Future Greener Seaports

A Review of New Infrastructure, Challenges, and Energy Efficiency Measures

Sadiq, Muhammad; Ali, Syed Wajahat; Terriche, Yacine; Mutarraf, Muhammad Umair; Hassan, Mustafa Alrayah; Hamid, Khalid; Ali, Zulfiqar; Sze, Jia Yin; Su, Chun Lien; Guerrero, Josep M.

Published in:
IEEE Access

DOI (link to publication from Publisher):
10.1109/ACCESS.2021.3081430

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Sadiq, M., Ali, S. W., Terriche, Y., Mutarraf, M. U., Hassan, M. A., Hamid, K., Ali, Z., Sze, J. Y., Su, C. L., & Guerrero, J. M. (2021). Future Greener Seaports: A Review of New Infrastructure, Challenges, and Energy Efficiency Measures. *IEEE Access*, *9*, 75568-75587. Article 9433559. https://doi.org/10.1109/ACCESS.2021.3081430

Received April 29, 2021, accepted May 10, 2021, date of publication May 17, 2021, date of current version May 27, 2021.

Digital Object Identifier 10.1109/ACCESS.2021.3081430

Future Greener Seaports: A Review of New Infrastructure, Challenges, and Energy Efficiency Measures

MUHAMMAD SADIQ[1], SYED WAJAHAT ALI[1], YACINE TERRICHE[2], MUHAMMAD UMAIR MUTARRAF[2], MUSTAFA ALRAYAH HASSAN[1], (Member, IEEE), KHALID HAMID[3], ZULFIQAR ALI[1], JIA YIN SZE[4], CHUN-LIEN SU[1], (Senior Member, IEEE), AND JOSEP M. GUERRERO[2], (Fellow, IEEE)

[1]Department of Electrical Engineering, National Kaohsiung University of Science and Technology, Kaohsiung City 807618, Taiwan
[2]Center for Research on Microgrids, Department of Energy Technology, Aalborg University, 9220 Aalborg, Denmark
[3]Department of Mechanical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan
[4]Maritime Energy and Sustainable Development Centre of Excellence, Nanyang Technology University, Singapore 639798

Corresponding author: Chun-Lien Su (cls@nkust.edu.tw)

This work was funded in part by the Ministry of Science and Technology of Taiwan under Grant MOST 107-2221-E-992-073-MY3.

ABSTRACT Recently, the application of renewable energy sources (RESs) for power distribution systems is growing immensely. This advancement brings several advantages, such as energy sustainability and reliability, easier maintenance, cost-effective energy sources, and ecofriendly. The application of RESs in maritime systems such as port microgrids massively improves energy efficiency and reduces the utilization of fossil fuels, which is a serious threat to the environment. Accordingly, ports are receiving several initiatives to improve their energy efficiency by deploying different types of RESs based on the power electronic converters. This paper conducts a systematic review to provide cutting-edge state-of-the-art on the modern electrification and infrastructure of seaports taking into account some challenges such as the environmental aspects, energy efficiency enhancement, renewable energy integration, and legislative and regulatory requirements. Moreover, the technological methods, including electrifications, digitalization, onshore power supply applications, and energy storage systems of ports, are addressed. Furthermore, details of some operational strategies such as energy-aware operations and peak-shaving are delivered. Besides, the infrastructure scheme to enhance the energy efficiency of modern ports, including port microgrids and seaport smart microgrids are delivered. Finally, the applications of nascent technologies in seaports are presented.

INDEX TERMS Digitalization, energy efficiency, Internet of Things, smart energy management, port microgrids, green/smart ports.

I. INTRODUCTION

Maritime transport has become the backbone of global trade, as more than four-fifths of the world's merchandise trade by volume is carried out by the sea. Therefore, the energy demand for maritime shipping, including port has increased by 2.6% per year on average between 2016-2019 [1]. This increased energy demand results in higher energy costs, increase greenhouse gas (GHG) emissions and other pollutants. According to the 4th International Maritime Organization (IMO) GHG study, the share of the shipping sector in air emission has increased from 2.76% in 2012 to 2.89% in 2018 [2] and it is expected to increase significantly. Furthermore, higher energy costs are a substantial burden for the ports, so controlling the energy demand or increasing the trade would be very beneficial to reduce transportation costs. Similarly, the development of green ports leads to a decrease in harmful gas emissions and increases efficiency [3]. In every sense, the concept of energy efficiency means a method to minimize energy consumption to attain the same amount of useful power. It is the main focus of port authorities that significant energy saving could be achieved

The associate editor coordinating the review of this manuscript and approving it for publication was Peter Palensky.

through the validation and adoption of policies, technological measures, and the integration of renewable energy sources (RESs) [4].

Role of ports to tackle climate change has received significant attention due to increased pressure from international (e.g. air quality mitigation) and regional regulations (e.g. EU, energy efficiency directive/2012) to improve environmental credibility [5], [6]. In this regard, different mitigation solutions are proposed, such as switching to cleaner fuel, replacing the older equipment with a new version, and restricting trucks' idle hours [7]. Meanwhile, the energy efficiency was ranked 3rd in the top ten environmental priorities endorsed by the European Council in the EU maritime sector in 2020 [8]. Additionally, international organizations such as IMO, the World Port Climate Initiative (WPCI), the International Association of Ports and Harbors (IAPH), the Associations of Waterborne, and Transport Infrastructure (PIANC) [9]–[12] have put pressure on the maritime sector to increase energy efficiency [13]. Besides, there is a significant positive relationship between the operational and energy efficiencies of the port. Therefore, the increased operational efficiency resources (e.g., berth, equipment) will shrink energy utilization that leads to energy efficiency [14]. In addition, port energy efficiency is immensely influenced by technological advancements such as electrification, digitalization, onshore power supply (OPS), converters, batteries, ultra-capacitors, flywheels, and the application of smart energy management systems [15].

In literature, ports have been evolved over five phases [16]. The first phase served as a nodal point of land and sea transportation provided with basic operations such as logistics, fishing, cruise, and rescue operations [17]. The second phase deployed basic equipment and infrastructure to reduce the dependency on the workforce. The third phase served as a cargo handling service provider equipped with warehouses, packaging, and distribution facilities [18]. The fourth phase ports are physically separated but linked through a common administration as a networked port [19]. The fifth or current phase is known as the customer and community-oriented modern port, which is distinguished by some main features [20]. Modern ports are more competitive and attractive. They are reinforced properly with enabling technologies such as Internet of Things (IoT), Radio-frequency identification (RFID), cloud, and fog computing, robots, other technological solutions, that allows ports to become more competitive in term of flow, customer management, and mitigation of environmental impacts. These ports can cope with the challenges of the previous generation's ports more effectively [21].

There are several reviews in the literature regarding seaport energy management, energy efficiency, sustainability and smart electrification [20], [22]–[26], however, some important aspects such as environmental and energy-related challenges, technological methods, operational strategies, the infrastructure of modern ports, and use of nascent technologies such as IoT are not taken into consideration collectively. This paper, therefore, takes into account from conventional ports to greener ports and fills the existing research gap in challenges, energy efficiency measures, infrastructure, and the applications of nascent technologies for smarter and efficient ports. This paper aims to investigate the recent development in these areas and provide the reader with a systematic review. The rest of the paper is organized as follows: In section II, challenges for modern ports are discussed, followed by an explanation of techniques, energy efficiency, and operational measures in section III. In section IV, the infrastructure of modern ports such as port microgrid, smart port microgrid, and charging stations are explained. In section V, applications of nascent technologies in seaport are detailed. Finally, section VI concludes the review.

II. CHALLENGES

Ports are facing unique challenges of environmental, energy efficiency enhancement, renewable energy integration, regulatory and legislative policies, power and grid stability, Infrastructure complexity, and increased energy demand [27]. The key challenges of ports are described as follows.

A. ENVIRONMENTAL

The ports are facing crucial environmental challenges such as CO_2 emission, air pollutions, noise, vessel congestions, and waste [28]. As maritime industry is responsible for producing 2.2%,15%, and 6% of CO_2, nitrogen oxides (NO_x), and sulfur oxides (SO_x), respectively [29]. In order to tackle the issue of global climate change, it is essential to implement environmental measures and control the external effects of port activities to make the ports image green. There are many regional and international studies to address the port's climate change [30]. The regional studies include, green effect project, EU project, and European Sea Ports Organization and the international studies include IMO, WPCI, PIANC, and IAPH [9]–[12]. To address these concerns, many ports of the world are taking serious initiatives to overcome the adverse effect of GHG emissions. For this, the Port of Tianjin and Shanghai have amended their laws to install OPS at all new terminals [29]. Similarly, the port Hamburg, port of Helsinki, and port of Antwerp are also taking strict actions to reduce the environmental impacts of ports. For instance, the Hamburg authorities have decided to reduce CO2 emission by expanding renewable energy and phasing out coal energy sources [31]. Also, the port of Helsinki has committed 100% carbon-free with the central efforts of energy efficiency and renewable energy by the implementation of the Carbon-neutral Helsinki Action Plan 2035 [32]. Remarkably the port has also decided to minimize the port energy consumption by modernizing the heating system, installation of LED lights and solar system in the port area till 2035 [32]. Similarly, the port of Antwerp has ordered for the construction of methanol and hydrogen-powered tugboat to reduce air emissions with in the port. These tugboats will be operational by the end of 2021 [33].

Likewise, the port of Singapore has offered 25% fee discounts for vessels that are using alternative technology for the reduction of GHG emissions [34]. Noticeably, Singapore's port authority has also invested a huge amount of money, nearly 70 million USD, for greening the ports and related technologies. The European Union (EU) is also taking stringent actions to reduce the GHG emission from the ports, particularly during the ship hoteling process. The European ports have declared a deadline for the implementation of OPS until 2025 and offered 20-50% subsidies for OPS's performance [25]. Besides, the ports of Vancouver, Seattle, Tacoma have also decided to reduce 75% of diesel generators [35]. The Baltic seaports such as Stockholm, Tallinn, Turku have signed a memorandum of understanding for the implementation of OPS for ship by following agreements [36]:

- All mentioned ports should provide new connections with a voltage of 11 kV and 50 Hz frequency.
- All ports of the Baltic Sea need to find ways to lessen the adverse environmental impacts of ports.
- All signed Baltic region ports will encourage the other shipping companies and ports to deliver and follow the same specifications.

From the other perspective, the continuous noise from diesel-powered auxiliary engines is considered a risk for human health. As auxiliary engines used for docked ship energy are considered the primary source of noise at the port. The port of Helsinki has taken adaptive measures with special consideration regarding noise by ordering the vessels not to use auxiliary engines for electricity generations during moored [37]. On the other hand, the world's ports are also challenging with the issues of vessel congestions that often happened due to mismanagement in port handling equipment [38]. In the meantime, the Scandinavian ports are focusing on sewage waste, especially from cruise ships [29]. Solid waste produced from ports activities (ship, cargos, and cruise) create problems that need legal requirements and proactive initiative. For example, Brazilian ports follow specific rules for solid waste management, which are issued by government organizations (such as National Waterway Transport Agency, the National Environmental Council, and National Sanitary Surveillance Agency) [39]. To tackle these mentioned challenges, some important technological methods are discussed in section III (B).

B. ENERGY EFFICIENCY ENHANCEMENT

Ports are large users of energy, including electricity and diesel fuel [29]. It is essential for the ports to manage their energy usage. There is an upward trend toward the electrification of port infrastructure, which increases the degree of automation, improves energy efficiency, reduces energy costs and GHG emission [40]. The process of port electrification means a higher electricity demand is required by port operations to fill the energy gap left by diesel engines. This increased electricity demand may or may not met by the local grid or other microgrids, and that the current substations need to be upgraded, resulting in increased power generation. These users require an energy management system and agile power infrastructure. The energy management system should be considered in its entirety. The energy efficiency of ports includes operational and technical measures to reduce energy utilization and increase the use of renewable energy, thus reducing the GHG emissions, which are directly proportional to the amount of fuel combustion [41]. The seaport energy consumption is parted between necessary and wasted energy. Hence the wasted energy should be minimized. The energy efficiency was ranked 3rd after air pollutants and climate change in the EU environmental priorities in 2020 [8]. Under the development of modern ports, the following challenges related to energy efficiency enhancement are being considered [42]:

- Secure and resilient energy supply;
- Deploying modern communication system;
- CO_2 saving environmental requirements;
- Grid stability and power quality issues;
- Maintaining energy costs.

These challenges for modern ports could be solved by deploying RESs, and proper implementation of modern communications systems such as IoT, Big data, etc. Energy resiliency can be built through decentralized networks and integrated power systems. Integrated power system technologies should be regarded to ensure that technology and data are linked, and the results are resilient, cost-effective, and guaranteed.

C. RENEWABLE ENERGY INTEGRATION

The energy for port operations could be obtained from different sources such as renewable energy sources, clean fuels, or it can also be connected with the utility grid. Sometimes energy can be produced within the port area. Due to increased global energy demand, the use of traditional energy sources such as fossil fuels is creating environmental issues. In contrast to conventional energy sources, the integration of renewable energy resources such as photovoltaic and wind power is a challenge for grid management due to the fluctuated power supply. In the meantime, it is growing faster due to its positive environmental impacts and economic feasibility [43]. Renewable energy is produced from replenished natural resources, such as wind, solar lights, hydro, geothermal heat, and biomass energy [3]. One of the main challenges of renewable energy integration is the low inertia of the system. This occurs when the grid of the seaport is not connected to the stiff grid with the large capacity of synchronous generators. The low inertia is the main cause of grid instability. Several methods are introduced in the literature to tackle this issue by modifying the feedback control system such as virtual inertia control, Virtual impedance control, etc [44]. The second challenge is related to the over-generation periods when the energy generated by PVs or wind turbine is greater than the demand of the seaport. This leads to disconnections of fuel-based generators and storing excess energy in the storage system [45]. It plays a vital role in ports because most RESs are located near the ports, especially for wind turbines (e.g., Kitakyushu, Rotterdam in Japan), Waves (e.g., Port of Kembla in Australia) [46]. Besides, solar panels can be installed on the roof of warehouses in the port area. Some examples can be found in the OHI terminal Tokyo and administration buildings of the San Diego port. Still, these types of infrastructure might not be suitable for large-scale solar energy exploitation [47], [48]. In [49], the integration of solar panels, wind turbines, and energy storage systems is briefly described. The benefits of integrated energy include [50]:

- Decreased project development cost;
- Better utilization of land;
- Transmission evacuation cost-saving;
- Operation and maintenance costs sharing and
- Complementary energy generation profile.

In [51], the applications of renewable energy in Damietta port have been studied. This study suggested that the use of renewable energy, such as offshore wind and hydrogen fuel cell energy sources, is very cost-effective when compared with conventional energy. A study [52] mentioned that solar PV leasing players in Singapore have demonstrated the feasibility and future potential in ports, for example, the Jurong port of Singapore. A similar analysis shows that the Hamburg port has installed PV on the roof-tops of the big warehouses owned by the Hamburg port authority. In Germany, the government has declared some major projects of renewable energies for their port feasibility. To achieve this, the government has invested 18.9 billion euros in building renewable energy sources, particularly onshore and offshore wind energy sources, to satisfy the ports' energy demand [53].

Wind energy has been implemented successfully in the ports of Hamburg, Zeebrugge, Rotterdam, Venice, and Kitayjush, while the port of Genoa is planning to use wind energy for the reduction of a considerable amount of CO_2 in the near future. Likewise, solar energy is being applied for the heating of water at the port of Hamburg offices [24]. It is also a plan in the different ports such as Rijeka, Antwerp, Venice, Genoa, Tokyo, and San Diego [24] as the world power climate initiative is promoting liquefied natural gas (LNG) in the maritime industry; hence, the ports are gradually orienting towards LNG. The provision of LNG in the harbor area will be a source of the natural development of ports as its trade already take place there. However, it still has many challenges of infrastructure, distribution as well as bunkering location optimization. Meanwhile, the use of LNG is very beneficial for the port area as it will help considerably in the reduction of SO2, NOx, and PM [54], [55]. And the use of biofuels in the harbor area is also studied in [56] and [57]. Table 1 highlights some important practical challenges in the ports.

TABLE 1. Practical challenges in seaports.

Challenges	Description [58]–[60]
Carbon footprints	GHG emissions are one of the most challenging issues for global ports. Many ports around the world are trying to mitigate carbon footprints. The Marseille Fos Port has proposed a prototype of an "eco-calculator" for quantifying GHG emissions of each transiting container. Similarly, the port of Antwerp introduced a hydrogen-powered tugboat as a part of efforts to become carbon neutral. Hydrotug boat uses a dual-fuel hybrid engine, which mainly runs on hydrogen, which leads to reduce CO2 emission around the port.
Renewable energy integration	World seaports are minimizing dependence on fossil fuels and focusing on the use of renewable energy sources. For this achievement, they are trying to ease the renewable energy integration with an energy storage system without upgrading the existing system.
Energy storage capacity	Energy storage systems have a crucial role, especially during power outages as, during the transition between grid and generators, all data centers are temporarily powered by energy storage systems. Consequently, the ports are focusing on a low-cost monitoring solution for an ESS that alert when the battery needs changing in case any problem occurs. This solution can limit the batteries changing as well as secure the services.
Ports orientation	Port orientations are also a challenge for modern ports due to increased fleet sizes. Problems come from the mix of traffic, including public transit and tourist vehicles. This challenge will be addressed with the help of new digital solutions such as apps and digital signs, especially for cruises and passenger ferries.
Trailer collection	Many ports have developed a (Radio-frequency identification) RFID system to help truck drivers to locate the dock by using their smartphones. There is a challenge to interface the run management system with the RFID tag displayed on the trailer; the purpose behind this service is to expedite the traffic flow in the port area.
Container flow	Shipping companies are also facing the challenges of container flow due to increased port congestion, and trucks stand still in case of any problem in port cranes. CMA CGM shipping company is working to optimize the container flow with the help of real-time data analytics to improve the supply chain.

D. REGULATORY AND LEGISLATIVE

The environmental effectiveness of ports largely depends on the various regulatory policies adopted by port authorities [23]. Different ports may follow different regulations by considering local, geographical, economic, and political backgrounds. The four world-leading ports, Rotterdam, Antwerp, Shanghai, and Singapore, have adapted pricing, monitoring, and measuring policies to make their territory environmentally green. Pricing policy is divided into incentive and penalty pricing [61]. Motivating or giving an incentive pricing to the good-doers and giving a penalty to the wrongdoers is observed in all above-mentioned ports as an effective tool to promote the environmental performance in the maritime sector. Similarly, monitoring and measuring air and water quality is a very common tool being used in all ports. A carbon footprint monitoring project has been developed in Singapore port to determine the base line year, collect and track emission data over time [62]. Likewise, World Port Climate Action Plan is an international initiative by a group of world-leading ports to tackle the emission challenges in the port sector. These ports include Port of Long Beach, Port of Los Angeles, Port of Antwerp, Port of Rotterdam, Port of Hamburg, Port of Barcelona, Port of New Jersey & New York, Port of Amsterdam, Port of Gothenburg, and Port of Le Havre [63]. In addition, the Port of Los Angeles has developed an energy management action plan to improve energy efficiency [64], [65].

The ISO-50001 was introduced in 2011 as an effective and efficient tool for the achievement of energy reduction goals. It follows the Conventional Plan-Do-Check-Act (PDCA) in the following ways [25]:

- The baseline is set by reviewing the energy audit. Following audit results, the overall strategy such as energy-saving targets, performance indicators, and action plan is set (Plan).
- Selected measures, either operational or technological ones, which have been incorporated into the action Port of Los Angeles to Develop Energy Management Action plan, are being implemented next (Do).
- The processes and operations that are being monitored and affecting the performance of formulated energy policies and reduction targets(Check).
- Based on the strategic decisions and results that ensure continuous improvement of energy performance and enhancing energy management systems(Act).

A systematic, fact-based, data-driven process is required to implement ISO-50001 for continuous energy efficiency improvement. A high level of commitment and resources needed for the certification of ISO 50001. In [66], [67], the port of Felixstowe and port of Antwerp has implemented the ISO-50001 in the years 2013 and 2015, respectively. Only a few other large ports such as Valencia and Hamburg have followed since then [68].

EN-16001 and ISO-50001 are considered an alternative to each other. EN-16001 has been introduced a few years earlier, in 2009, often called the predecessor of IS-50001. These two common shares many similarities, such as PDCA, but also have some distinct features. For example, ISO-50001 has introduced three new concepts; the first concept is related to the fundamental role of top management, which is responsible for defining the energy policies, objectives to be achieved, setting operational functions, and allocations of available resources. So for the help of top management, and energy management team must establish according to ISO-50001. The second concept is related to the Plan phase, which emphasized more energy reviews for a solid baseline, which allows energy performance monitoring. This concept is relating to the Do phase, where ISO-50001 emphasizes the design processes by implementing technological and operational measures. However, EN-16001 has some different aspects that are not included in ISO-50001:

- The priority scales of energy aspects facilitating the identifications of those requiring a more thorough examination.
- Identifying the company's workforce, which may have more energy consumption behavior.
- Cost reduction aspect relating to potential up-gradation for energy consumption reduction in their entity.

III. TECHNIQUES AND ENERGY EFFICIENCY MEASURES

In this section, control techniques and different technological and operational measures about energy efficiency have been detailed.

A. CONTROL TECHNIQUES

Numerous energy management techniques have been reported in the literature, such as Multi-agent systems (MAS), integrated power supply systems, power factor correction, etc. In this paper, the authors focused on MAS and integrated power supply concepts for efficient implementation of energy management in ports.

1) MULTI-AGENT SYSTEM BASED ENERGY CONTROL

The concept of port energy demand control with multi-agent systems is shown in Fig. 1. The time sequence and communication signal exchanged by the agents are also shown in the same figure. The port agents are categorized into three major types [69]: local agents that are responsible for representing single component power system, cluster agents that are responsible for representing aggregate responses of clusters and send signals to local agents, and the aggregation agents that are responsible for aggregating the reactions they receive from the clusters supervised by them. The operations of each type of agent are briefly explained:

Port Manager Agent (PM/A) is placed in the higher hierarchy level of control. It receives aggregated energy responses from local and cluster agents [70]. PM/A is responsible for supplying the energy demand of all port activities as well as appropriate shifting of power utilization in non-peak hours [71]. The PM/A collects forecasted energy demand from all cluster agents and calculates new optimized electricity prices according to the port loads profile. Following this strategy, the port manager agent provokes adoptable port energy loads by shifting their energy demand in low pricing periods and to accomplish peak-shaving during high energy demand periods [70]. The shore power supply agents (SPS/A), PEVs Aggregation Agents (PEV/A), and Reefer Aggregation Agents (RA/A) are located just one level below the PM/A in the hierarchical structure. They provide communication services by aggregating flexibility-change of power demand curves they receive from all clusters of PEVs and Reefers they supervise. Furthermore, they also forward the marginal flexibility received from PM/A to all cluster agents. Reefer Area (R/A) and Plugged-in Electric Vehicle Agent (PEV/A) are responsible for modeling the operations they have control of. They estimate the flexibility of reefers and PEVs to change their power demand according to the needs of the port. The calculated flexibility and the respective change of power demand are then sent to the CPEV/As and CR/As. A cluster of Plugged-in Agents (CPEV/A) and Cluster of Reefer Agent (CR) are located just above the agents assigned to each PEV and reefer. These clusters are generally located at medium and low voltage transformers and exclusively supplies clusters of PEV's and reefers. The typical functions of agents include to aggregate demand response of PEVs, and reefers and forward it upstream relevant agents. Also, CPEV/A and CR/A forward pricing strategy obtained by PM/A to each supervised PEVs, and reefers, respectively. In addition, limitations signals transmitted from specific cluster agents, in case of technical violations,

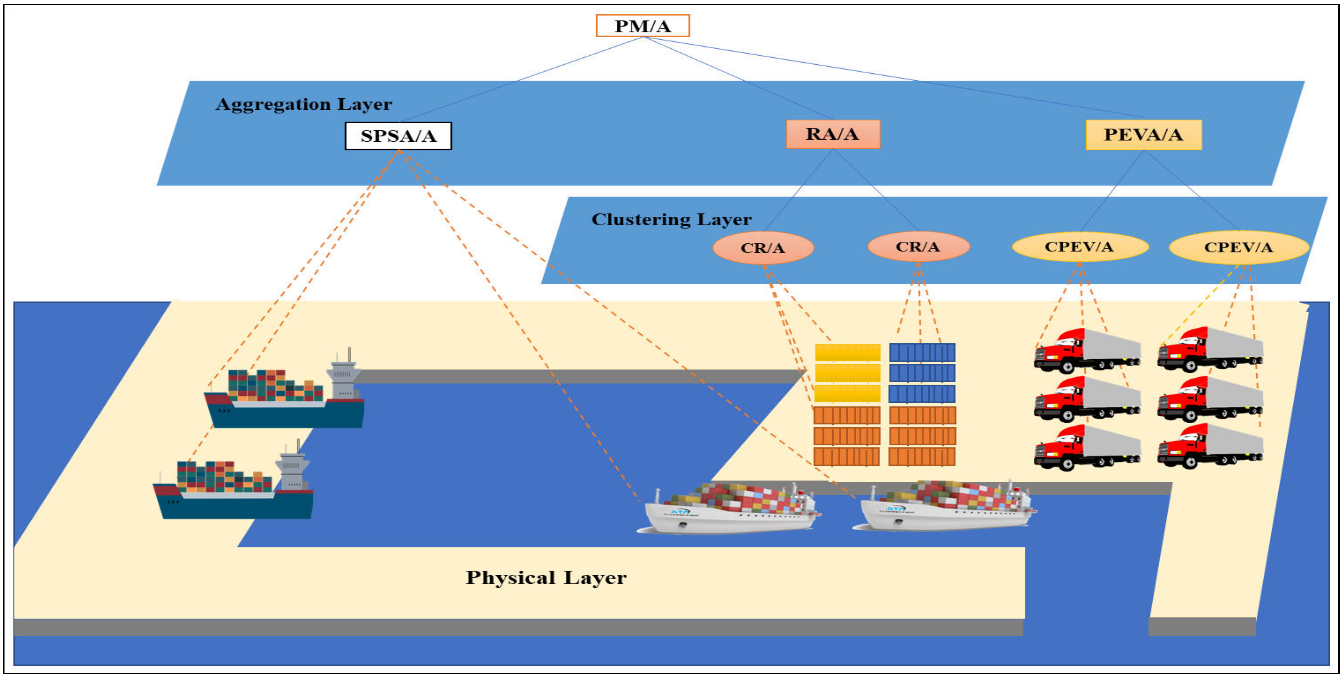

FIGURE 1. Concept of a hierarchical structure of MAS based real-time control system for large ports [69].

e.g. (Supplied power exceeds nominal transformer power) [70]. The concept of MAS has been applied for the optimization of electric vehicle charging station location in Valencia (Spain) [72].

2) INTEGRATED POWER SUPPLY CONCEPT

The complexities and power requirements of modern ports have increased with the growth in the number of equipment. Integrated power from Maxim integrated and Siemens ensures reliable, efficient, intelligent, eco-friendly, and safe power supply to ports. It offers the key benefits of operation management and integrated digital monitoring by selecting extensive software. This concept also provides several key advantages, such as [73]:

- Transparency in internal billing, systematic efficiency improvements, and predictive asset management;
- Flexibility for increasing electrification, new power integration, e-mobility cargo handling, and intelligent reefer management;
- Optimized power quality with the help of load management and optimal voltage & frequency conditions of operations;
- Reduced CO2 emission with increased systematic energy efficiency.

Its hardware ranges from low-voltage circuit breakers to land connection systems and entire microgrids. Recently, the concept of integrated power applied in the port of Nacala-a- Velha in Mozambique for a more reliable and efficient power supply is introduced in [29].

B. TECHNOLOGICAL METHODS

Due to technological advancements in power generation and distribution systems, different new eco-friendly technologies have been installed to replace diesel generators and enhance energy efficiency. Hence, these technical advancements lead to a decrease in GHG emissions and other particle pollutants. These advancements include electrifications, digitalization, onshore power supply, and energy storage systems [4].

1) ELECTRIFICATION

There are two main areas in the port for loading and unloading, specifically quayside and landside, where different types of cargo handling equipment are being used for other port operations [74]. In the quayside, mostly ship-to-shore (STS) cranes and quay cranes (QCs) are used for handling the containers. While the landside/yard side has varieties of equipment based on the port structure [75]. Some types of equipment such as rail-mounted gantry (RMG), rubber-tired gantry (RTG), automated guided vehicles (AGVs), and yard tractors (YTs) are being operated for the port's handling purpose. Mostly, YTs and AVGs are used for horizontal transportations of containers, while RMGs and RTGs are used for the stacking of containers [76]. In [74], the author has studied the environmental performance and energy efficiency analysis of four cargo handling equipment such as electric tire, tire transtainers, rail, and automatic rail in the port of Kaohsiung in Taiwan. According to this study, the author revealed that tire transtainers and automatic rail have lesser GHG emissions with high energy efficiency. In some cases, QCs are fitted with shuttles to overcome handling time. These unique designs of QCs have flexibility and high capacity as compared to conventional QCs. In horizontal port operations, AGVs have become more efficient, safe, and reliable. AGVs can be battery-powered, diesel-powered, and/or hybrid. It is suggested that to use B-AVGs by charging the

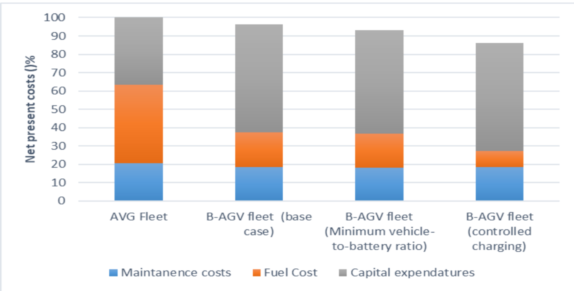

FIGURE 2. Net present costs, including fuel costs, by AGVs [77].

FIGURE 3. Terminal automation with digital technologies.

battery in off-peak hours. Fig. 2 depicts the components of the net present value of AGV and variants of B-AGVs, where the results show that B-AGVs are more profitable than AGVs [77]. Generally, YCs are classified into RMG and RTG cranes. RTGs are manual with free movement, while RMGs can be both automated or manual. RMGs are also called automated stacking Cranes [78]. A comparative study by [79] between RTGs and E-RTGs, to analyze the energy-saving and GHG emissions. This study revealed that E-RTG cranes are much better than conventional RTGs, offering 86.60%, 67.79% energy savings, and GHG emissions, respectively. Furthermore, E-RTG cranes have 30% less maintenance and repair costs as compared to conventional diesel-driven RTGs.

2) DIGITALIZATION

Nowadays, various types of automated vehicles are being integrated into the existing systems by implementing digital technologies. These equipment include AGVs, IAVs, and QCs. The integration of AGVs in the existing systems has numerous benefits, including increased productivity, reduced energy consumptions, labor costs saving, and environmental and human health safety [80]. The role of digital technologies in smart port is crucial to bridge the challenges such as port congestion, and orientation which are associated due to the increased number of ships, vehicles, and other equipment in ports. Digital solutions can identify, monitor, and aggregate the required data to support the environmental and operational efficiency of ports.

These advanced digital technologies such as remote sensors and big data analytics help to reduce the CO_2 emissions, cost of operations, chances of system failures, and also helpful to information security, warehouse, and smart energy management as depicted in Fig 3. Furthermore, digital technologies, e.g., IoT, helps to monitor logistic operations and fuel utilization in the smart port [81]. Electronic data exchange is used for the proper facilitation of communications between shipping lines and port terminals.

The port of Rotterdam uses IoT for repair and maintenance, Hamburg uses 3D printing applications, the port of Singapore uses cloud computing and big data, Antwerp employs blockchains, and while the port of Los Angeles has offered digitalized information for all maritime sectors [82], [83]. A study was carried out by [84] regarding the green performance of intelligent autonomous vehicles. It is a new type of automated guided vehicle with some better features such as the ability to pick up/drop off automatically, maneuvering flexibility in 180-degree directions, no need for any fixed track, embedded with sensor technology to detect moving and static obstacles around. A relevant study by [85] and [86] found that automated lifting vehicles are more environmentally friendly than AGVs. In [87], the automation developed in QCs is discussed. These computerized QCs are equipped with two trolleys and can handle two or more twenty-foot equivalent units simultaneously. Many other digital technologies, e.g., robots and drones for warehouse management, are being aligned in automated terminals [88]. Presently, only one percent of ports terminal is fully-automated, and two percent are semi-automated in the world, e.g., terminals in the ports of Melbourne, Los Angeles, Rotterdam, and Tanger-Med. Thus, traditional ports are expected to be fully digitalized in the near future [82].

3) ONSHORE POWER SUPPLY

Maritime shipping is considered the most fuel-efficient mode of transport, and about 90% of global trade depends on maritime shipping. Meanwhile, maritime shipping causes about 5-8% of global emissions; therefore, the sector has pressure and new regulations to reduce the GHG emissions for improving environmental performance. One of them is the application of an OPS in ports [89]. OPS is the process of connecting the ship to shore power instead of running their generators during berthing for the provision of electricity for lighting, heating, cooling, and other services mainly being applied for cruise vessels and ferries due to their unusual stay at berth (up to 40%), and ferry calls [90], [91]. Generally, onboard diesel generators generate this electricity, which is substituted by LNG or liquefied compressed gas (LPG). Though, all these systems are the source of GHG emissions as well as noise pollutions [92]. The connection and disconnections procedure of OPS is described in [93]. As most ships operate with 60 Hz electricity as shown in Fig 4 whereas most terrestrial grids have 50 Hz, so the Hitachi ABB power static frequency converters can be very helpful for the adjustment of

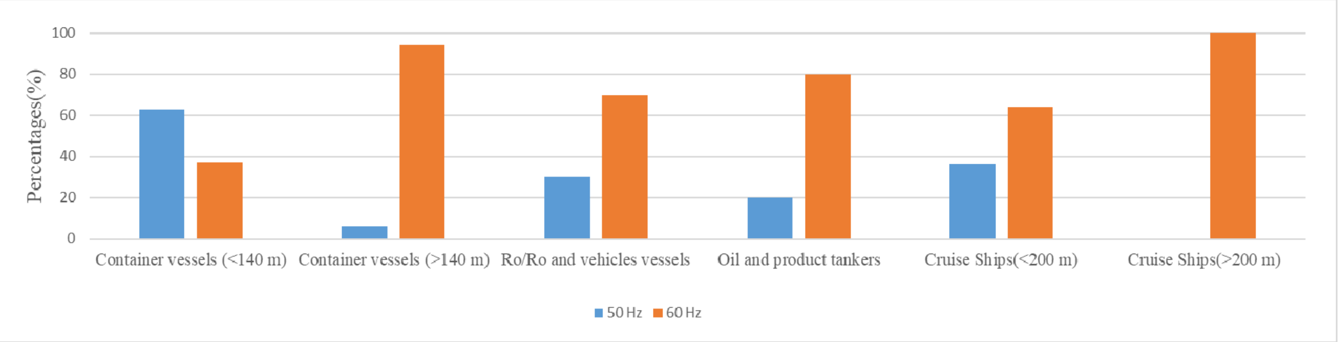

FIGURE 4. Frequency of different types of ships [99].

the ship with the required frequency [94]. Recently, Siemens has built Germany's largest shore power system at the port of Kiel, with 16 megavolt amperes which are capable of supplying two ships simultaneously, and will help to reduce more than 8000 tons of CO_2 emission annually [95]. OPS is being applied in different seaports in the world, and it is mandatory in some cities such as California. Meanwhile, Europe has decided to provide OPS in all seaports till the year 2025 [89].

In [96], a comparison between speed reduction and OPS for emission reduction at ports has been described & conclude that OPS is better than speed reduction as speed reduction leads to an increase in black carbon. However, the OPS decreases the black carbon as well as GHG emissions simultaneously. Meanwhile, an economic comparison between OPS and marine fuel shows that OPS is beneficial for those countries with diverse ports where the price of electricity is less than fuel [96]. With the development of the advanced OPS technology, CO_2 emission is decreased by 99.5%, 85%, and 9.4% in the cruise port regions of Norway, France, and the US, respectively [97]. The Stena Line is one of the world's largest ferry operators, which has upgraded its existing shore-to-ship power system with a wireless shore-to-ship power connection developed by ABB at Stena Ro-Ro terminal of Hook of Holland [98]. Likewise, Wartsila has developed an innovative concept of wireless charging from shore with key benefits of safety, reduced maintenance, and increased charging time. With this concept, a frequency converter is used to transform the 50/60 Hz 3-phase system into AC voltage with an output of several kHz. This voltage feeds a sensing coil unit located on the shore side, while the receiving coil unit is mounted onboard the ship. The high-frequency voltage is then converted into DC voltage. More than 2 MW of energy can be transferred between coils within distance ranges from 150 and 500mm [101]. The main challenges for the implementation of shore power suggested by [102] are high installing costs, different requirements (cables, connectors, voltage, frequency, etc.) for various ships, system design requirements, and the no standardized global regulations exist for OPS yet. The power demand of the ship is shown in Fig. 5.

4) ENERGY STORAGE SYSTEMS

Integration of ESSs contributes to fuel-efficient operations through load-leveling optimization, which leads to reduce GHG emissions and energy costs [103]. It integrates and balances the renewable energy generation for storing or fed back to the main grid, as solely dependence on renewable energy is problematic due to fluctuated power supply to the local grid. Leading energy storage systems are super-capacitors, flywheels, and batteries. ESSs can be installed on cargo handling equipment to reduce 20-50% fuel consumption. A study performed by [104] suggests that energy storage systems(HESS) for cargo handling equipment will results in approximately 57% energy consumption reduction as compared to conventional cargo handling equipment. The use of hybrid cranes is increasing with the increase of global marine transportation [79]. These typical cranes have great potential to recover energy from hoist-down and braking operations with the applications of energy storage systems. Two different approaches can be used to recycle the recovered energy. Either sending the excess energy to the main utility grid or recycle it via any energy storage systems like batteries/flywheels/super capacitors [105]. Similarly, the integration of HESS like electrochemical batteries (Lithium-ion) and supercapacitors or flywheels for on-board energy storage in RTGs leads to many benefits such as reduced fuel consumption, GHG emissions, and increases the engine life by reducing the peak power demand. Recently, Hyster has launched a new Hyster J155-190XNL forklift integrated with a 350-volt lithium-ion battery and with a lifting capacity of 15500-19000 pounds. It also has older versions, "All trucks have heavy-duty applications, fewer maintenance requirements, and provide zero-emissions said," Martin Boyd, vice president [106].

C. OPERATIONAL MEASURES

The operational measures for energy efficiency cover the procedures that emphasize on energy-aware design of operations in the ports. The purpose of energy-aware planning is to reduce energy utilization and processing time interval of equipment by operating the equipment in the off-peak hours and optimize the operations by considering energy prices [4].

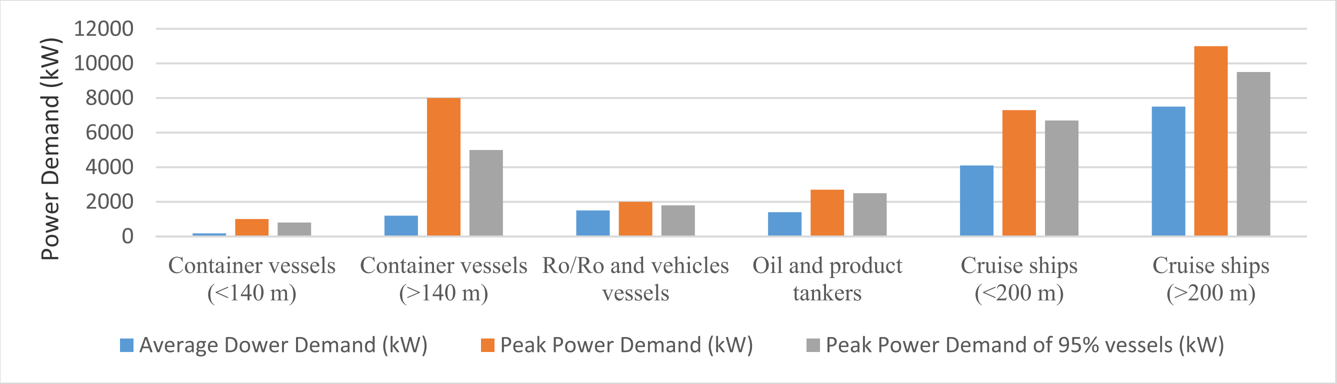

FIGURE 5. Power demand of different types of ships [100].

1) ENERGY-AWARE OPERATIONS

The operating efficiency of the port depends on the management of available resources [107]. Within this study, energy-aware port operations will be focused on. Container ports have three main functions, namely yard side, quayside, and landside [108]. On the yard side, the main focus is the planning of container transportation and stacking. From the perspective of energy-aware operations, many problems related to yard allocations and yard handling equipment are considered [109]. In [110], the energy consumption and scheduling of YCs have been studied [111] expresses the automated container terminals' attention toward energy-aware methods, and an analytical control model developed for the stabilization of energy utilization of AGVs with QCs. Similarly, a hybrid automation method is used to mimic the separate event and dynamics. The recommended procedure achieves a similar makespan with minimum energy utilization since the method allows vehicles to reduce speed in the yard [112]. The energy consumption behavior of AGVs and ASCs have been studied in [112], where the results show that 65 kWh energy can be consumed for the loading of 90 containers. Energy-efficient scheduling for YCs, YTs, and QCs, and their energy utilization behavior is deliberated in [113]. The conventional container terminal follows the single-cycle operations, where QCs, YTs, and YCs make the empty travel after loading or unloading the vehicles, while in the modern port system when these mentioned cranes perform a loading activity and an unloading activity for another vehicle without any empty travel, this is known as dual cycle operations. These cycle operations are evaluated for YCs, YTs, and QCs. Results show that dual cycle operation reports better energy saving than single-cycle operations [114].

In [115], formulate the integrated berth allocation and QCs assignment issues with energy utilization. The trade-off between energy and time-saving in the QC operations is explained in [116]. In [117], the authors described the operational and non-operational energy intake of QCs in detail. Operational energy utilization is counted as the number of moves/hours with the energy use during loading or unloading. Meanwhile, non-operational energy utilization is about lighting and auxiliary units. Besides, efficient scheduling of water-born AGVs for inter-terminal cargo routing leads to effective energy utilization [118].

Advanced container terminal operating system software such as crane optimizer, yard optimizer, and truck scheduler is being used for port terminal optimization to reduce energy costs and harmful emissions. Crane optimizer increases crane productivity with improved service quality, while yard optimizer helps to optimize the yard allocation and storage area utilization. Similarly, a truck scheduler helps to reduce the truck idle time by optimizing information accuracy and flow [119], [120].

2) PEAK-SHAVING

The use of electrified equipment is increasing in ports due to their economic and efficient behavior. This leads to high electricity consumption at certain periods. Peak shaving becomes an essential operational strategy to decrease peak power utilization in the port area [121]. Fig. 6 shows the various procedures that may level the load profile curves:

a. Load shifting; to shift energy demand from peak to off-peak periods.
b. Power-sharing; use of stored energy during peak energy demand.
c. Load shedding; switching off non-critical loads during peak hours.

These methods of peak shaving can be implemented to ensure successful maneuvers of reefer containers, QCs, and electrified equipment [121]. This strategy, in turn, decreases the variable cost of power utilization as the tariff of the variable cost depends on peak power utilization. Almost 25% to 30% of monthly electricity bills may be attributed to a higher tariff [122]. The STS cranes are one of the significant energy users in the port, which inspires the authors in [121] to suggest minimizing the numbers of QCs for the concurrent lifting of containers as QCs synchronization lessens the energy utilization during peak hours.

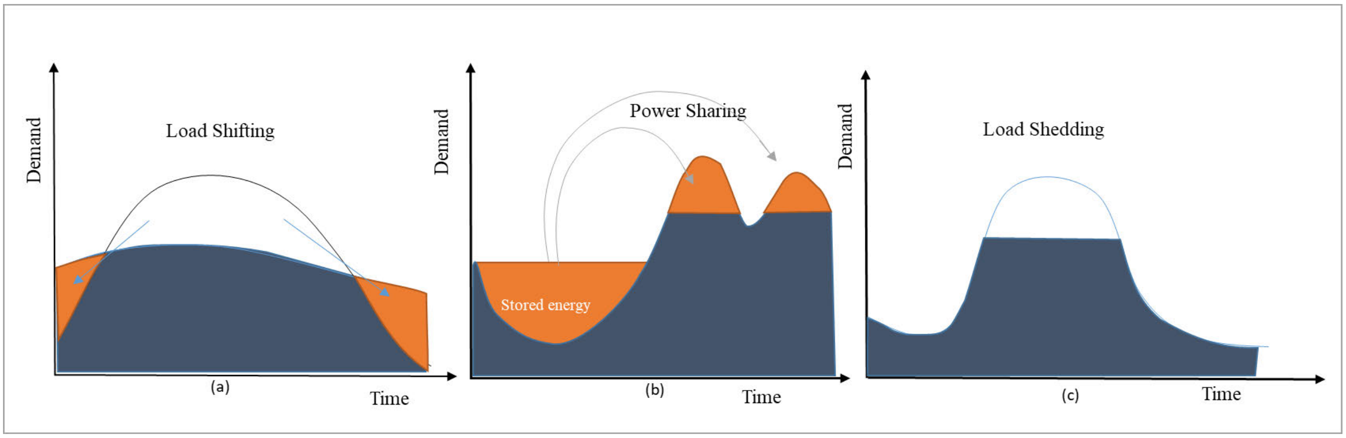

FIGURE 6. **Methods of peak-shaving [4].**

References [122] and [123] proposed the application of the peak-shaving method for QCs with twin lift and dual hoist technology. The energy storage system and coordination of cranes duty cycles are two main operational and technological tools for peak shaving. Hence, the simple postponement of only 21s of start point between two cranes dramatically reduces the maximum peak of group demand and level the total load profile curve. According to the solutions mentioned above for energy savings, only a 2-minute delay is registered during each operation without considerable time losses where it decreases a significant amount in power bills. These savings can be utilized during peak hours by reducing the peak energy demand. The analysis indicates that the life cycle of ultra-capacitors and flywheels are 10 and 20 years, respectively, with a seven-year payback period. The reefer containers consume about 30% to 45% of total port energy utilization; therefore, peak shaving applications are very beneficial to reduce energy consumption during peak hours [124].

IV. INFRASTRUCTURE OF MODERN PORTS

A seaport is a maritime facility that comprises equipment, space, and passengers. Early ports acted as a simple harbor while modern seaports are regional multi-modal intersections of global supply chains, and tend to be distribution hubs of transportation that link to sea, river, canal, rail, road, and airports. Here authors focused on the infrastructure of modern ports.

A. PORT MICROGRID

A microgrid (MG) in every sense is a small-scale system located near the consumer. In other words, the interconnections of small generations to low-voltage distribution system known as MG [125]. This latter can be operated in grid-connected mode or/and islanded mode with different sources. These sources may be produced from wind, solar, biogas plants, ocean energy, hydropower units, and diesel generation units. The energy storage system is sometimes included to enhance their sustainability and efficiency. An MG can help to reduce the cost of network connection, line losses and provide high-energy efficiency. Furthermore, MG may help to enhance reliability, reduce emissions, provide the lowest investment costs, improve power quality as well as reduce distribution power losses [126].

Due to the considerable growth of maritime transportation, environmental issues are also increasing dramatically. To overcome the health and ecological effects of the maritime sector, the European Commission emphasized the implementation of shore-side power as an initial solution. Besides this, the port authority must be in line with the concept of an All-Electric Ship. The applications of shore-side power are still facing many technical challenges of power supply demand, frequency level, and voltage differences in the shore and shipside. So the integration of microgrids in conventional seaports is the first step toward future green ports [127], [128].

The author in [130] assesses the concept of a port microgrid for port energy management. The purpose of the port microgrid is to improve the integration and distribution of renewable energy into the primary utility grid. Moreover, in [131], the authors have stated that the port area is a unique territory, where port authorities can achieve quality, reliability, and save energy by applying new energy management techniques. In [46], a case study of two European ports has been discussed, where the port of Hamburg(Germany) and the port of Genoa(Italy) both have successfully applied microgrid technologies.

The topology of a port microgrid is shown in Fig.7, where the power supplied to this port is produced by various RESs as well as the main grid. The primary function of the port microgrid is to improve the operating behavior of the port functions [129]. The large increase of integrating the RESs in MGs and (MGCs) microgrids clusters results in increasing the requirements of control strategies. The multi-agent-based control strategies are very beneficial for the balancing of

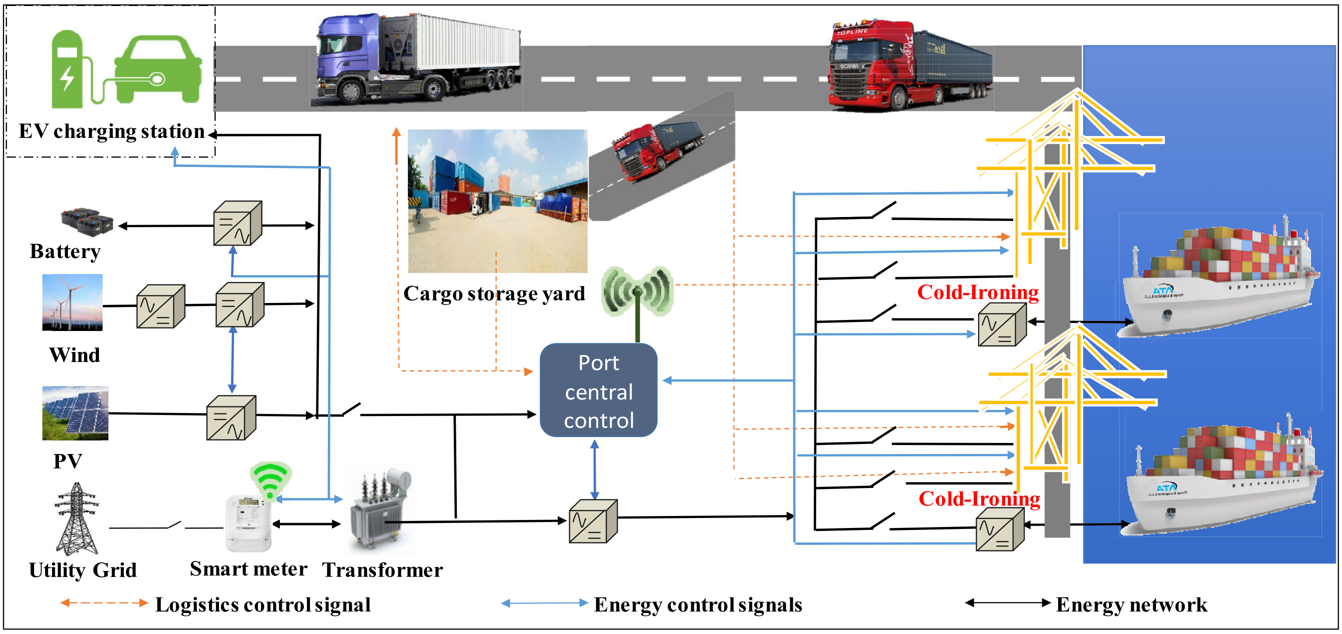

FIGURE 7. The topology of seaport microgrid [129].

power, stabilization of voltage and frequency, and achieving economic coordination in MGs and MGCs [71]. The operation and control of MGs and MGCs are very different from conventional power systems due to the characteristics of power electronic converters. In the meantime, MG must achieve the balance between supply and demand to maintain the stability of voltage/frequency, whether it is grid-connected or islanded mode. To effectively manage these issues, techniques of hierarchical control have been suggested [132]. The key factors of MGs deployment and development in the US(United States) have been their perspective to improve resiliency, reliability of critical facilities such as communications, waste treatment, transportations, drinking water, food, health care, and emergency response infrastructure [133].

Consequently, the US has been exploring the feasibility of extending the MGs beyond critical facilities to serve the communities. In Europe, climate change and the integration of renewable energy into the main grid have been a challenge for microgrid activity [134]. MGs have the flexibility to integrate the intermittent distributed renewable energy into the main grids and also allows for the local balancing of supply and demand [56]. The potential benefits of MGs in Sea-ports can be bundled into four main categories; economic, environmental sustainability, reliability, and energy security [135].

B. SEAPORT SMART MICROGRIDS

A smart grid in every respect is an electric power system, which comprises different advanced technologies, including communications systems to control and manage the production and distribution of electricity efficiently. The European Regulatory Group for Electricity and Gas defines the smart grid as an electricity network that can cost-effectively integrate the behavior and actions of all connected users [126]. Hence, ensure better efficiency, fewer power losses, and a high level of quality and security. The concept of a smart grid is characterized by; consumer-friendly, self-healing, optimized asset utilization, resistance to physical & cyber-attack, robust communications, eco-friendly, better energy safety, and improved efficiency and reliability. The illustration of smart energy management at the port is depicted in Fig.8. In this figure, there are five energy demand sources, such as a ship, quay cranes, warehouse/reefers area, charging station, and RMGs. These loads are connected to the smart energy management system with the help of smart communication devices. Three energy sources are solar panels, wind turbines, and utility grid supply, and energy storage systems. The intelligent energy management system efficiently monitors the power via communication systems using appropriate advanced control methods [136]. The road map of the port's smart grid, including the initial stages of energy balancing, equipment load analysis, smart grid benefits, and scenario analysis, have been discussed in detail in [137]. These initial stages help for examining daily fluctuations of RESs, optimization of peak-shaving, energy storage planning, and costs and tariffs management.

MGs play a vital role in the development of the smart grid concept as an MG is a piece of a large grid, which involves nearly all components of the main utility grid. However, a smart grid took place in larger utility such as high transmission and distribution lines, while MGs are smaller scale and can operate independently from a large utility power grid. In [138], the authors define port sustainability as "A sustainable port where port authority together with port

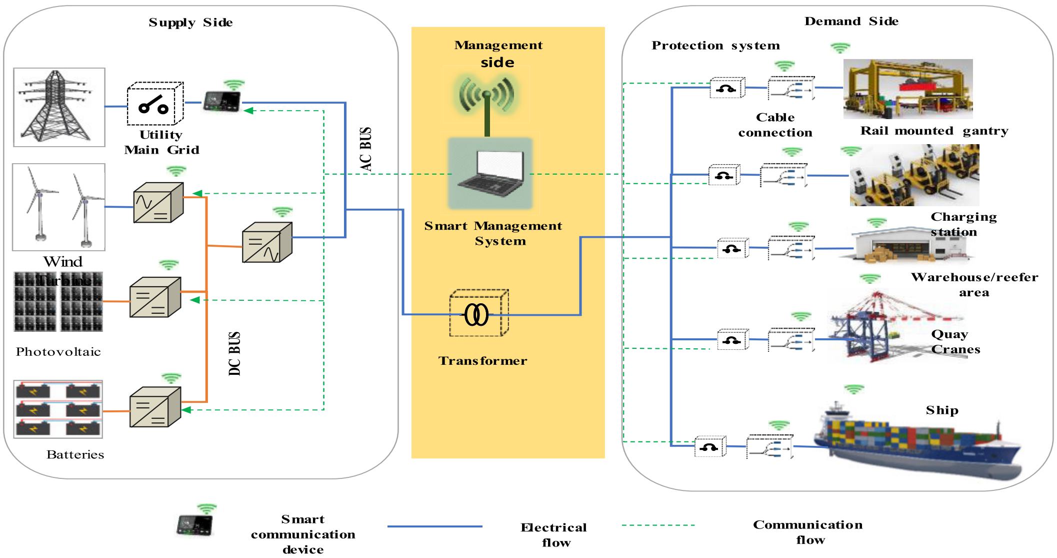

FIGURE 8. An illustration of smart energy management at the port.

users, proactively and responsibly, develops port operations, based on an economical green growth strategy''. The port energy sustainability can be achieved by applying the concept of green/smart port [139].

C. CHARGING STATIONS IN MODERN SEAPORTS

The stringent emissions rules set by the International Maritime Organization and EU force ships and port authorities to constrain their environmental pollution within targets and enable them to employ RES [140]. To achieve this, port grids are shifting towards RESs to tackle the growth of onshore power supply as well as shore charging stations for cruise vessels and ferries [141]. These modern ships help to reduce fuel consumption and GHG emissions by approximately 10-35% by using advanced control strategies. These vessels will need charging stations in the port area for frequent recharging of batteries. Therefore, the port microgrid must be aligned to accommodate the shore charging facilities, especially for hybrid, and cruise vessels, and ferries in addition to onshore power supply applications [142].

The basic block diagram of DC fast-charger power stages is shown in Fig.9. It comprises two conversation stages from three-phase AC/DC and DC/DC with galvanic isolation. The AC/DC rectification stage contains the power factor correction circuit, which ensures the power quality requirements, meanwhile the DC/DC stages provide the galvanic isolation between the grid and the EV and also helps to incorporate parallel connectivity at the charger output stages. Charging for batteries is divided into two main categories slow and fasting charging, which have different time-domain for recharging the batteries usually 8 h or more for the former and 1 h or less for later. There are different charging methods for batteries such as multi-rate constant current, constant current-constant voltage (CC/CV), pulse charge, boost charge, fuzzy, and boost logic control. The most popular method for charging lithium-ion and led acid batteries is CC/CV charging [143].

Recent development towards port electrification is the most prominent solution toward zero-emission. Many countries with long coastlines are currently planning for significant emission reductions in their ports area, and trying to develop plugged-in battery-powered ferry operations and also the extension of related infrastructure. For example, Norway has taken serious actions, they are producing almost 98% of electricity from RESs, mostly hydropower. In Norway, significant governmental regulations and corresponding industrial efforts have been recently dedicated to reducing the GHG emissions from marine transportation at the domestic level. It is also at the forefront of electrifications of ferries and other port infrastructure. it is expected that Norway will have 22 battery-powered ferries by the year 2022 [141]. An overview of some recent plugged-in-battery powered/fully-electric vessels are enlisted in Table 2.

V. NASCENT TECHNOLOGIES IN SEAPORT

The growing size and volume of containers, ships, and other equipment bring many challenges such as congestion and orientation in the ports. The applications of nascent technologies, e.g. IoT, RFID, Artificial Intelligence, Big data, and Cloud computing offer great opportunities in ports. In this context, the smart port has emerged and they use nascent technological solutions to increase efficiency and improve security and environmental sustainability [152].

A. SMART PORT

The concept of a smart port is to focus on methods and strategies being applied to decrease the environmental impacts and

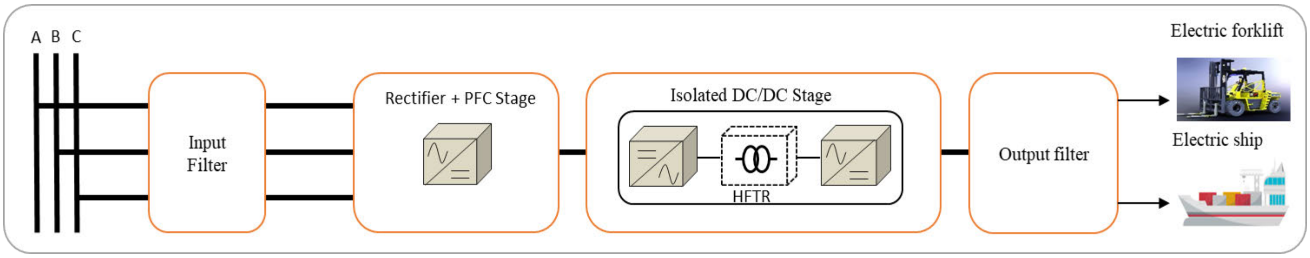

FIGURE 9. Basic block diagram of DC charger.

TABLE 2. List of some latest plugged-in marine vessels.

Vessel Name	Type	Year	Country	Battery Capacity	Manufacturer	Ref.
MV Hallaig	Hybrid ferry	2013	United Kingdom	700 kW	Ferguson Shipbuilder	[144]
MF Ampere	All-electric ferry	2015	Norway	1040 kW	Norled AS, Shipyard Fjellstrand, and Siemen	[145]
Vision of the Fjords	Hybrid ferry	2016	Norway	600 kW	Brodrene Aa	[146]
The Elektra	Hybrid ferry	2017	Finland	1000 kW	Siemens	[147]
Color Line	Hybrid ferry	2019	Norway	5000 kW	Ulstein Shipyard	[148]
Ellen	All-electric ferry	2019	Denmark	4000 kW	Ridzon, Poland	[149]
Catamaran	All-electric ferry	2020	Thailand	174-192 kW	Danfoss	[150]
Festoya	Hybrid ferry	2020	Norway	1582 kW	Remontowa Shipbuilding SA	[151]

also to increase the economic interests of the ports [163]. [21] defines a smart port as a port that is well equipped and enhanced with technological innovations. In more detail, a smart port is an automated port where all devices are connected with the IoT, advanced sensors, cloud/fog computing, RFID, and big data technologies. All of these technologies are supported by various networks and information technology (IT) infrastructures, such as Wide Area Network, Local Area Network, and other positioning systems. A smart port is also helpful for the flow of traffic and trade to optimize port activities by using intelligent solutions. These advanced technologies can work together efficiently. Meanwhile, the KPI's and criteria of the smart port has discussed in [164]. The authors have described the smart port concept in terms of the dimensions of operations, energy consumption, and environmental impacts at the port area. Table 3 depicts some global ports implementing smart port projects. Five main features to distinguish the smart port are [20]:

- Use of technologies such as data center, communications, networking, and automation.
- Cluster management, such as shipping companies and their stakeholders, expanded worldwide.
- The use of smart technologies leads to increase energy efficiency and reduce GHG emissions.
- Development of hub infrastructures to raise partnership among various global ports.
- Smart port services, such as vessel and container management.

B. IoT APPLICATIONS IN FUTURE SEAPORTS

The maritime sector has been indispensable for the prosperity and economic growth of the world. For example, approximately 74% of European goods are transported through the Sea. Due to the rapid development in the worldwide seaborne trade, there have been creating problems of sea traffic congestion, maneuverability limitations, lack of efficient navigation systems, increased emissions, and lack of efficient communication systems between ships and ports. In order to tackle these issues, ports are trying to take benefits of IoT technologies. With the help of IoT principles, objects/things/devices are being transferred from conventional to smart technologies [165]. Smart devices lead to several specific applications in the port area, as illustrated in Fig.10.

The truck appointment system (TAS) is an advanced technology for queue management, mostly used in different sectors such as medical appointments, vehicle inspections center, border crossing, etc. It is typically being used in modern ports to regulate traffic and to reduce port congestion. TAS is currently being applied in many European ports such as Valencia, Haminakotka, Gothenburg, Antwerp, and Gdansk [25], [166].

Other promising IoT applications, such as PORT MOD and RTPORT, in which PORT MOD is a visual and stimulating tool for container terminal operations. It is a stand-alone Java program that addresses the container handling challenges. PORT MOD helps to identify inefficiencies and bottlenecks in container flow, crane operations, straddle carriers, and correct estimation of machine pooling during loading

TABLE 3. Some global ports with smart port initiatives.

Continent	Country	Port	Reference	Features
Asia	China	Shangai (Yanshan port)	[153]	Port has implemented automated container terminals with remotely controlled RMGs, AGVs, and bridge cranes
		Tianjin port	[154]	Enhanced the integration of new technologies such as big data, 5G technologies, and artificial intelligence.
	Singapore	Tuas Megaport	[155]	Working on the implementation of automated yard functions and wharf as well as fully-electric AGVs.
America	USA	Los Angeles	[156]	Integrating shipping data across port eco-system with data analytics to increase supply chain performance through real-time data.
		Long Beach	[157]	Port of Long Beach has invested almost 185Millions in the development of port infrastructure, especially shore power.
Europe	Belgium	Antwerp	[158]	Implemented the use of blockchain technology to improve security among competing parties for digital exchange, also using digital cameras and sensors to ensure correct ship berthing and preventive maintenance.
	Germany	Hamburg	[159]	Real-time monitoring of navigation, shore power supply from renewable energy, and use of mobile GPS sensor for fleet management.
	France	Le Havre	[160]	Focusing on several projects related to energy management, energy efficiency, traffic monitoring and coordination, and air quality improvement.
	Spain	Barcelona	[161]	Storm forecasting system, and cargo environmental footprints quantifications.
	Netherland	Rotterdam	[162]	Use of IoT for the optimal conditions of ship berthing.

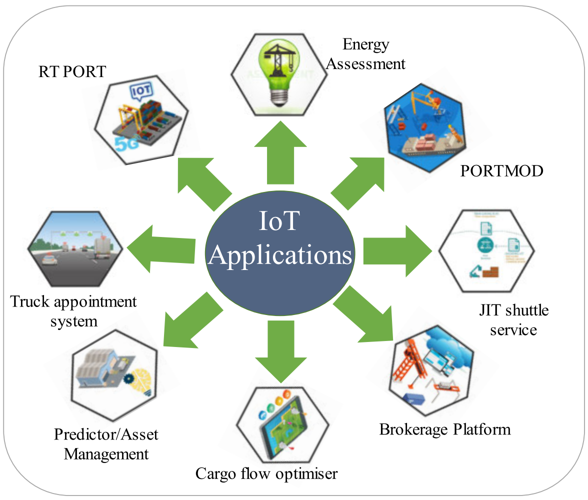

FIGURE 10. IoT applications at ports.

and unloading processes. At the same time, RTPORT is a real-time control module supported by 5G that helps in smart terminal operations. The core purpose of RTPORT module is to provide a full-fledged automated cargo terminal management system by using 5G networks. This tool was tested in the port of Livorno for the first time, where they found that proper usage of RTPORT with 5G technology leads to energy efficiency and improves environmental impacts due to optimized real-time cargo management services.

Cargo flow optimizer is also an optimization tool for rail/ocean/inland waterways cargo flows. This tool is applied in the port of Antwerp, which facilitates an overview of the most efficient connections from the hinterland to the port [167]. The optimized prediction of cargoes will contribute to planning and controlling the terminals that ultimately lead to reliable and resilient operations. The continuous growth in container transport volume and increased vessel size resulting in port congestion, queuing, delays, and dwell of cargo and ships in the ports [38]. Consequently, to solve this significant challenge, the port of Valencia has started a Just-in-time(JIT) rail shuttle service by the name of the Valencia Zaragoza-rail corridor to increase rail transport services. JIT, rail shuttle services implementation will help to minimize handling costs, improved rail infrastructure, reduce container dwell time, and improve logistics chain communications among ports. Besides this, the energy assessment framework and asset predictors are IoT tools to manage assets and energy. The energy assessment framework is cost-effective and a roadmap for reducing port environmental impacts. It is being applied at the port of Piraeus, to investigate the cost-effective integrations of renewable energy with ESSs in the port. Asset predictor is a machine learning and optimization tool for the well-organized use of port resources [168]. It helps to predict imbalanced classification problems by using machine learning algorithms.

Finally, the brokerage platform is another promising feature being developed in modern ports. It is a cloud-based marketplace for exchanging and leasing intra-port assets [166]. It is being exercised in the port of Antwerp. Marketplace solutions facilitate the optimized utilization of specialized equipment in the ports such as cranes, chassis, barges, and wagons, etc. Enhanced planning of equipment and service will result in a shorter time of container staying at the port and better yard utilization.

VI. CONCLUSION

The port area is a large consumer of energy and a GHG emitter. The challenge of climate change and GHG emissions reduction is not limited to one port due to their distinct features. Moreover, there is no specific global criteria for port decarbonization. In this article, different challenges, energy efficiency measures, modern infrastructure and applications of nascent technologies in seaports have been presented. An overall background on challenges in ports was presented first. Then, typical techniques and energy efficiency measures were presented. Novel trends of technological methods were also detailed, such as electrification, digitalization, OPS, and applications of ESSs. It is observed that, the use of ESSs is becoming crucial to provide electricity in peak periods.

Although proper regulatory policies present a promising pathway to decarbonize the port sector and improve efficiency, the actual implementation is still limited. Similarly, ports modern infrastructure (i.e. port microgrids, seaport smart microgrids) and applications of nascent technologies (i.e. IoT, big data, cloud computing) can play an important role to reduce GHG emissions and improve energy efficiency. We suggest that proper policies development and incentives must be provided to purchase smart technologies associated with port energy efficiency improvement. In the future, there is great potential to improve energy efficiency with applications of ESSs and nascent technologies such IoT in ports terminal operations.

ACKNOWLEDGMENT

The first author, Muhammad Sadiq, would like to explain his thanks to Le Quang Nhat Hoang and Electrical Power and Energy Lab at National Kaohsiung University of Science and Technology for their valuable technical support in conceptualization during this research.

REFERENCES

[1] UNCTAD. *Review of Maritime Transport 2019*. Accessed: Dec. 25, 2020. [Online]. Available: https://unctad.org/webflyer/review-maritime-transport-2019

[2] *Fourth Greenhouse Gas Study 2020*. Accessed: Apr. 7, 2021. [Online]. Available: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

[3] M. Acciaro, T. Vanelslander, C. Sys, C. Ferrari, A. Roumboutsos, G. Giuliano, J. S. L. Lam, and S. Kapros, ''Environmental sustainability in seaports: A framework for successful innovation,'' *Maritime Policy Manage.*, vol. 41, no. 5, pp. 480–500, Jul. 2014.

[4] Ç. Iris and J. S. L. Lam, ''A review of energy efficiency in ports: Operational strategies, technologies and energy management systems,'' *Renew. Sustain. Energy Rev.*, vol. 112, pp. 170–182, Sep. 2019.

[5] P. Rosa-Santos, F. Taveira-Pinto, D. Clemente, T. Cabral, F. Fiorentin, F. Belga, and T. Morais, ''Experimental study of a hybrid wave energy converter integrated in a harbor breakwater,'' *J. Mar. Sci. Eng.*, vol. 7, no. 2, p. 33, Feb. 2019.

[6] A. Balbaa and N. H. El-Amary, *Green Energy Seaport Suggestion for Sustainable Development in Damietta Port, Egypt*. U.K.: WIT Press, 2017.

[7] S. R. Bull, ''Renewable energy today and tomorrow,'' *Proc. IEEE*, vol. 89, no. 8, pp. 1216–1226, Aug. 2001.

[8] D. Roman, R. Maria, C. Wooldridge, and M. P. Duran, ''ESPO environmental report 2020 EcoPortsinSights 2020,'' Eur. Sea port, Europe, Tech. Rep., 2020.

[9] *Port Emissions Toolkit Guide No.2: Development of Port Emissions Reduction Strategies*, Int. Assoc. Ports Harbors, Tokyo, Japan, 2008.

[10] PIANC, ''Renewables and energy efficiency for maritime ports,'' PIANC, Brussels, Belgium, MarCom WG Rep. 159-2019, 2019.

[11] *Carbon Foot-Printing for Ports: Guidance Document. World Port Climate Initiative*, World Ports Climate Initiative, 2010.

[12] *Tool Box for Greenhouse Gases IAPH International Association of Ports and Harbors*, IAPH.

[13] H. Jia, R. Adland, V. Prakash, and T. Smith, ''Energy efficiency with the application of virtual arrival policy,'' *Transp. Res. D, Transp. Environ.*, vol. 54, pp. 50–60, Jul. 2017.

[14] T. Spengler and G Wilmsmeier, ''Energy consumption and energy efficiency indicators in container terminals—A national inventory,'' in *Proc. IAME*, Aug. 2016, pp. 1–28.

[15] S.-M. Kim and S.-K. Sul, ''Control of rubber tyred gantry crane with energy storage based on supercapacitor bank,'' *IEEE Trans. Power Electron.*, vol. 21, no. 5, pp. 1420–1427, Sep. 2006.

[16] A. Loukili and S. L. Elhaq, ''A model integrating a smart approach to support the national port strategy for a horizon of 2030,'' in *Proc. Int. Colloq. Logistics Supply Chain Manage. (LOGISTIQUA)*, Apr. 2018, pp. 81–86.

[17] P. T.-W. Lee and J. S. L. Lam, ''Developing the fifth generation ports model,'' in *Dynamic Shipping and Port Development in the Globalized Economy*. London, U.K.: Palgrave Macmillan, 2016, pp. 186–210.

[18] S. J. Pettit and A. K. C. Beresford, ''Port development: From gateways to logistics hubs,'' *Maritime Policy Manage.*, vol. 36, no. 3, pp. 253–267, Jun. 2009.

[19] A de Barcelona, ''The evolution of sea transport: 4th generation ports,'' Barcelona Treb., Barcelona, Spain, Tech. Rep., Nov. 2012.

[20] K.-L.-A. Yau, S. Peng, J. Qadir, Y.-C. Low, and M. H. Ling, ''Towards smart port infrastructures: Enhancing port activities using information and communications technology,'' *IEEE Access*, vol. 8, pp. 83387–83404, 2020.

[21] A. Rajabi, A. K. Saryazdi, A. Belfkih, and C. Duvallet, ''Towards smart port: An application of AIS data,'' in *Proc. IEEE 20th Int. Conf. High Perform. Comput. Commun., IEEE 16th Int. Conf. Smart City, IEEE 4th Int. Conf. Data Sci. Syst. (HPCC/SmartCity/DSS)*, Jun. 2018, pp. 1414–1421.

[22] H. Davarzani, B. Fahimnia, M. Bell, and J. Sarkis, ''Greening ports and maritime logistics: A review,'' *Transp. Res. D, Transp. Environ.*, vol. 48, pp. 473–487, Oct. 2016.

[23] J. S. L. Lam and T. Notteboom, ''The greening of ports: A comparison of port management tools used by leading ports in Asia and Europe,'' *Transp. Rev.*, vol. 34, no. 2, pp. 169–189, Mar. 2014.

[24] K. Y. Bjerkan and H. Seter, ''Reviewing tools and technologies for sustainable ports: Does research enable decision making in ports?'' *Transp. Res. D, Transp. Environ.*, vol. 72, pp. 243–260, Jul. 2019.

[25] E. Sdoukopoulos, M. Boile, A. Tromaras, and N. Anastasiadis, ''Energy efficiency in European ports: State-of-practice and insights on the way forward,'' *Sustainability*, vol. 11, no. 18, p. 4952, Sep. 2019.

[26] S. Lim, S. Pettit, W. Abouarghoub, and A. Beresford, ''Port sustainability and performance: A systematic literature review,'' *Transp. Res. D, Transp. Environ.*, vol. 72, pp. 47–64, Jul. 2019.

[27] *Innovative Power Distribution for Ports and Harbors*, Siemens, Munich, Germany, 2017.

[28] J. Blackman. *Smart Ports: Seven Practical Challenges for Port Authorities and Terminal Operators-Article*. Accessed: Aug. 28, 2020. [Online]. Available: https://www.apucis.com/enGB/reports/article/F6710C98-9F77-11BB-18F0-248F9D1F8956?PageSpeed=noscript

[29] *Smart Ports; Competitive Cities Global Center of Competence Cities-Urban Development*, Siemens, Munich, Germany, 2017.

[30] M. Tichavska and B. Tovar, ''Environmental cost and eco-efficiency from vessel emissions in Las Palmas Port,'' *Transp. Res. E, Logistics Transp. Rev.*, vol. 83, pp. 126–140, Nov. 2015.

[31] HPA. *Port of Hamburg|New Climate Plan and Climate Protection Law for Hamburg*. Accessed: Apr. 7, 2021. [Online]. Available: https://www.hafen-hamburg.de/en/news/new-climate-plan-and-climate-protection-law-for-hamburg

[32] Port of Helsinki. *Carbon-Neutral Port of Helsinki 2035 Manifestation*. Accessed: Aug. 28, 2020. [Online]. Available: https://www.portofhelsinki.fi/en/port-helsinki/sustainable-port-operations/carbon-neutral-port-helsinki-2035-manifestation

[33] *Port of Antwerp Takes Step Towards Methanol, Hydrogen Bunkers | S&P Global Platts*. Accessed: Apr. 7, 2021. [Online]. Available: https://www.spglobal.com/platts/en/market-insights/latest-news/petrochemicals/092220-port-of-antwerp-takes-step-towards-methanol-hydrogen-bunkers

[34] Port of Helsinki. *Management of Environmental Impacts*. Accessed: Aug. 28, 2020. [Online]. Available: https://www.portofhelsinki.fi/en/port-helsinki/environmental-responsibility/management-environmental-impacts

[35] O. US EPA. *Northwest Ports Achievements in Reducing Emissions and Improving Performance*. Accessed: Dec. 25, 2020. [Online]. Available: https://www.epa.gov/ports-initiative/northwest-ports-achievements-reducing-emissions-and-improving-performance

[36] Ports of Stockholm. *Four Baltic Sea Ports Signed a Memorandum of Understanding and Set a Common Approach for the New on-Shore Power Supply for Vessels*. Accessed: Dec. 25, 2020. [Online]. Available: https://www.portsofstockholm.com/about-us/news/2016/four-baltic-sea-ports

[37] Port of Helsinki. *Management of Environmental Impacts*. Accessed: Aug. 26, 2020. [Online]. Available: https://www.portofhelsinki.fi/en/port-helsinki/environmental-responsibility/management-environmental-impacts

[38] James Blackman. *Seven Practical Challenges for Port Authorities and Terminal Operators*. Accessed: Aug. 28, 2020. [Online]. Available: https://enterpriseiotinsights.com/20190729/channels/fundamentals/seven-practical-challenges-for-smart-ports

[39] C. Jaccoud and A. Magrini, ''Regulation of solid waste management at Brazilian ports: Analysis and proposals for Brazil in light of the European experience,'' *Mar. Pollut. Bull.*, vol. 79, nos. 1–2, pp. 245–253, Feb. 2014.

[40] J. L. Almazán, ''Energy supply to ports and shipping trainmos II,'' Eur. Union, U.K., Tech. Rep., 2015.

[41] *Greenhouse Gas Emissions From Ships in Ports—Case Studies in Four Continents*, Transp. Res. Part D, U.K., 2017.

[42] *Smart Ports; Competitive Cities—Siemens Smart Ports: Competitive Cities*, Siemens, Munich, Germany, Sep. 2017.

[43] A. F. Nnachi, P. J. Ehlers, C. G. Richards, and D. V. Nicolae, ''Double-port interface for small scale renewable sources integration,'' in *Proc. IEEE Int. Conf. Ind. Technol. (ICIT)*, Feb. 2013, pp. 503–508.

[44] M. S. Alam, F. S. Al-Ismail, A. Salem, and M. A. Abido, ''High-level penetration of renewable energy sources into grid utility: Challenges and solutions,'' *IEEE Access*, vol. 8, pp. 190277–190299, 2020.

[45] T. S. Ustun, C. Ozansoy, and A. Zayegh, ''Modeling of a centralized microgrid protection system and distributed energy resources according to IEC 61850-7-420,'' *IEEE Trans. Power Syst.*, vol. 27, no. 3, pp. 1560–1567, Aug. 2012.

[46] M. Acciaro, H. Ghiara, and M. I. Cusano, ''Energy management in seaports: A new role for port authorities,'' *Energy Policy*, vol. 71, pp. 4–12, Aug. 2014.

[47] S. Wang and T. Notteboom, ''The role of port authorities in the development of LNG bunkering facilities in north European ports,'' *WMU J. Maritime Affairs*, vol. 14, no. 1, pp. 61–92, Apr. 2015.

[48] S. Aksoy and Y. Durmusoglu, ''Improving competitiveness level of turkish intermodal ports in the frame of green port concept: A case study,'' *Maritime Policy Manage.*, vol. 47, no. 2, pp. 203–220, Feb. 2020.

[49] S. Venkataraman, C. Ziesler, P. Johnson, and S. Van Kempen, ''Integrated wind, solar, and energy storage: Designing plants with a better generation profile and lower overall cost,'' *IEEE Power Energy Mag.*, vol. 16, no. 3, pp. 74–83, May 2018.

[50] R. Sioshansi and P. Denholm, ''Benefits of colocating concentrating solar power and wind,'' *IEEE Trans. Sustain. Energy*, vol. 4, no. 4, pp. 877–885, Oct. 2013.

[51] I. S. Seddiek, ''Application of renewable energy technologies for eco-friendly sea ports,'' *Ships Offshore Struct.*, vol. 15, no. 9, pp. 953–962, 2019.

[52] S. L. Song and K. Poh, ''Solar PV leasing in Singapore: Enhancing return on investments with options,'' in *Proc. IOP Conf. Earth Environ. Sci.*, 2017, vol. 67, no. 1, Art. no. 012020.

[53] HPA. *Hamburger Hafen Energy Cooperation Port of Hamburg*. Accessed: Oct. 17, 2020. [Online]. Available: https://www.hamburg-port-authority.de/fileadmin/user_upload/broschuere_smartportenergy_web.pdf

[54] R. T. Poulsen and H. Sornn-Friese, ''Achieving energy efficient ship operations under third party management: How do ship management models influence energy efficiency?'' *Res. Transp. Bus. Manage.*, vol. 17, pp. 41–52, Dec. 2015.

[55] H. Winnes, L. Styhre, and E. Fridell, ''Reducing GHG emissions from ships in port areas,'' *Res. Transp. Bus. Manage.*, vol. 17, pp. 73–82, Dec. 2015.

[56] R. Bosman, D. Loorbach, J. Rotmans, and R. van Raak, ''Carbon lock-out: Leading the fossil port of rotterdam into transition,'' *Sustainability*, vol. 10, no. 7, p. 2558, Jul. 2018.

[57] D. Kang and S. Kim, ''Conceptual model development of sustainability practices: The case of port operations for collaboration and governance,'' *Sustainability*, vol. 9, no. 12, pp. 1–15, 2017.

[58] J. Blackman, ''Seven practical challenges for port authorities and terminal operators,'' Enterprise IoT Insights, Tech. Rep., 2019.

[59] James Blackman. *Smart Port Perspectives, Marseille: 5G, Blockchain, and a Digital Map for Tight Ships*. Accessed: Apr. 5, 2021. [Online]. Available: https://enterpriseiotinsights.com/20190726/channels/news/marseille-digital-map-for-tight-ships

[60] Len Williams. *Seven Ways Seaports are Adapting to Modern Challenges*. Accessed: Apr. 5, 2021. [Online]. Available: https://eandt.theiet.org/content/articles/2020/01/seven-ways-seaports-are-adapting-to-modern-challenges/

[61] B. De Borger, C. Courcelle, and D. Swysen, ''Optimal pricing of transport externalities in an international environment: Some empirical results based on a numerical optimization model,'' *Regional Sci. Urban Econ.*, vol. 34, no. 2, pp. 163–201, Mar. 2004.

[62] M. G.-P. at W. O.Forum, undefinedBusan, and undefined2010, ''Green ports and green shipping: Singapore's contribution,'' Tech. Rep.

[63] P. Verhoeven, ''World ports sustainability report 2020,'' World Ports Sustainability Program, Tech. Rep., 2020, pp. 11–12 and 28.

[64] C. San Pedro. *Port of Los Angeles to Develop Energy Management Action Plan*. Accessed: Apr. 10, 2021. [Online]. Available: https://www.portoflosangeles.org/references/news_060313_emap

[65] M. Boile, S. Theofanis, E. Sdoukopoulos, and N. Plytas, ''Developing a port energy management plan: Issues, challenges, and prospects,'' *Transp. Res. Rec., J. Transp. Res. Board*, vol. 2549, no. 1, pp. 19–28, Jan. 2016.

[66] C. Cheng, ''Port of Felixstowe committed to protecting the environment,'' Tech. Rep., 2012.

[67] P. Landau, ''Annual report 2015,'' *Bull. Mediev. Canon Law*, vol. 32, no. 1, pp. 11–12, 2015.

[68] D. Borst, ''German experience regarding the implantation of ISO 50001 and its results,'' Accenture, China, Tech. Rep., 2017, pp. 1–27.

[69] F. D. Kanellos, ''Real-time control based on multi-agent systems for the operation of large ports as prosumer microgrids,'' *IEEE Access*, vol. 5, pp. 9439–9452, 2017.

[70] F. D. Kanellos, E.-S.-M. Volanis, and N. D. Hatziargyriou, ''Power management method for large ports with multi-agent systems,'' *IEEE Trans. Smart Grid*, vol. 10, no. 2, pp. 1259–1268, Mar. 2019.

[71] Y. Han, K. Zhang, H. Li, E. A. A. Coelho, and J. M. Guerrero, ''MAS-based distributed coordinated control and optimization in microgrid and microgrid clusters: A comprehensive overview,'' *IEEE Trans. Power Electron.*, vol. 33, no. 8, pp. 6488–6508, Aug. 2018.

[72] J. Jordán, J. Palanca, E. DelVal, V. Julian, and V. Botti, ''MASEV: A MAS for the analysis of electric vehicle charging stations location,'' in *Proc. Int. Conf. Practical Appl. Agents Multi-Agent Syst.*, 2018, pp. 326–330.

[73] *Sustainable Power Supply for Eco-Friendly Ports Shore Connection Power Supply System for Ships*, Siemens, Munich, Germany, 2017.

[74] Y.-C. Yang and C.-L. Lin, ''Performance analysis of cargo-handling equipment from a green container terminal perspective,'' *Transp. Res. D, Transp. Environ.*, vol. 23, pp. 9–11, Aug. 2013.

[75] S. Voß, R. Stahlbock, and D. Steenken, ''Container terminal operation and operations research—A classification and literature review,'' *OR Spectr.*, vol. 26, no. 1, pp. 3–49, Jan. 2004.

[76] H. J. Carlo, I. F. A. Vis, and K. J. Roodbergen, ''Storage yard operations in container terminals: Literature overview, trends, and research directions,'' *Eur. J. Oper. Res.*, vol. 235, no. 2, pp. 412–430, Jun. 2014.

[77] J. Schmidt, C. Meyer-Barlag, M. Eisel, L. M. Kolbe, and H.-J. Appelrath, ''Using battery-electric AGVs in container terminals—Assessing the potential and optimizing the economic viability,'' *Res. Transp. Bus. Manage.*, vol. 17, pp. 99–111, Dec. 2015.

[78] R. Stahlbock and S. Voß, ''Operations research at container terminals: A literature update,'' *OR Spectr.*, vol. 30, no. 1, pp. 1–52, Nov. 2007.

[79] Y.-C. Yang and W.-M. Chang, ''Impacts of electric rubber-tired gantries on green port performance,'' *Res. Transp. Bus. Manage.*, vol. 8, pp. 67–76, Oct. 2013.

[80] D. Bechtsis, N. Tsolakis, D. Vlachos, and E. Iakovou, "Sustainable supply chain management in the digitalisation era: The impact of automated guided vehicles," *J. Cleaner Prod.*, vol. 142, pp. 3970–3984, Jan. 2017.

[81] M. Fruth and F. Teuteberg, "Digitization in maritime logistics—What is there and what is missing?" *Cogent Bus. Manage.*, vol. 4, no. 1, Jan. 2017, Art. no. 1411066.

[82] A. S. Alamoush, F. Ballini, and A. I. Ölçer, "Ports' technical and operational measures to reduce greenhouse gas emission and improve energy efficiency: A review," *Mar. Pollut. Bull.*, vol. 160, Nov. 2020, Art. no. 111508.

[83] *San Pedro Bay Ports Clean Air Action Plan 2017 Final*, San Pedro Bay Ports, Los Angels, CA, USA, 2017.

[84] S. Kavakeb, T. T. Nguyen, K. McGinley, Z. Yang, I. Jenkinson, and R. Murray, "Green vehicle technology to enhance the performance of a European port: A simulation model with a cost-benefit approach," *Transp. Res. C, Emerg. Technol.*, vol. 60, pp. 169–188, Nov. 2015.

[85] H. J. Carlo, I. F. A. Vis, and K. J. Roodbergen, "Transport operations in container terminals: Literature overview, trends, research directions and classification scheme," *Eur. J. Oper. Res.*, vol. 236, no. 1, pp. 1–13, Jul. 2014.

[86] H. Y. Bae, R. Choe, T. Park, and K. R. Ryu, "Comparison of operations of AGVs and ALVs in an automated container terminal," *J. Intell. Manuf.*, vol. 22, no. 3, pp. 413–426, Jun. 2011.

[87] A. H. Gharehgozli, D. Roy, and R. de Koster, "Sea container terminals: New technologies and OR models," *Maritime Econ. Logistics*, vol. 18, no. 2, pp. 103–140, Jun. 2016.

[88] Cris Mona. *Connected Ports Driving Future Trade*. Accessed: Nov. 20, 2020. [Online]. Available: https://www.scribd.com/document/461158472/accenture-connected-ports-driving-future-trade-pdf

[89] T. P. V. Zis, "Prospects of cold ironing as an emissions reduction option," *Transp. Res. A, Policy Pract.*, vol. 119, pp. 82–95, Jan. 2019.

[90] I. Krämer and E. Czermański, "Onshore power one option to reduce air emissions in ports," *Sustainability Manage. Forum | NachhaltigkeitsManagementForum*, vol. 28, nos. 1–2, pp. 13–20, Jun. 2020.

[91] A. Innes and J. Monios, "Identifying the unique challenges of installing cold ironing at small and medium ports—The case of aberdeen," *Transp. Res. D, Transp. Environ.*, vol. 62, pp. 298–313, Jul. 2018.

[92] A. Rolan, P. Manteca, R. Oktar, and P. Siano, "Integration of cold ironing and renewable sources in the barcelona smart port," *IEEE Trans. Ind. Appl.*, vol. 55, no. 6, pp. 7198–7206, Nov. 2019.

[93] Mayur Agarwal. *What is Alternate Marine Power (AMP) or Cold Ironing?* Accessed: Aug. 11, 2020. [Online]. Available: https://www.marineinsight.com/marine-electrical/what-is-alternate-marine-power-amp-or-cold-ironing/

[94] Hitachi ABB. *Shore-to-Ship Power Converters*. Accessed: Aug. 11, 2020. [Online]. Available: https://www.hitachiabb-powergrids.com/offering/product-and-system/substations/shore-to-ship-power-and-smart-ports/Shore-to-ship-converters

[95] Jonathan Kemper. *Siemens Builds Germany's Largest 'Power Outlet' for Ships for Port of Kiel*. Accessed: Aug. 11, 2020. [Online]. Available: https://www.metec-tradefair.com/en/News/Business_News/Siemens_builds_Germany's_largest_'power_outlet'_for_ships_for_Port_of_Kiel

[96] T. Zis, R. J. North, P. Angeloudis, W. Y. Ochieng, and M. G. H. Bell, "Evaluation of cold ironing and speed reduction policies to reduce ship emissions near and at ports," *Maritime Econ. Logistics*, vol. 16, no. 4, pp. 371–398, Dec. 2014.

[97] F. Ballini and R. Bozzo, "Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology," *Res. Transp. Bus. Manage.*, vol. 17, pp. 92–98, Dec. 2015.

[98] ABB. *ABB Provides Innovative Shore Power Solution for Ships in the Netherlands*. Accessed: Aug. 11, 2020. [Online]. Available: https://new.abb.com/news/detail/12156/abb-provides-innovative-shore-power-solution-for-ships-in-the-netherlands

[99] P. Ericsson, "Shore-side power supply," M.S. thesis, Dept. Energy Environ., Div. Chalmers Univ. Technol., Chalmers Univ., Gothenburg, Sweden, 2008, p. 180.

[100] J. Kumar, L. Kumpulainen, and K. Kauhaniemi, "Technical design aspects of harbour area grid for shore to ship power: State of the art and future solutions," *Int. J. Electr. Power Energy Syst.*, vol. 104, pp. 840–852, Jan. 2019.

[101] Wärtsilä. (2018). *Wireless Charging*. Accessed: Aug. 11, 2020. [Online]. Available: http://www.wartsila.com

[102] P.-H. Tseng and N. Pilcher, "A study of the potential of shore power for the port of kaohsiung, taiwan: To introduce or not to introduce?" *Res. Transp. Bus. Manage.*, vol. 17, pp. 83–91, Dec. 2015.

[103] C. Nuchturee, T. Li, and H. Xia, "Energy efficiency of integrated electric propulsion for ships—A review," *Renew. Sustain. Energy Rev.*, vol. 134, Dec. 2020, Art. no. 110145.

[104] W. Niu, X. Huang, F. Yuan, N. Schofield, L. Xu, J. Chu, and W. Gu, "Sizing of energy system of a hybrid lithium battery RTG crane," *IEEE Trans. Power Electron.*, vol. 32, no. 10, pp. 7837–7844, Nov. 2017.

[105] N. Zhao, N. Schofield, W. Niu, P. Suntharalingam, and Y. Zhang, "Hybrid power-train for port crane energy recovery," in *Proc. IEEE Conf. Expo Transp. Electrific. Asia–Pacific (ITEC Asia–Pacific)*, Aug. 2014, pp. 5–10.

[106] Martin Boyd. *Green Port: Emissions Free Lithium-Ion Lift Truck Launches*. Accessed: Aug. 14, 2020. [Online]. Available: https://www.greenport.com/news101/Products-and-Services/powerful-lithium-ion-lift-truck

[107] G. Wilmsmeier and T. Spengler, "Energy consumption and container terminal efficiency," *FAL Bull.*, vol. 329, nos. 350–356, p. 10, 2016.

[108] C. Bierwirth and F. Meisel, "A follow-up survey of berth allocation and quay crane scheduling problems in container terminals," *Eur. J. Oper. Res.*, vol. 244, no. 3, pp. 675–689, Aug. 2015.

[109] D.-H. Lee, Z. Cao, and Q. Meng, "Scheduling of two-transtainer systems for loading outbound containers in port container terminals with simulated annealing algorithm," *Int. J. Prod. Econ.*, vol. 107, no. 1, pp. 115–124, May 2007.

[110] J. He, Y. Huang, and W. Yan, "Yard crane scheduling in a container terminal for the trade-off between efficiency and energy consumption," *Adv. Eng. Informat.*, vol. 29, no. 1, pp. 59–75, Jan. 2015.

[111] T. Hague, "Automated container terminal C," in *Proc. ITSC*, Bhopal, India, 2013.

[112] J. Xin, R. R. Negenborn, and G. Lodewijks, "Energy-aware control for automated container terminals using integrated flow shop scheduling and optimal control," *Transp. Res. C, Emerg. Technol.*, vol. 44, pp. 214–230, Jul. 2014.

[113] D. Chang, T. Fang, J. He, and D. Lin, "Defining scheduling problems for key resources in energy-efficient port service systems," *Sci. Program.*, vol. 2016, pp. 1–8, Jan. 2016.

[114] B. K. Lee, J. M. W. Low, and K. H. Kim, "Comparative evaluation of resource cycle strategies on operating and environmental impact in container terminals," *Transp. Res. D, Transp. Environ.*, vol. 41, pp. 118–135, Dec. 2015.

[115] D. Chang, Z. Jiang, W. Yan, and J. He, "Integrating berth allocation and quay crane assignments," *Transp. Res. E, Logistics Transp. Rev.*, vol. 46, no. 6, pp. 975–990, Nov. 2010.

[116] J. He, "Berth allocation and quay crane assignment in a container terminal for the trade-off between time-saving and energy-saving," *Adv. Eng. Informat.*, vol. 30, no. 3, pp. 390–405, Aug. 2016.

[117] D. Liu and Y.-E. Ge, "Modeling assignment of quay cranes using queueing theory for minimizing CO2 emission at a container terminal," *Transp. Res. D, Transp. Environ.*, vol. 61, pp. 140–151, Jun. 2018.

[118] H. Zheng, R. R. Negenborn, and G. Lodewijks, "Closed-loop scheduling and control of waterborne AGVs for energy-efficient inter terminal transport," *Transp. Res. E, Logistics Transp. Rev.*, vol. 105, pp. 261–278, Sep. 2017.

[119] Maritime Terminals. *Maritime Terminals | INFORM GmbH*. Accessed: Apr. 9, 2021. [Online]. Available: https://www.inform-software.com/logistics/maritime-terminals#solution

[120] *Container Terminal Automation*. Accessed: Apr. 10, 2021. [Online]. Available: http://www.pema.org

[121] H. Geerlings, R. Heij, and R. van Duin, "Opportunities for peak shaving the energy demand of ship-to-shore quay cranes at container terminals," *J. Shipping Trade*, vol. 3, no. 1, pp. 1–20, Dec. 2018.

[122] G. Parise, L. Parise, A. Malerba, F. M. Pepe, A. Honorati, and P. B. Chavdarian, "Comprehensive peak-shaving solutions for port cranes," *IEEE Trans. Ind. Appl.*, vol. 53, no. 3, pp. 1799–1806, May 2017.

[123] M. Uddin, M. F. Romlie, M. F. Abdullah, S. A. Halim, A. H. A. Bakar, and T. C. Kwang, "A review on peak load shaving strategies," *Renew. Sustain. Energy Rev.*, vol. 82, pp. 3323–3332, Feb. 2018.

[124] J. H. R. van Duin, H. Geerlings, A. Verbraeck, and T. Nafde, "Cooling down: A simulation approach to reduce energy peaks of reefers at terminals," *J. Cleaner Prod.*, vol. 193, pp. 72–86, Aug. 2018.
[125] A. S. Singh and B. Surjan, "Microgrid: A review," in *Proc. IEEE Global Humanitarian Technol. Conf., South Asia Satellite*, Aug. 2014, pp. 185–198.
[126] Y. Yoldaş, A. Önen, S. M. Muyeen, A. V. Vasilakos, and İ. Alan, "Enhancing smart grid with microgrids: Challenges and opportunities," *Renew. Sustain. Energy Rev.*, vol. 72, pp. 205–214, May 2017.
[127] Z. Shuai, Y. Sun, Z. J. Shen, W. Tian, C. Tu, Y. Li, and X. Yin, "Microgrid stability: Classification and a review," *Renew. Sustain. Energy Rev.*, vol. 58, pp. 167–179, May 2016.
[128] N. B. Bintiahamad. (2019). *Integration of Microgrid Technologies in Future Seaports*. Accessed: Jul. 14, 2020. [Online]. Available: https://www.forskningsdatabasen.dk/en/catalog/2471559831
[129] S. Fang, Y. Wang, B. Gou, and Y. Xu, "Toward future green maritime transportation: An overview of seaport microgrids and all-electric ships," *IEEE Trans. Veh. Technol.*, vol. 69, no. 1, pp. 207–219, Jan. 2020.
[130] G. Parise, L. Parise, L. Martirano, P. B. Chavdarian, C.-L. Su, and A. Ferrante, "Wise port & business energy management: Portfacilities, electrical power distribution," in *Proc. IEEE Ind. Appl. Soc. Annu. Meeting*, Oct. 2014, pp. 1–6.
[131] T. Lamberti, A. Sorce, L. DiFresco, and S. Barberis, "Smart port: Exploiting renewable energy and storage potential of moored boats," in *Proc. MTS/IEEE Ocean. Genova Discov. Sustain. Ocean Energy New World*, 2015, pp. 1–3.
[132] L. Meng, E. R. Sanseverino, A. Luna, T. Dragicevic, J. C. Vasquez, and J. M. Guerrero, "Microgrid supervisory controllers and energy management systems: A literature review," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1263–1273, Jul. 2016.
[133] A. Molavi, J. Shi, Y. Wu, and G. J. Lim, "Enabling smart ports through the integration of microgrids: A two-stage stochastic programming approach," *Appl. Energy*, vol. 258, Jan. 2020, Art. no. 114022.
[134] E. G. Corr, "Societal transformation for peace in El Salvador," *Ann. Amer. Acad. Political Social Sci.*, vol. 541, no. 1, pp. 144–156, 1995.
[135] *Methodological Approach for Estimating the Benefits and Costs of Smart Grid Demonstration Projects*, EPRI, Palo Alto, CA, USA, 2010, Art. no. 1020342.
[136] R. Bayindir, I. Colak, G. Fulli, and K. Demirtas, "Smart grid technologies and applications," *Renew. Sustain. Energy Rev.*, vol. 66, pp. 499–516, Dec. 2016.
[137] L. Tao, H. Guo, J. Moser, and H. Mueller. (Jun. 2014). *A Roadmap Towards Smart Grid Enabled Harbour Terminals*. Cired.Net. [Online]. Available: http://www.cired.net/publications/workshop2014/papers/CIRED2014WS_0394_final.pdf
[138] E. Lalla-Ruiz, L. Heilig, and S. Voß, *Environmental Sustainability in Ports, Sustainable Transportation and Smart Logistics*. Amsterdam, The Netherlands: Elsevier, 2018, pp. 65–89.
[139] S. Kim and B. Chiang, "Sustainability practices to achieve sustainability in international port operations," *J. Korea Port Econ. Assoc.*, vol. 30, no. 3, pp. 15–37, 2014.
[140] J. Kumar, C. Parthasarathy, M. Västi, H. Laaksonen, M. Shafie-Khah, and K. Kauhaniemi, "Sizing and allocation of battery energy storage systems in Åland islands for large-scale integration of renewables and electric ferry charging stations," *Energies*, vol. 13, no. 2, p. 317, Jan. 2020.
[141] B. S. Karimi, M. Zadeh, and J. A. Suul, "Shore charging for plug-in battery-powered ships: Power system architecture, infrastructure, and control," *IEEE Electrific. Mag.*, vol. 8, no. 3, pp. 47–61, Sep. 2020.
[142] J. Kumar, A. A. Memon, L. Kumpulainen, K. Kauhaniemi, and O. Palizban, "Design and analysis of new harbour grid models to facilitate multiple scenarios of battery charging and onshore supply for modern vessels," *Energies*, vol. 12, no. 12, p. 2354, Jun. 2019.
[143] D. Ronanki, A. Kelkar, and S. and S. Williamson, "Extreme fast charging technology—Prospects to enhance sustainable electric transportation," *Energies*, vol. 12, no. 19, pp. 1–17, 2019.
[144] CMAL. *Caledonian Maritime Assets Ltd, MV, Hallaig*. Accessed: Dec. 22, 2020. [Online]. Available: https://www.cmassets.co.uk/project/mv-hallaig/
[145] Ketil Aagensen. *Electrical Grid*. Accessed: Dec. 22, 2020. [Online]. Available: http://www.corvus-energy.com
[146] Web Source. *Vision of the Fjords—Marine References | ABB*. Accessed: Dec. 22, 2020. [Online]. Available: https://new.abb.com/marine/marine-references/vision-of-the-fjords
[147] Web Source. *The Elektra: Finland's First Hybrid-Electric Ferry—Ship Technology Global*. Accessed: Dec. 22, 2020. [Online]. Available: https://ship.nridigital.com/ship_apr18/the_elektra_finland_s_first_hybrid-electric_ferry
[148] Web Source. *Color Hybrid ferry (COLOR LINE)*. Accessed: Dec. 22, 2020. [Online]. Available: https://www.cruisemapper.com/ships/Color-Hybrid-ferry-1186
[149] Steve Hanley. *Ellen, Denmark's First Electric Ferry*. Accessed: Dec. 22, 2020 [Online]. Available: https://cleantechnica.com/2020/06/12/ellen-denmarks-first-electric-ferry-passes-all-tests-with-flying-colors/
[150] Danfoss Editron. *DanFoss Powers up the World's Strongest Electric Ferry | DanFoss*. Accessed: Dec. 22, 2020. [Online]. Available: https://www.danfoss.com/en/about-danfoss/news/cf/danfoss-powers-up-the-world-s-strongest-electric-ferry/
[151] David Tinsley. *The Motorship Battery Hybrid Power for Double-Ender*. Accessed: Dec. 22, 2020. [Online]. Available: https://www.motorship.com/news101/ships-and-shipyards/battery-hybrid-power-for-double-ender
[152] 27Group. *Ports of The Future-Smart and Green Ports—27 Advisory*. Accessed: Jul. 12, 2021. [Online]. Available: https://27.group/port-of-the-future-smart-and-green-port/
[153] J. X. Luo, "Fully automatic container terminals of Shanghai Yangshan Port phase IV," *Frontiers Eng. Manage.*, vol. 6, no. 3, pp. 457–462, Sep. 2019.
[154] Liu Wenjing. *Tianjin Port Builds a Next-Generation Smart and Green Port with 5G, AI, and Big Data—C114*. Accessed: Aug. 24, 2020. [Online]. Available: http://m.c114.com.cn/w2503-1111105.html
[155] Fabian Koh. *Tuas Port Set to be World's Largest Fully Automated Terminal, Singapore News & Top Stories—The Straits Times*. Accessed: Jul. 23, 2020. [Online]. Available: https://www.straitstimes.com/singapore/tuas-port-set-to-be-worlds-largest-fully-automated-terminal
[156] POLA. *Supply Chain Business, Port of Los Angeles*. Accessed: Jul. 23, 2020. [Online]. Available: https://www.portoflosangeles.org/business/supply-chain
[157] U. Epa, O. of Transportation, A. Quality, and C. Division, "Shore power technology assessment at U.S. ports," Environ. Protection Agency, Eastern Res. Group, USA, Tech. Rep. EPA-420-R-17-004, Mar. 2017.
[158] Catalina Grimalt. *Smart Port: Port of Antwerp*. Accessed: Jul. 23, 2020. [Online]. Available: https://www.portofantwerp.com/en/smart-port
[159] HPA. *Smart Port—The Intelligent Port*. Accessed: Jul. 23, 2020. [Online]. Available: https://www.hamburg-port-authority.de/en/hpa-360/smartport/
[160] Accueil. *Innovation in the area—Le Havre Smart Port City*. Accessed: Jul. 23, 2020. [Online]. Available: https://www.lehavre-smartportcity.fr/en/ambition/innovation-in-the-area/
[161] Web Source. *Barcelona, a Smart Port That is Constantly Innovating*. Accessed: Jul. 23, 2020. [Online]. Available: https://www.thesmartcityjournal.com/en/cities/389-barcelona-a-smart-port-that-is-constantly-innovating
[162] James Blackman. *Where Digital Transformation Sets Sail: The Five Smartest Ports in the World—Enterprise IoT Insights*. Accessed: Jul. 23, 2020. [Online]. Available: https://enterpriseiotinsights.com/20190104/channels/fundamentals/five-smartest-ports-in-the-world
[163] P. Badurina, M. Cukrov, and Č. Dundović, "Contribution to the implementation of 'Green Port' concept in croatian seaports," *Pomorstvo*, vol. 31, no. 1, pp. 10–17, Jun. 2017.
[164] K. El-sakty, "Logistics road map for smart SeaPorts," *Renew. Energy Sustain. Develop.*, vol. 2, no. 2, pp. 91–95, 2016.
[165] S. Aslam, M. P. Michaelides, and H. Herodotou, "Internet of ships: A survey on architectures, emerging applications, and challenges," *IEEE Internet Things J.*, vol. 7, no. 10, pp. 9714–9727, Oct. 2020.
[166] Corealis. *Capacity With a Positive Environmental and Societal Footprint: Ports in the Future Era*. Accessed: Oct. 11, 2020. [Online]. Available: https://www.corealis.eu/
[167] Corealis. *Mosaic Factor | Home*. Accessed: Oct. 11, 2020. [Online]. Available: https://www.mosaicfactor.com/en/index.php
[168] Web Source. *Mobility, Energy and Parking: Dynniq is a Dynamic, High-Tech and Innovative Company*. Accessed: Oct. 11, 2020. [Online]. Available: https://dynniq.com/

MUHAMMAD SADIQ received the B.S. degree in textile engineering from the Balochistan University of Information Technology, Engineering and Management Sciences, Quetta, Pakistan, in 2013, and the M.S. degree in industrial engineering and management from the University of the Punjab, Lahore, Pakistan, in 2019. He is currently pursuing the Ph.D. degree in electrical engineering with the National Kaohsiung University of Science and Technology, Taiwan. He joined Nishat Mills as a Deputy Manager for two years. His research interests include harbor microgrids, energy management, and modeling of DC EV charging station for harbor applications.

SYED WAJAHAT ALI received the bachelor's degree in electronics engineering from the University of Engineering and Technology, Peshawar, Pakistan, in 2008, and the master's degree in electrical engineering from COMSATS University Islamabad, Pakistan, in 2012. He is currently pursuing the Ph.D. degree in electrical engineering with the National Kaohsiung University of Science and Technology (NKUST). In 2013, he joined COMSATS University Islamabad, as a Lecturer. His research interests include power quality, power system analysis and control, and offshore wind energy systems and their energy management.

YACINE TERRICHE received the B.S. degree in electrical engineering from the University of Science and Technology, Constantine, Algeria, in 2011, the M.S. degree in electrical engineering from the University of Constantine 1, Constantine, and the Ph.D. degree in electrical engineering from Aalborg University, Aalborg, Denmark, in 2020. During his Ph.D., he worked as a Research Assistant with the Kaohsiung University of Science of Technology, Kaohsiung, Taiwan, from 1 December 2019 to 15 September 2020. Since 15 November 2020, he has been working as a Research Assistant with Aalborg University. His research interests include power electronics modeling and control, signal processing, power quality issues, active and passive power filters, static VAR compensators, and maritime microgrids.

MUHAMMAD UMAIR MUTARRAF received the B.Sc. degree in electrical engineering from the University of Engineering and Technology, Lahore, Pakistan, in 2013, and the M.Eng. degree in control theory and control engineering from Xidian University, China, in 2017. He is currently pursuing the Ph.D. degree with the Department of Energy Technology, Aalborg University, Denmark. His research interests include power electronics, modeling, and control and integration of energy storages in AC and DC shipboard microgrids.

MUSTAFA ALRAYAH HASSAN (Member, IEEE) received the B.Sc. degree in electrical engineering from the University of Blue Nile, Sudan, in 2006, the M.Sc. degree in electrical power engineering from the University of Khartoum, Sudan, in 2013, and the Ph.D. degree in electrical engineering from the Hebei University of Technology, China, in 2019. He worked as a Lecturer with the International University of Africa, Khartoum, Sudan, in 2014. From 2019 to 2020, he worked as an Assistant Professor and the Head of the Electrical Department, University of Blue Nile. Since 2019, he has been a Visiting Assistant Professor with the African Center of Excellence in Energy for Sustainable Development, University of Rwanda, Kigali, Rwanda. He is currently a Postdoctoral Researcher with the National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan. He has authored or coauthored many conferences and journal articles. His current research interests include power electronic converters, distributed generation systems, renewable energy integration, smart grid, DC microgrids stability and control, shipboard DC microgrids, nonlinear control systems, adaptive passivity-based control, and sliding mode control. He reviewed many articles with several IEEE journals, such as the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, IEEE TRANSACTIONS ON TRANSPORTATION ELECTRIFICATION, IEEE JOURNAL OF EMERGING AND SELECTED TOPICS IN POWER ELECTRONICS, IEEE ACCESS, and *IET Power Electronics*.

KHALID HAMID was born in Waziristan Khyber Pakhtunkhwa, Pakistan, in March 20, 1994. He received the Bachelor of Science (B.Sc.) degree in mechanical engineering from the University of Engineering and Technology, Lahore, Pakistan, in 2015, and the Master of Science (M.Sc.) degree in thermal science from the National Chiao Tung University, Hsinchu, Taiwan, in December 2020. He then joined Nidec Company to continue his professional career in thermal science. His research interests include renewable and thermal energy, environmentally friendly techniques in thermal management solution for different electronic devices, and liquid cooling for automobile. In recent years, he has focused on heat pipe, vapor chamber, and heat sink and heat pump drying system. He has collaborated actively with researchers in several other disciplines of thermal science and technology.

ZULFIQAR ALI was born in Gilgit Baltistan, Pakistan, in 1996. He received the B.Sc. degree in computer systems engineering from the Mirpur University of Science and Technology (MUST), Mirpur, Pakistan, in 2017. He is currently pursuing the master's degree with the Department of Electrical Engineering, National Kaohsiung University of Science and Technology (NKUST), Kaohsiung, Taiwan. His research interests include DC microgrid, power converter control, fault protection, fault detection, fault isolation, smart grid, artificial intelligence, machine learning, signal processing, and DC shipboard power systems.

JIA YIN SZE received the B.Eng. (Hons.) and Ph.D. degrees from the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore, in 2002 and 2007, respectively. She is currently a Research Lead at the Maritime Energy and Sustainable Development Centre of Excellence, with research interests include the adoption of alternative energy options and electrification of harbour craft. Prior to joining the Centre, she has spent 12 years as a Research Scientist/a Fellow at the Data Storage Institute, A*STAR, School of Mechanical and Aerospace Engineering, NTU, and Energy Research Institute, NTU, working on semiconductor devices, materials engineering, and thermal energy storage systems.

CHUN-LIEN SU (Senior Member, IEEE) received the Diploma degree in electrical engineering from the National Kaohsiung Institute of Technology, Taiwan, in 1992, and the M.S. and Ph.D. degrees in electrical engineering from the National Sun Yat-sen University, Taiwan, in 1997 and 2001, respectively. In 2002 and 2006, he was an Assistant Professor and an Associate Professor with the Department of Marine Engineering, National Kaohsiung Marine University, respectively. From 2012 to 2017, he was as a Full Professor at the Energy and Control Research Center, where he was the Director. From August 2017 to January 2018, he was a Visiting Professor with the Department of Energy Technology, Aalborg University, Denmark. He was the Director of the Maritime Training Center, National Kaohsiung University of Science and Technology (NKUST), from February 2018 to July 2020. Since August 2020, he has been a Professor with the Department of Electrical Engineering, NKUST, and the Director of the Center for Electrical Power and Energy. His research interests include power system analysis and computing, power quality, maritime microgrids, and offshore energy. His recent focuses are on electrical infrastructure for offshore wind farms and maritime microgrids for electrical ships, vessels, ferries, and seaports. He received the Best Paper Prize of the Industrial and Commercial Power Systems Conference at IEEE-IAS, for the period 2012–2013, and the Best Paper Award of the IEEE International Conference on Smart Grid and Clean Energy Technologies, in 2018. He was a Guest Editor of the IEEE Transactions on Industrial Informatics Special Issues: Next Generation Intelligent Maritime Grids, in 2017, and *IET Renewable Power Generation* Special Issues: Power Quality and Protection in Renewable Energy Systems and Microgrids, in 2019.

JOSEP M. GUERRERO (Fellow, IEEE) received the B.S. degree in telecommunications engineering, the M.S. degree in electronics engineering, and the Ph.D. degree in power electronics from the Technical University of Catalonia, Barcelona, in 1997, 2000, and 2003, respectively.

Since 2011, he has been a Full Professor with the Department of Energy Technology, Aalborg University, Denmark, where he is responsible for the Microgrid Research Program. Since 2014, he has been the Chair Professor with Shandong University. Since 2015, he has been a Distinguished Guest Professor with Hunan University. Since 2016, he has been a Visiting Professor Fellow with Aston University, U.K., and a Guest Professor with the Nanjing University of Posts and Telecommunications. Since 2019, he has been a Villum Investigator. He has published more than 500 journal articles in the fields of microgrids and renewable energy systems, which are cited more than 30,000 times. His research interests include different microgrid aspects, including power electronics, distributed energy-storage systems, hierarchical and cooperative control, energy management systems, smart metering, the Internet of Things for AC/DC microgrid clusters, and islanded minigrids. His recent focuses are on maritime microgrids for electrical ships, vessels, ferries, and seaports. In 2015, he was elevated as a IEEE Fellow for his contributions on distributed power systems and microgrids. He received the Best Paper Award of the IEEE Transactions on Energy Conversion, for the period 2014–2015, the Best Paper Prize of the IEEE-PES, in 2015, and the Best Paper Award of the *Journal of Power Electronics*, in 2016. During five consecutive years, from 2014 to 2018, he was awarded by Clarivate Analytics (former Thomson Reuters) as an Highly Cited Researcher. He is an Associate Editor for a number of IEEE Transactions.