption diesel	
… [add more lines as required regarding consumption of energy type]	
Warehouse end use: lighting	
Warehouse end use: cooling	
Warehouse end use: heating	
Warehouse end use: … [add lines as required]	
Office building energy consumption	
Office building consumption electricity	
Office building consumption diesel	
… [add more lines as required regarding consumption of energy type]	
Office building end use: lighting	
Office building end use: cooling	
Office building end use: heating	

Office building end use: … [add lines as required]	
Depot energy consumption	
Depot consumption electricity	
Depot consumption diesel	
… [add more lines as required regarding consumption of energy type]	
Depot end use: lighting	
Depot end use: cooling	
Depot end use: heating	
Depot end use: … [add lines as required]	
… [add more lines as required] (e.g., cold storage)	
Car park connected to the port	
No. of cars parked per year	
Duration of time cars are parked	
Energy consumption by cars	
Charging profile (e.g., hourly)	
Energy production connected to the port	
Energy produced per year (MWh) (total)	
Solar produced (in MW)	
Solar capacity (in MW)	
Wind produced (in MW)	
Wind capacity (in MW)	
Waste incineration produced (in MW)	
Waste incineration capacity (in MW)	
Hydrogen produced (in MW)	
Hydrogen capacity (in MW)	
… produced (in MW)	
… capacity (in MW)	
… [add more lines as required]	
Amount of external energy (e.g., purchased fuels, energy from the port or the grid), consumed/year	
Plans for energy production in the future? What and when?	
Energy storage (e.g., liquid fuels, battery storage) connected to the port	
Liquid fuel capacity	
For internal consumption or temporary storage for transit	
For temporary storage for transit	
Battery storage	
For internal consumption or temporary storage for transit	
For temporary storage for transit	
… [add more lines as required to add other types of energy storage]	
Plans for energy storage in the future? What and when?	
TRANSPORT SYSTEM - VISITORS TO THE PORT	
Ships	
No. of ship calls per year	
Type of vessels	
Amount of fuel transferred to these vessels	
Percentage of vessels using cold ironing while at berth	
Amount of onshore energy transferred for cold ironing	
Trains	

Rail connection to the port	
No. of trains wagons arrive at the port per year	
Amount of energy transferred to them by the port	
any additional energy consumption related to the handling of train cargo	
Drayage trucks	
No. of trucks arriving at the port per year	
Energy consumption for these trucks	
Amount of energy transferred to them by the port	
NODE IN ENERGY SYSTEM	
Own distribution grid separate from the municipal network?	
medium voltage (i.e., 10-11 kV) or low voltage (i.e., 400 V)?	
Co-located industries (port area)	
[Name of industry]	
Energy consumption per year	
By type of energy	
[Name of industry]	
Energy consumption per year	
By type of energy	
[Name of industry]	
Energy consumption per year	
By type of energy	
OTHER	
Other energy-consuming activities/facilities/equipment	
Energy consumption/year and per energy type (electricity, diesel…) for that activity/facility//equipment	
ENERGY PLAN	
Energy plan included in Port strategic plan?	
Content?	
Plans for decarbonization of the port? What and when?	
Biggest current challenges related to energy supply	
Biggest future challenges related to energy supply	

Lighthouse gathers leading maritime stakeholders through a Triple-Helix collaboration comprising industry, society, academies and institutes to promote research, development and innovation within the maritime sector with the following vision:

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