

# Seaport

Subjects: [Energy & Fuels](#)

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Seaports are well known as the medium that has evolved into the central link between sea and land for complex marine activities. The growth in maritime logistics particularly necessitates a large volume of energy supply in order to maintain the operation of sea trade, resulting in an imbalance between generation and demand sides. Future projections for three major concerns show an increase in load demand, cost of operation, and environmental issues. The involvement of a variety of heavy loads such as all-electric ships, cranes, cold ironing, and buildings infrastructure renders it a complicated arrangement task in several aspects, which necessitates further research and leaves space for improvement.

Port Activities

Seaports

Maritime

Seaport load

Seaport energy revolution

Maritime Policy

Electrification

Port classification

## 1. Port Activities and Power Consumers

Port engagement with respect to energy can be classified into energy generation and power consumption mainly in the form of electricity and fuel. It is crucial to comprehend the load components and monitor energy-related activities taking place within the port before initiating any energy planning. The purpose is to analyze the amount of energy demand and ensure that there is enough power supply to prevent power shortages. However, load profile measures at seaports vary according to several factors such as the type of port and activities conducted at that particular port.

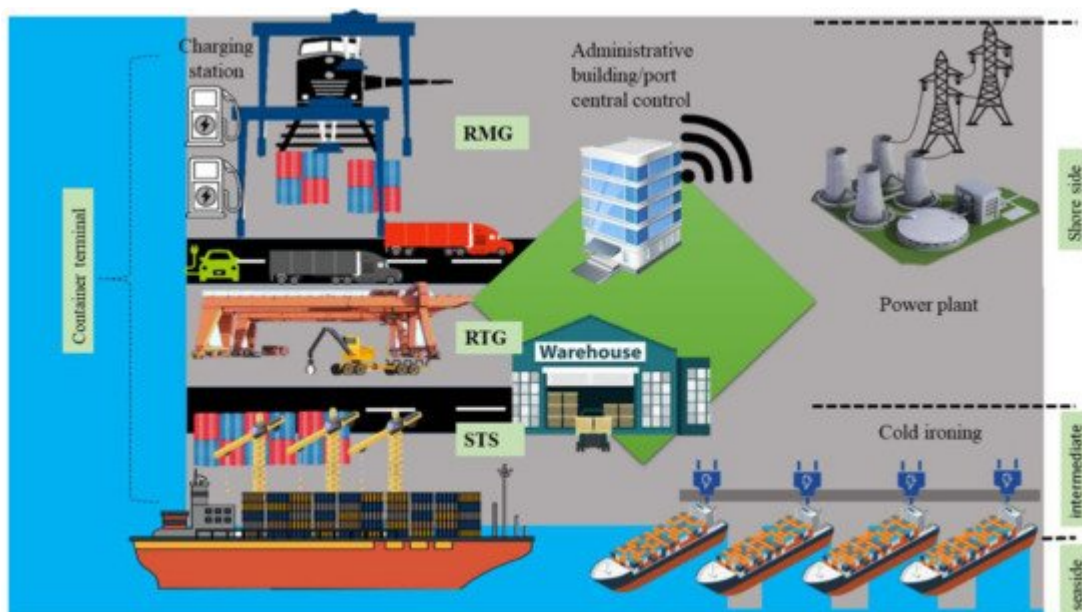
Seaports by definition can be viewed as centers of economic activities associated with any kind of arrival (tourist or goods), service of ships, and cargo <sup>[1]</sup>. The most common ports can be categorized into commercial/industrial ports <sup>[2]</sup>, container terminal ports <sup>[3]</sup>, and intermodal ports <sup>[4][5]</sup>. In another classification provided in <sup>[6]</sup>, ports are classified into three types, such as local ports, national ports, and international ports. These classifications are based on the ports' characteristics, region of the port, the volume of loads it serves, vessel type, port's operation and services, the annual number of passengers, and the annual number of ships berthing in and out from the port. Different types of ports and their characteristics are summarized in **Table 1**.

**Table 1.** Classification of ports <sup>[6]</sup>.

Port Type	Characteristics
Local port	Serves for local needs Limited space and capacity

Port Type	Characteristics
	Small size No logistic activity handling Do not support cruise ships Boats, vessels, yachts, and small-sized ships < 500 passengers
National port	Serves country needs Medium-sized (larger than local port) Cover all ships type with small logistic and cruise activities Medium-sized ships < 2500 passengers, cargo (packages), and logistics (only trucks)
International port	Serves international needs Largest sized Provide huge logistic infrastructure Cruise ships > 2500 passengers, cargo, containerships, and RTG cranes

nodes of transportation (water and road traffic) with different characteristics. From this perspective, the seaport area can be sorted into the seaside, shore side, and intermediate space. Each space is utilized for a different type of activity, transportation, and application, all of which have an impact on the amount of energy demand. **Figure 1** illustrates the most common activities running in the seaport area and its load components.



**Figure 1.** Seaport activities and load components (abbreviations: rail mounted gantry (RMG), rubber tyred gantry (RTG), and ship to shore (STS)).

Loads on the shore-side: On the shore side, administrative buildings and a custom facility, as well as a warehouse for goods, are built. In this infrastructure, electricity is consumed mostly for lighting; Heating, Ventilation, and Air Conditioning (HVAC) system; and equipment [7]. Many factors influence the building's energy consumption, including weather conditions, building materials, occupant behavior, work durations, equipment, and electrical load used [8].

In terms of transportation, different land vehicles such as trucks, cranes, yard tractors, and trains are powered by diesel fuel, and electricity is needed for electric vehicle (EV) charging stations. Typically, diesel is used as the primary source for motor movement in the cranes. However, recent research studies on electrical cranes show a lot of interest in energy storage systems for storing potential energy regenerated from lowering and lifting cranes operations [9].

Loads on the seaside: The seaside includes a marine vessel or any watercraft transportation voyages across the ocean that serves the purpose of carrying passengers or delivering cargo. Ships will make more voyages, consume more fuel, and increase the volume of water traffic as global trade expands. Normally heavy fuel oil (HFO) is consumed for big vessels and bulk carriers. General cargo vessels consume the most HFO, followed by oil tankers and cruise ships accounting for 66,000 t, 43,000 t, and 25,000 t of HFO annual consumption, respectively [10]. The spill of fossil-based marine fuel into the water and its combustion into the air can become a major threat to the environment [11]. Despite its undesired environmental impacts, HFO continues to be the preferred fuel of the maritime transport industry due to its relatively low cost, widely available resources, and the ability to suit engines that were originally designed for HFO [10].

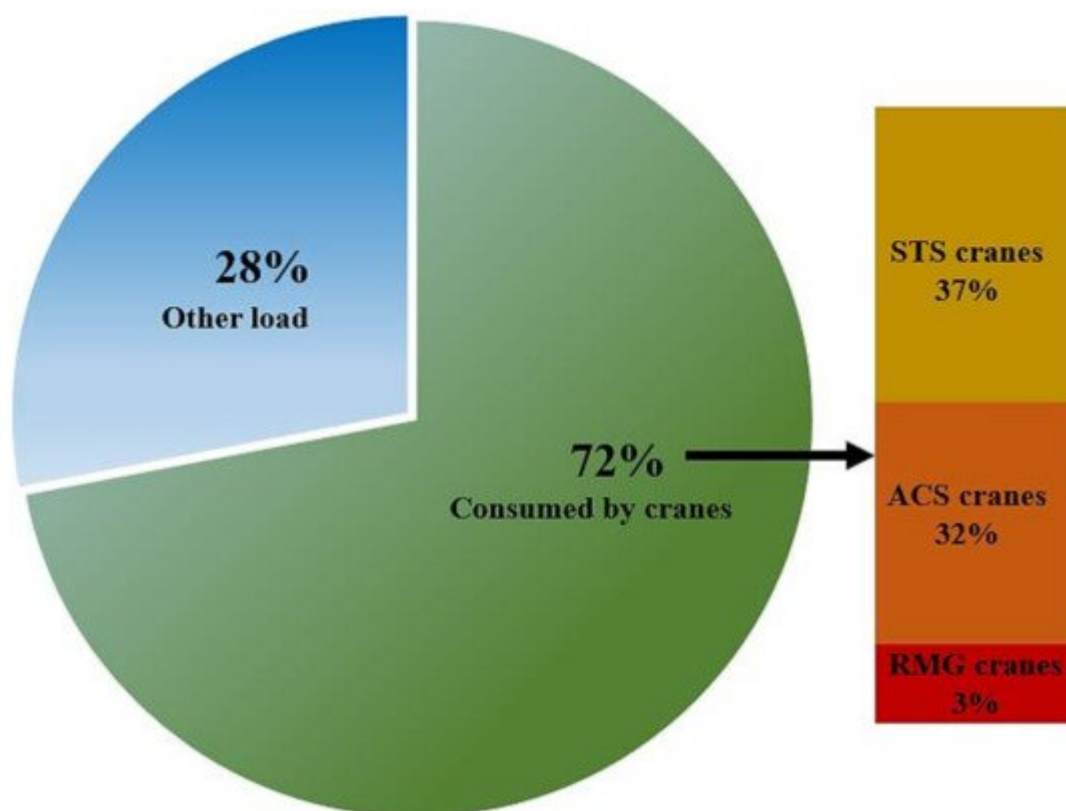
In order to prevent heavy utilization of HFO and to be in line with port development, ship technology is embracing the electrification concept by implementing an Integrated Power System (IPS) and storage system known as All Electric Ship (AES) [12]. Energy usage for a vessel is hard to measure as it depends on numerous aspects such as the size of the vessel, onboard loads, vessel speed, sea waves, and weather conditions.

During berthing for transit or transferring goods, the auxiliary engines of the ships are kept operating in order to supply the energy for onboard loads [13]. To overcome continuous fossil fuel burning, cold-ironing facilities are provided at the intermediate area between the sea and shore side. Power requirement varies from 300 kW to 7 MW depending on the type of ships and berthing duration [14]. In addition to the onshore power supply, the port must accommodate shore charging facilities. Some of the vessels with storage components such as hybrid vessels and AES will need a charging station in the port area for recharging their batteries and supplying onboard loads.

Loads in the intermediate area: In this region, there are cold ironing, charging stations, and container terminal facilities. The container terminal is an important part of international logistics and requires a large amount of energy, both fuel and electricity [15], for loading and unloading cargo as well as the transshipping goods to the next mode of transportation [16]. Container terminals serve three primary functions: yard side, quayside, and landside [17]. Each side has its operation and transportation needs. Cold storage facilities among the terminal operation consume a lot of energy, as it is a temperature-controlled storage solution for perishable goods. The Port of Wilmington built a 101,000 square foot refrigerated warehouse to refrigerate food, pharmaceutical, floral, and other items that require maintaining specific temperatures for storage [18]. It allows distribution companies to deliver their goods locally, nationally, and globally in good conditions.

In the container terminal, there are various types of cranes in use, from ship to shore (STS)/quay cranes (QC) to automated guided vehicles (AGVs)/automated straddle carriers (ASCs), and, finally, rail-mounted gantry (RMG)

cranes, before they are transferred into truck/trains [19]. Considering peak power demand, cranes need about 72% of total energy (STS cranes about 37%, ACS cranes 32%, and RMG around 3%) [20]. The breakdown of the cranes' power demand is shown in the pie chart of **Figure 2**.



**Figure 2.** Breakdown of cranes power demand during demand peak intervals.

From the appliances that are used and activities conducted within the marine port, it can be observed that the seaport sector has a large energy demand that makes the energy-handling problem a complex task. Hence, a reliable power system is required that can provide sufficient energy supply to all distribution loads. Any shortcoming in energy delivery will cause a big disruption to the seaport's operations.

Therefore, it is very important to distinguish between critical and non-priority loads so that the critical loads will receive priority during emergencies in order to obtain energy supplies [21]. **Table 2** summarizes the findings regarding seaport-related services and their load.

**Table 2.** Seaport activities and loads variation [2][22].

Seaport's Services	Load	Factor Influence Energy Consumption	Load Classifications	Form of Energy
Vessel	Passenger ships (cruise, ferry), container ships, electric ships, tugs, gliders, bunkers, boats, tankers,	Size of the ship, activity conduct on the ship, time of operation, weather, wave, speed	(1)Peak load (2)Critical load	(1)Electricity (2)

Seaport's Services	Load	Factor Influence Energy Consumption	Load Classifications	Form of Energy
	hovercraft, sailboats, submarines, yachts		(3) Non-critical load	Fossil fuel
Goods handling	Cargo, container, quay, logistic, freight forwarder, customs warehouse, storage, security, loading-unloading	Number of cranes, amount of cargo, hours of operation	(4) Variable load	
Administration	Management and administrative building, planning, service solution, IT, monitoring	Type of electrical equipment, weather, building material, hours of operation, occupant behavior	(5) Constant load	
Transportation	Electric vehicles, cranes, trucks, yard tractors, trains	Number of transportation, hours of consumption		
Electric Facility	Cold ironing, charging station for electric vehicles	Time of berthing, number of ships per berthing, size, and ship's load		
Maintenance	Repair and maintenance	Type of the maintenance		

of every subsystem linked to it by implementing an energy efficiency program. It is critical to identify the root of the problem and core issues in the port in order to achieve a good outcome from planning.

The European Sea Ports Organisation (ESPO) in their latest report (October 2020) highlighted the top ten priorities of the port sector from 1996 to 2020 [23]. **Figure 3** shows the top three port issues from 2009 until 2020. As observed in this figure, most of the issues listed have remained the same while their relative positions have changed over time. However, air quality and energy consumption remained mostly the highest priorities. These data are important as it identifies the vital concerns that port managing sectors are working on.

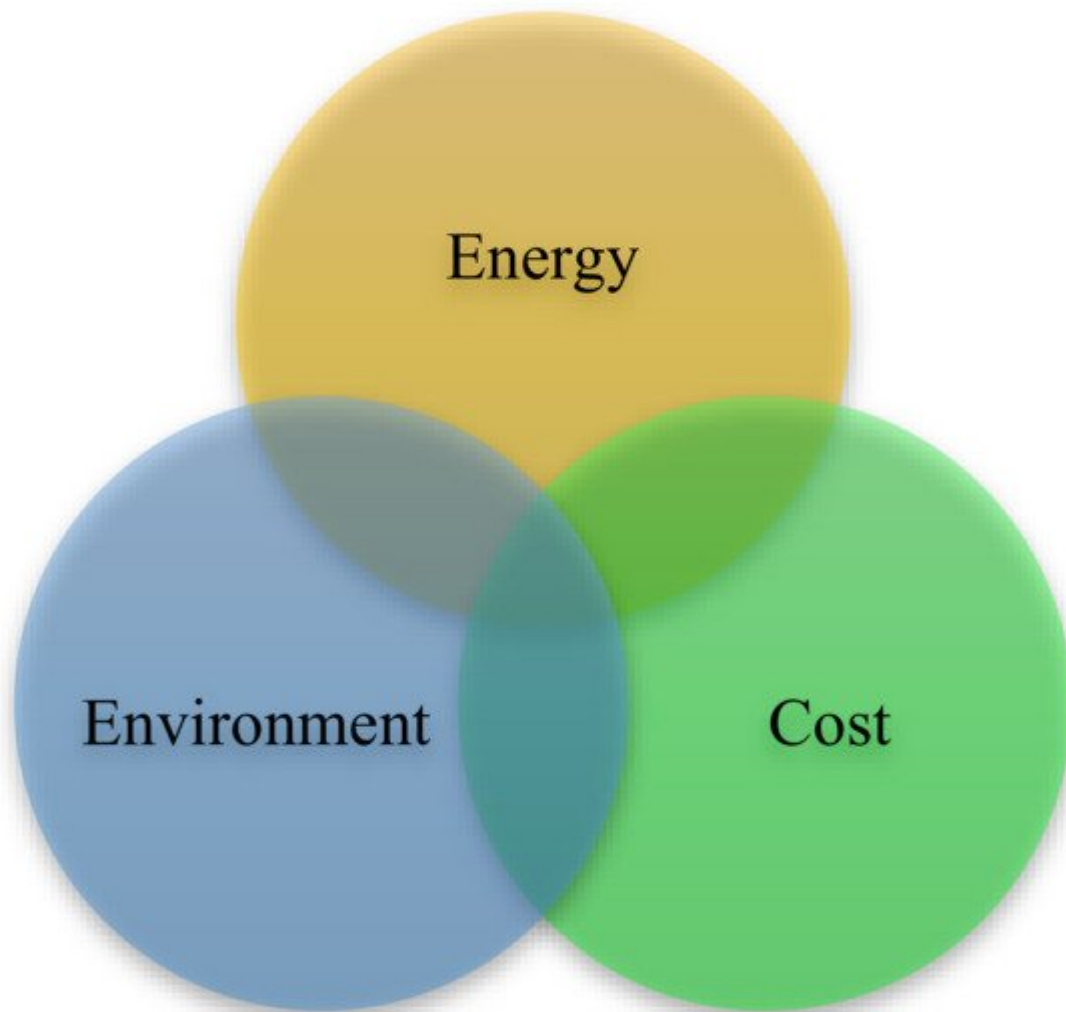


**Figure 3.** Top three issues in the port from 1996 to 2020 [23].

According to the top three priority issues highlighted in **Figure 5**, air quality has persisted as number one from 2013 to 2020 followed by energy consumption. The problem arises from the fact that air quality, noise, port waste, and climate change are strongly related to environmental concerns. This indicates that environmental issues are

big problems in the port sector and require immediate action. Without fast action, the emissions from maritime transportations are predicted to rise by 250% in 2050 from the amount released in 2012 [24]. Heavy utilization of fossil fuel in marine transportation and other areas contributes to serious air pollution from Carbon Dioxide (CO<sub>2</sub>) and greenhouse gas (GHG) emissions. This is because the fossil sources encompass hazardous contents, which in burning it will emit chemical and dangerous gases such as particulate matter (PM); CO<sub>2</sub>; sulphur dioxide (SO<sub>2</sub>); nitrogen oxides (NOx); and black carbon (BC) to the air [25]. Consequently, this emission results in acid rain and serious climate changes. It is also capable to reaching 400 km [26] of land and produces a negative effect on human health such as asthma, tuberculosis, impact on children's lung growth, cardiovascular disease, and lung cancer.

Meanwhile, ports' energy consumption has increased due to various reasons. Development and expanded port functionalities over time raise the energy demand from many facilities and loads with low and heavy consumption. Continuous heavy use of energy will cause fast energy resources depletion. The inequality between energy production and demand results in frequent unplanned power outages. Poor power quality, lack of energy monitoring, and old instruments are also among the factors that cause the high energy consumption problem resulting in additional energy **costs** in ports' daily operation. The need for improvement both in infrastructure and port power system will acquire a huge amount of investment. Lacking proper planning and a solid development framework will cause great losses. Based on these scenarios, three major issues related to seaports include energy, environment, and cost, as shown in **Figure 4**.



**Figure 4.** The three vital issues in the maritime sector.

Due to the serious environmental impacts caused by pollution from marine logistics, ports are moving toward a greener industry by implementing various alternatives. Particularly, in recent years, the arising awareness on environmental issues has made this target one of the compulsory goals in achieving high-energy efficiency levels. Authorities have formulated port policies consistently with tight regulation in order to ensure minimum GHG emissions. In this regard, the International Maritime Organization (IMO) in the latest regulation limits the sulfur content in fuel to 0.5% m/m, known as 'IMO 2020' [27]. The change in sulfur limitation from 2000 to 2020 is shown in **Table 3**. The five most important outcomes from IMO 2020 are as follows: (1) cleaner air, (2) higher quality fuel, (3) positive impact on human health, (4) ship operator role, and (5) changes for enforcement authorities.

**Table 3.** Change in fuel sulfur limit. Source: Marpol 2018, Marpol Annex VI.

Date	Sulfur Limit in Fuel (% m/m)	
	SO <sub>x</sub> ECA	Global
2000	1.5	4.5

Date	Sulfur Limit in Fuel (% m/m)	
	SO <sub>x</sub> ECA	Global
2010	1.0	3.5
2012		
2015	0.1	0.5
2020		

In line with the green port objective, the Port Authority of Genoa (GPA) is developing a plan integrating renewable energy in their marine sector known as the Port Energy Environmental Plan (PEEP). The ultimate goal of the PEEP is to reduce 20,000 t of CO<sub>2</sub> annually by utilizing 12 plug cold ironing facilities, wind turbines, and photovoltaic power stations with an overall investment of 60 million Euros [28].

In order to move towards a healthier environmental space, ports must plan and manage their operations and future potential expansion in a sustainable manner. Saeyeon Roh et al. [29] in their research stated that the majority of the existing literature's emphasis is on the environmental aspects for sustainable development, but they fail to clarify what factors influence this process. Several authors studied the causes that contribute towards air pollution and environmental damage from the operation of the harbors. Bunkering from the vessels generates the risk of oil spill with potentially disastrous impacts on the food chains of beaches [30]. Matishov and Selifonova [31] pointed out that the source of water resources damage comes from a high density of ship transportation via waterborne traffic. Meanwhile, Brigitte Behrends and Gerd Liebezeit [32] addressed that the two leading destructive factors generated by shipping movement are atmospheric and seawater contaminations. In an attempt to safeguard nature and waterways, new legislation for future growth of ports and their construction at both international and domestic levels are released from time to time, aiming to handle environmental issues based on strict standards for core ports' strategies. For instance, legislations in a few countries are listed in **Table 4** below [30];

**Table 4.** List of legislations in a few countries.

Country	Legislation
EU	Classification Societies—Regulation (EC) No 391/2009; Ship-Source Pollution—Directive 2000/59/EC; Marine Equipment—Directive 96/98/EC and Directive 2014/90/EU
Australia	Environmental Protection Act 1986 (WA)
New Zealand	Resource Management (Marine Pollution) Regulations
USA	Diesel Emission Reduction Act (DERA)
Singapore	Environmental Protection and Management Act (Cap.94A)

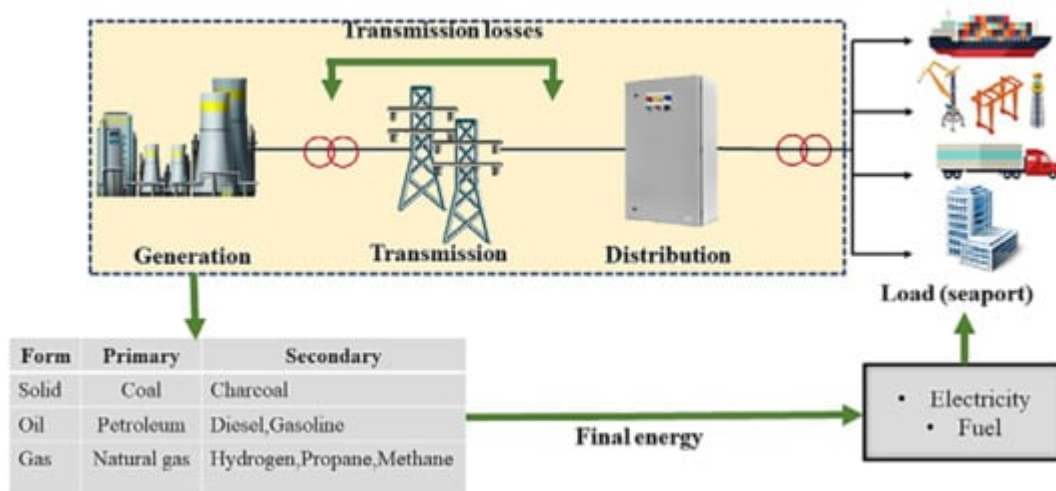


Without a doubt, all of these environmental legislations offer vast advantages in terms of health, clean air, economy, energy, and potential for new technology if they are properly considered in port planning. Nevertheless, the great challenge is that all the planning steps must be compatible with the rules, from the initial step of research and development, collecting real-time data, collaboration among the parties, implementing, monitoring, and analysis. All of these stages are time consuming and involve high capital investment where payback period analysis is necessary. Cost is one of the main drivers to run all strategic planning. Due to this risk, the relevant parties, especially the ports themselves, are reluctant to implement any environmental program.

## 3. Seaport Energy Revolution

### 3.1. Conventional System

In the beginning phases of the maritime system, there has been no concern for energy because it was solely utilized for shipping transportation. When the industrial revolution arrived, energy demand began to raise. Electricity and fuel are the two main forms of energy used in this sector. Depending on the availability and variation of the primary sources in a particular country, both electricity and fuel are produced from fossil-based sources (coal, oil, and natural gas). Electricity is not freely available in nature, so it must be produced by transforming primary energy to electricity through a process. **Figure 5** displays the entire power station network, from generation to the seaport.



**Figure 5.** The overall framework of the conventional structure.

In the 1880s, coal was first used to generate energy and became a fundamental driver of steamships [\[33\]](#). Coal is a combustible black rock that is formed over millions of years by the decay of land vegetation and generates energy under high pressure. Coal is convenient to use because it is easily combustible and cheap. Apart from electricity, another fundamental source of energy, particularly for maritime transportation, is fossil fuel, which contains hydrogen and carbon in its particles.

Previously, many vessels, particularly those with bunker fuel, used HFO to allow the ship's propeller or alternator to rotate. This can be accomplished by either burning fuel in the engine combustion chamber or producing steam in the boiler. Due to its relatively higher density and lower cost, HFO is a preferable marine fuel source. HFO is characterized by its heavy molecules containing long-chain hydrocarbons, density greater than 900 kg/m<sup>3</sup> at 15 °C, and kinematic viscosity greater than 180 mm<sup>2</sup>/s at 50 °C [34]. The HFO comes in three varieties, which are listed in **Table 5**.

**Table 5.** Three variants of HFO and their sulfur content [27].

No	Variant	Sulfur Content
1	High Sulfur Fuel Oil (HSFO)	3.5%
2	Low Sulfur Fuel Oil (LSFO)	1.0%
3	Ultra-Low Sulfur Fuel Oil (ULSO)	0.1%

Sulfur content is a key differentiator between these three types of HFO. However, from 1 January 2020, HFO can only be used by vessels equipped with exhaust gas cleaning systems (EGCS), and IMO has set new regulations banning vessels from using fuels that have sulfur substances above 0.5% [27]. Due to the tight prohibitions, HSFO and LSFO are no longer practical options for marine transport. The only choice to comply with this limit is ULSO, which has a sulfur content of 0.1%. Unfortunately, the desulfurization process of HFO requires very high costs and is not economical anymore.

Even though electricity and fuel are greatly used in the seaport sector since their early stages of development, due to the arising issues, there is a great interest in alternative solutions. This alternative includes considering electrification of vehicles, cold ironing systems, alternative fuels (i.e., LNG, biofuels, methanol, hydrogen, and low-sulfur fuels), and implementation of both renewable energy and energy storage by implementing microgrid power systems.

### 3.2. Ports and Ships Electrification

From the seaport perspective, electrification can be viewed as the replacement of fossil fuel-based energy with new advanced technologies through the use of electricity. Marine transportation contributes significantly to air pollution and climate change mainly for two reasons: (1) The port is the area where emission sources are least regulated and (2) high reliance on fossil fuels. With the increasing number of ships, the ports' energy management is required to provide sufficient power to supply the ship during berthing. Large ships have a power range between 1 MW and 6 MW [35]. While the main engines are normally switched off during berthing, the vessel's auxiliary engines are switched on to supply power to all loads inside the vessel such as lighting, ventilation, cooling, and other onboard equipment. A study on different types of vessels in Reference [14] shows that the average berthing time per vessel is between 21 and 52 h. Burning diesel oil during berthing for such a long time injects severe GHG emission.

In order to resolve this problem, shore-side electricity practice known as cold ironing is introduced to mitigate undesirable environmental impacts at seaports. Employment of this technique allows a ship to shut off its auxiliary engines when docking, and it receives electricity supplies from the shore to maintain the entire load in the ship. It provides substantial advantages by reducing the dependency on fossil fuels and lessening GHG emissions. The energy required for cold ironing can be supplied directly from the utility grid, RESs, and ESS. Alexander Innes and Jason Manios [\[36\]](#) in their article highlighted a few ports around the world that already utilized cold ironing. Despite the promising benefits of a cold ironing system, many ports, particularly small ports, do not install it due to a few constraints. In order to overcome this, alternative power sources are formed by using shipboard microgrid (SMG), where this method acts as mobile cold ironing facilities by sharing power from multiple ships in the port [\[12\]](#)[\[37\]](#). Another innovative solution with the same concept is known as vehicle-to-grid (V2G) and boat-to-grid (B2G) paradigms [\[38\]](#)[\[39\]](#)[\[40\]](#).

However, with the high energy requirement for the entire port operation, reliance on power from the grid alone is not enough. Thus, the port industry has started to explore clean energy resources including renewable energy. A few ports even built their renewable energy power plant. Currently, Jurong Port is the world's largest port that has installed a solar power generation facility, which is estimated to generate more than 12 mil kWh of solar energy per year and covers 60% of the port power demand [\[41\]](#). In addition, it also does help to reduce 5200 tones carbon emissions in a year. Meanwhile, Aalborg Port, Denmark, not only constructed solar cell systems with an annual production of 80,000 kWh but also included a 2 MW wind turbine in the plan [\[42\]](#).

By utilizing multiple RESs and paying attention to the need for a storage solution, smart technologies such as a microgrid system, are being introduced. Microgrid's alternative is great at solving power supply problems, and it has been gaining more attention lately. The interest in microgrids is increasing due to their promising advantages in providing sustainable, reliable, efficient, and environmentally friendly power supply [\[43\]](#). Market acceptability of microgrid technologies due to their reliability and cost-efficient power supply makes them a practical and effective solution in power delivery. Although microgrids have been widely developed around the world, their application in harbor areas remained limited. Due to this situation, the development of a microgrid in a port presents significant challenges. Diversity of loads in the seaports (cranes, ship, container, cold ironing, building, etc.) induces difficulties in load forecasting and accurate measurements of power requirement. In order to avoid prohibitive costs and inefficient systems, a comprehensive study on ports microgrids planning, energy management, regulation, and other aspects is required.

Along with the industrial developments and innovations in power systems, ship transportation is also emerging toward the All-Electric Ship (AES) concept [\[44\]](#)[\[45\]](#). Conventionally, ships used a steam turbine as a prime mover, but it switched to steam piston engines in 1850 [\[46\]](#). The ship's electrification began with an IPS that uses electric propulsion. It gradually evolved into a hybrid power system (HPS) by incorporating energy storage elements. S. fang et al. [\[47\]](#) in their research study modeled the next version of AES by using photovoltaic sources. The goal is to provide better energy production through a hybrid concept that combines diesel generation with renewable sources.

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