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MANAGEMENT STRATEGY FOR SEAPORTS ASPIRING TO GREEN LOGISTICAL GOALS OF IMO: TECHNOLOGY AND POLICY SOLUTIONS

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ABSTRACT

Recently, because of serious global challenges including the consumption of energy and climate change, there has been an increase in interest in the environmental effect of port operations and expansion. More interestingly, a strategic tendency in seaport advancement has been to manage the seaport system using a model which balances environmental volatility and economic development demands. An energy efficient management system is regarded as being vital for meeting the strict rules aimed at reducing the environmental pollution caused by port facility activities. Moreover, the enhanced supervision of port system operating methods and technical resolutions for energy utilisation also raise significant issues. In addition, low-carbon ports, as well as green port models, are becoming increasingly popular in seafaring nations. This study comprises a comprehensive assessment of operational methods, cutting-edge technologies for sustainable generation, storage, and transformation of energy, as well as systems of smart grid management, to develop a green seaport system, obtaining optimum operational efficiency and environmental protection. It is thought that using a holistic method and adaptive management, based on a framework of sustainable and green energy, could stimulate creative thinking, consensus building, and cooperation, as well as streamline the regulatory demands associated with port energy management. Although several aspects of sustainability and green energy could increase initial expenditure, they might result in significant life cycle savings due to decreased consumption of energy and output of emissions, as well as reduced operational and maintenance expenses.

Keywords: Green seaport, management strategy, clean energy, decarbonization, sustainable maritime

INTRODUCTION

Seaports have contributed significantly to global economic development [1]; they have played an important part in enabling import and export activities between nations since before the Industrial Revolution, which directly supported the development of international commerce and the world's supply chain [2][3]. However, it has been observed that energy costs are enormous for ports and facilities, so energy savings could be a significant and efficient solution to lowering these costs [4]. In addition, emission reduction contributes directly to the green viewpoint and sustainability of ports [5][6]. More interestingly, energy efficiency mainly refers to supplying similar services while using less energy, and it is frequently related to the employment of renewable and eco-friendly resources to provide such services [7][8]. Indeed, energy efficiency is critical for ports and facilities seeking to reduce energy usage and become more environmentally friendly [9]. In October 2014, the European Council established an aim of 30% energy saving and 27% renewable energy share in total energy utilisation in all industries by 2030 [10]. In particular, regulations were implemented with the goal of mitigating greenhouse gas (GHG) emissions in port waterways, inland regions, and yards, in order to foster sustainability and the green viewpoint [11][12]. Pollution reduction was a direct and obvious consequence of the electrification of equipment [13], energy efficiency [14], the employment of alternative fuels, low-sulphur fuels, and sustainable sources of energy [15][16]. The above-mentioned factors, along with working efficiency, constitute a significant portion of defining next-generation ports [17][18]. Furthermore, energy efficiency is considerably influenced by technological developments in power production, distribution, storage, consumption, and conversion [19]–[21]. Energy systems used in docks contain numerous components, such as converters, batteries, and distributors. Novel methods for enhancing grid intelligence, mentioned above, as well as novel devices, such as super-capacitors and flywheels, aim to effectively store energy and promote energy efficiency even further [22][23]. Port machinery outfitted with energy management components, for example, could greatly save energy by saving power during hoist-down, storing that energy, and then utilising it during hoist-up or travelling movements [24][25]. Notably, smart power delivery systems have the potential to improve the energy economy in the reefer industry and technological advancements significantly contribute to the efficiency of consuming energy [26][27]. Also, ports can take advantage of the development of novel fuel-efficient motors and fuel cells because green energy sources are increasingly being used and technological advancements in harnessing renewable energy are also linked to ports [28][29]. Thus, emerging technologies, including microgrid and smart grid systems for controlling the demand and supply of energy, could enhance port energy management in this situation.

Facing the problems relating to the development strategies of green ports, the motivation for this effort was to provide a thorough understanding of working strategies, techniques, and energy management systems, with the goal of achieving energy savings for sustainable and green ports. Besides, this paper presents technologies and methods to decrease GHG pollution in the shipping sector; methods for detecting and identifying energy consumption in ports are also illustrated. Research gaps are identified and research directions are proposed for future investigations. The structure of this paper includes: Section 2 focuses on the methodology for searching references in the literature; Section 3 discusses the critical factors affecting green port strategies, such as technology factors, management factors, and policy factors. Suggestions for green logistics for green ports are then analysed in Section 4. Finally, conclusions and future directions are presented in Section 5.

METHODOLOGY

In order to collect data and the most appropriate literature for this paper, some important keywords were used, including: 'renewable energy', 'clean energy', 'seaport', 'green maritime', 'green seaport', 'green logistics', 'energy plan', 'energy management for port', 'energy management in shipping', 'low-carbon energy for maritime', 'net-zero', and 'CO_2 emission'. The search was carried out on the websites of prestigious associations and organisations, as well as Google Scholar. For selected papers, they had to be peer-reviewed and published in good ISI/Scopus journals relating to energy, energy economy, maritime, port, logistics, and energy policy. After that, three filters were used to select the most relevant papers, as shown in **Fig. 1**.

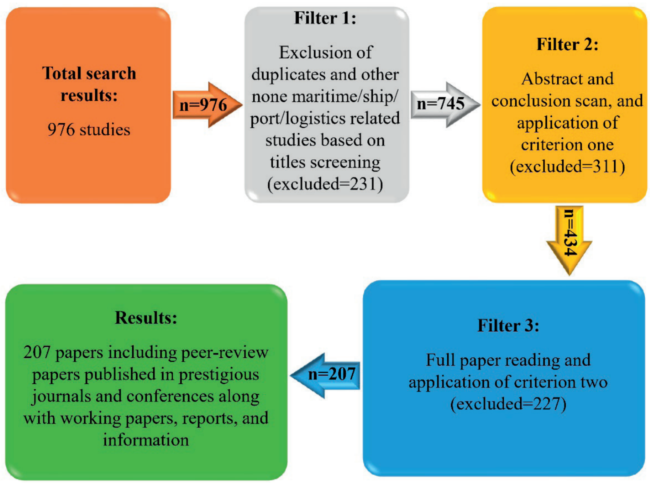

Fig. 1. Methodology used for selecting the most suitable papers/reports/information

The following criteria were used for filters. With the aim of selecting the most suitable papers/reports/information: (1) – a preliminary survey with the aforementioned keywords for the 1st filter, (2) – checking the title and abstract of papers/reports/information for the 2nd filter, (3) – checking and carefully reviewing the content of papers/reports/information for the 3rd filter. Finally, 200 of the most relevant and suitable papers/reports/information were selected for this work.

CRITICAL FACTORS AFFECTING GREEN PORT STRATEGIES

TECHNOLOGY FACTORS

Cold-ironing technology

Cold ironing is the practice of connecting ship berths to shore-side electricity instead of operating auxiliary engines to supply electricity for ship operation [30]. Its effectiveness in reducing emissions is determined by the percentage of green energy output in that nation; therefore, nations with less ecologically favourable electricity generation simply discharge emissions elsewhere. According to Winkel et al. [31], if all ports in Europe utilised shore power, an estimated €2.94 billion in expenses could have been saved in 2020, along with an 800,000-ton decrease in carbon emissions. However, the main obstacles are the installation costs and the fact that each ship has to apply the connecting technique on board, which they only do if they expect to employ it regularly [32]–[34]. Based on the report by WPCI, there are just 28 ports, worldwide, with cold ironing installed; this indicates minimal take-up, to date [35].

There are primarily two kinds of engines in vessels: the main engine, such as the propulsion engine, and the auxiliary engine [36]. Most ships switch off their main engines upon docking. Auxiliary engines provide energy for hotelling operations including power system repair, lighting, and refrigeration. Depending on the types of fuel, these auxiliary diesel engines burn fossil fuel in the idle position and release CO_2, SO_2, and NOx [37]–[39]. Cold ironing is also known as alternative marine control, onshore power supply, and shore-side power. The grid, renewable sources, LNG, or other sources of electrical power can provide electricity which can reduce emissions if they replace burning fuels [32], [40], [41]. In general, the higher the average ship handling times are, the higher the potential ports save through cold-ironing [40]. Due to the different policies and costs in each region, emission reduction varies according to the area. By cold ironing, global carbon emissions, based on the emission intensity of port electricity supplies, are decreased by 10%, while SO_2 emissions in UK ports are decreased by 2% [40]. Similarly, there is a reduction of 57.16% in CO_2 emissions in Kaohsiung Port, Taiwan [42]. Comparisons of the supply of shore-side power with marine fuels in bulk carrier services indicate that a shore-side power supply can offer economic benefits to countries, the electricity price is less than 0.19 USD/kWh [43]. Moreover, operating expenses and energy consumption can be decreased by up to 75% through shore-side power [43], which benefits not only vessel owners but also port authorities. Cold ironing can significantly influence cruise ports due to the large amount of power needed for large vessels when several passengers are on board during hotelling [44]–[46]. Hall [47] reported that CO_2 emission reductions with shore-side power are 99.5% for the port of Oslo in Norway and 9.4% for Fort Lauderdale in the US. However, since the pricing structures of cold ironing are different, a return of investment analysis is required. More progress could be achieved through more technical, economic, regulatory, and environmental studies in the future. The integration of cold ironing with berth allocation and quay crane allotment problems can assess new trade-offs.

Refrigerated container technology

The refrigerated container trade needs the constant refrigeration of each container, so that the goods remain cool. The trade has expanded consistently and outweighed other market sectors in the liner shipping field in recent years [48]. According to various studies, the percentage of energy consumed by reefer vessels varies between 20-45% of total energy usage in ports [48]–[50]. As a result, improvements in energy efficacy in refrigerated containers is recommended. Joan et al. [51] concluded that container heating could be prevented by covered spaces for reefer containers. Furthermore, finding the number of plugs for reefers, identifying the location of the reefer zone for minimising travel distances, formulating better electrical distributing systems, developing a powerful strategy for each reefer cargo, and calculating the exact consumption of energy for reefer containers were all considered to be important research perspectives for the energy efficacy in the reefer zone [52]. Apart from that, efficient refrigerated container management fulfils ship demands, while also lowering the associated costs. Given the journey periods, operators devised an optimal plan to minimise energy usage and losses [53]. Indeed, an exterior power source was required for reefer area control in reefer containers due to their cooling power consumption. A time-space model, appropriate for moving reefer vessels, was also developed [54]. Nevertheless, the majority of the aforementioned studies were from the viewpoint of transportation. The energy flow modelling was quite simple and the energy consumption for a single container move was set as '4kWh,' which completely neglected the potential operation flexibility of scheduling transport, which facilitated the study from the perspective of flexibly managing energy [55], [56].

Lighting technology

Lighting is thought to be one of the most energy-intensive components, particularly at night. Indeed, some investigations were conducted on energy-saving lighting systems in buildings, which included the utilisation of smart lighting systems based on sensors, for future structures in California [57], as well as a lighting strategy based on occupancy for an open Dutch working environment [58]. Several previous studies researched the control of fluorescent luminaires based on sunshine [59] and the utilisation of daylight for cheap illumination [60]. Furthermore, control devices that employed daylight could save a lot of energy, particularly for interior uses [61]. Remarkably, daylight gathering utilised natural light to counterpoint artificial lighting collected from established lighting systems, with the aim of reaching a target illumination level while lowering electric loads [62]. Moreover, controlling LED illumination systems, based on occupant position and daylight dispersal, resulted in significant energy reductions [63][64]. Nonetheless, effectively lighting an outdoor location, like a port, while also adhering to each space's unique illuminance rules, was considered a sophisticated job. Outdoor illumination in ports consumes a significant amount of energy [65], surpassing 70% of the total energy requirements of a port, in some instances [66]. Because of their complicated operations and services, ports have a high energy consumption; hence, they could be classified as small cities, communities, or villages [26]. In fact, the majority of existing port methods and technologies are out of date, but there is significant potential for considerable energy savings, along with an enormous reduction in the environmental impacts of ports [67]. Besides this, ports are required to follow stringent monitoring and societal rules in this situation [30]. The Nearly Zero Energy Port project is a hopeful step toward the sustainability of ports [9] and, simultaneously, port exterior illumination is critical for safety and comfort [68], as well as to enhance their aesthetics [69][64]. In many ports, technologies are applied to enhance lighting energy efficiency. To ensure energy efficiency, LED lamps could be used in port storage facilities, administration buildings, and lighting for outdoor terminals [50]. Assuming that 11 h of light is required, by using LED lamps an annual electricity saving of 922 MWh could be obtained [50]. In addition to LED technology, lighting levels and the design of armatures also contribute to electricity savings [51].

Other technologies

Automated mooring systems can be used as energy consumption mitigation methods and with major effects [11][70]. In this system, vessels are often vacuum-moored and locked without many manoeuvres, which decreases the motor's energy consumption. A reduction of fuel consumption between 10-15% is possible, as a result of state-of-the-art technologies, including start-stop engines for diesel equipment [71]. Many ports can use reactive power compensation methods, which compensate the reactive power consumed by various electrified equipment [71]. With the application of this system, while the power factor increases, there is a decrease in network losses. In the future, ports will be able to work in CCS systems with facilities for collecting and depositing CO_2 waste without releasing it into the air [72]. Heat exchangers, water treatment technologies, and degassing installations are used in the port of Rotterdam, to capture heat and save energy [73]. Furthermore, energy can be saved more by material recycling or waste-to-energy strategy application in ports [72][74].

In fact, automated mooring devices can have a significant effect on energy usage [11], [70]. Vessels are mostly anchored by the use of a vacuum, in this method, attached to the berth without much manoeuvring; this lowers the engines' energy usage. Moreover, advanced techniques, including start-stop engines for engines running on diesel, could reduce the consumption of fuel by 10-15%. Many terminals could benefit from reactive power compensation methods, which involve compensating for the reactive power utilised by different electrified devices, resulting in a reduction in energy consumption [75].

MANAGEMENT FACTORS

Equipment management

The organisational effectiveness of a port is determined by how well the available resources are managed; there is a positive connection between reduced operation periods, e.g. ship handling times and cargo transit times in the yard, and operational effectiveness in ports [76]. Thus, the energy economy is the result of operational effectiveness [19][77]. As a result, the majority of optimisation studies associated with improved port operation plans contribute to energy efficiency. Many of the studies in the literature considered mathematical models that had a goal function related to the energy consumption of terminals, particularly cargo terminals that were divided into three functional regions: quayside, landside, and yard side [78][79]. Also, other publications mentioned the energy-aware utilisation of quayside resources such as berths, conveyors, and quay cranes (QC) [80]–[82]. For example, the consumption of energy of QCs that existed in the objective function was used to build a combined berth allocation and QC assignment problem in [83]. Similarly, Iris et al. [84][85] addressed the reduction of QC energy consumption in relation to marginal QC output, in which QC energy consumption issues should be tackled the trade-off between energy-saving and time-saving, minimising lateness. In addition, this study also considered QCs' non-working and working energy consumption [55]. It was noticeable that working energy consumption was determined by the number of movements per hour and energy consumed throughout loading or unloading, but non-working energy consumption was determined by lighting and auxiliary units. Moreover, the QC assignment was identified by the queuing activity of automated guided vehicles (AGV) [86] and it was shown that the optimal number of QCs decreased according to the consumption of energy per QC per hour [86].

Planning on the yard side focused primarily on container transport but stacking was also considered as one of the solutions for port management, to reduce energy consumption [7], [87]–[90]. He et al. [91] discussed yard crane (YC) scheduling with energy consumption, transforming it into a variant of vehicle routing issues. They reported that, for all YCs, energy savings of 25.6% were obtained, compared to practical findings. Positions in the same row are given priority by the energy-aware planning of YCs [92]. Therefore, researchers on energy-aware planning have recently concentrated on automated container terminals. Indeed, a predictive control model for balancing the throughput and energy consumption of a single QC with AGVs and ASCs is established, in which the discrete-event and continuous-time dynamics are simulated with a hybrid automation representation [93]. The results revealed that the proposed method achieves the same range of reduced energy consumption because the approach enables vehicles to decelerate in the yard. Another study, by Xin et al. [94], experimented with 1 QC, 2 AGVs, and 3 annualised slot capacities, indicating that an average 6.23 kWh of energy is required to load 8 containers efficiently [94]. Xin et al. [95] indicated that energy consumption of approximately 65 kWh can load 90 containers in a case of efficient energy management. In fact, emissions from port operations made fewer contributions to overall emissions but could be handled in a variety of ways, although only a trivial number of ports actually tracked their emissions. Wilmsmeier et al. [19] investigated methods to improve energy efficacy through the use of the latest handling equipment, the implementation of energy management systems, and differentiated port and terminal costs. Acciaro et al. [72] studied ports that implemented energy demand management approaches and produced their own eco-friendly energy on-site, namely solar panels, wind turbines, and heat plants. They also demonstrated that, while ports did not consider energy generation as an external revenue resource, controlling not only supply but also demand could alleviate their expenses and environmental impacts [34].

In recent years, electrification has become more common in ports because a substantial decrease in pollution from the emissions generated by electricity consumption, compared to those generated by using fossil fuels, is accompanied by cost-efficiencies when using electrical port equipment. More interestingly, peak shaving refers to practical strategies for reducing a port's peak consumption of energy and, in fact, there are numerous techniques for peak shaving. As reported, peak electricity usage was observed to account for approximately 25-30% of the monthly electricity bill [96]. Obviously, the energy bill had two major components, including an unchanging expense of electricity utilisation and a variable expense, based on the level of consumption [95]. Even though ports could not reduce the set cost, which was specified and paid yearly, lowering the variable cost could be concentrated on, which was mainly decided by peak energy use and total consumption of electricity [20]. Therefore, a high peak energy usage, such as occurs through the simultaneous utilisation of all devices, would result in high energy expenditure in the monthly bill. Several methods use the load profile curves (1) – Using any stored energy in the case of peak energy demand periods, (2) – Shifting the energy demand in the peak period to non-peak periods, (3) – Turning off non-critical loads over peak periods.

The efficient management of equipment in ports is considered as one of the solutions for achieving low energy consumption. In the ports, QCs and ship-to-shore (STS) cranes are mainly used on the quayside to load and unload cargo [97]. While rubber-tired gantries (RTG) and rail-mounted gantries (RTG) are used to stack containers, yard trucks (YT) and AGVs are used to horizontally transport containers. In recent years, highly automated equipment types are used to enhance operational efficiency, as well as decrease the involvement of humans [98]. Equipment, including automated QCs and RMGs, can be used in automated container ports and annualised slot capacities can be used for stacking operations in automated terminals. In bulk ports, cargo is mainly loaded and unloaded onto the ship by conveyors and pipelines [99], while it is stored in the yard of bulk ports in silos. Thus, increased energy efficiency and reduced emissions of GHGs are achieved in ports by electro-mobility (e-mobility) [100]. Due to its flexibility and productivity, RTG is one of the most common pieces of equipment used in yard stacking operations. Many researchers have been attracted by energy efficiency technologies for RTGs. Electrifying RTGs through electric drive systems is a crucial approach. Electrification of an RTG can be via a bus bar, touch wire, or cable reel system [100]. E-RTGs can switch between grid power and power from a diesel generator [100], and they work considerably better than conventional RTGs in connection with energy savings and reduction of CO_2. In comparison with diesel-fueled conventional RTGs, E-RTGs reduce energy expenses by 86.60% and GHG emissions by 67% [50]. More interestingly, researchers examined the installation of a flywheel with a smaller diesel engine for an RTG and predicted that fuel reductions of up to 35% were possible [101]. Similarly, Tan et al. [102] figured out that by installing a flywheel, the energy consumption was decreased by more than 30%, and the generator had a longer lifespan, less noise, and quicker system reactions. Apart from that, a power management system which considered stochastic loads reduced the use of fuel by 38%, for flywheel-installed RTGs [103]. Another proposed power management system for RTGs, based on hybridisation, could reduce fuel consumption by 20-60% [104]. By comparison with RTGs, there are fewer emissions from RMGs and ARMGs because they use electricity as an energy source [105]. Indeed, Yang et al. [106], [107] compared the energy needs of RTG, E-RTG, RMG, and ARMG. They indicated that E-RTG has the least energy consumption and RTG is the highest energy consumer. E-mobility developments greatly affected the electrification and automation of equipment in horizontal transport operations. Thus, AGVs have become more efficient, reliable, and safe [108]. Similar to the majority of other equipment, AGVs can be diesel-powered, battery-powered, or hybrid. Compared to the traditional AGVs, the use of a B-AGV fleet is recommended to charge the battery in off-peak hours [109]. The results indicate that the average energy consumption is 64% lower when B-AGV is used, as illustrated in Fig. 2.

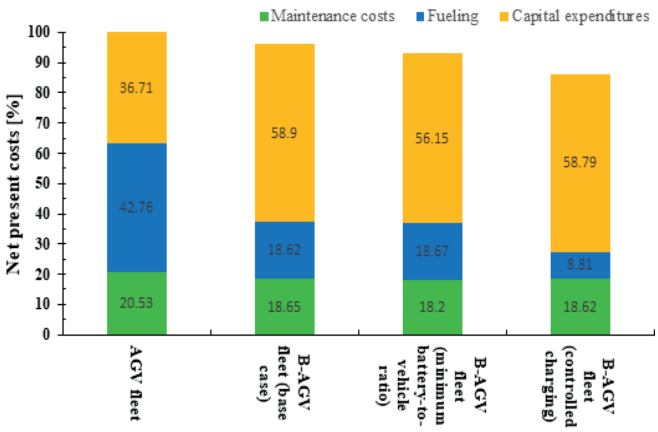

Fig. 2. Comparison of net costs for using different AGV models [109]

In fact, the impacts of electrification could be depicted using different kinds of handling, container terminals, energy costs, freight seasonality, yard sizes, and so on [110]. Economic and environmental studies are also critical for completely automated and electrified ports [111]. In future, the incorporation of electrified autonomous machinery and devices for energy storage, as well as smart meters, would broaden the potential area for further analysis [112]. In next-generation ports, electrification, automation, and smart energy management technologies would be employed [113][114]. In this respect, the functions of electrified and/or autonomous transport in smart grids for port activities should be considered in greater detail. Also, a clever energy planning system could be created by taking random energy demand and supply into account.

In general, peak shaving techniques could be employed in the processes of QCs, electrified machinery, and reefer containers. As a QC consumes a significant amount of energy at a port [96], it is necessary to restrict the number of QCs hoisting simultaneously. Additionally, while synchronising the QCs, not lifting them at the same time was seen to lower the peak electricity consumption significantly; it could raise average processing time as well as waiting duration [96]. It was also reported that, lifting 5 QCs at the same time reduced peak energy usage by 11.1%. Apart from that, employing less handling equipment and smoothing out the processes throughout peak hours could reduce maximum electricity consumption [96]. Peak demand would be reduced by 19.8% in the instance of 6 QCs, if the highest permissible energy demand was fixed to 12 MW. Simultaneously, the typical waiting time was only increased by 3.4 seconds per container. Peak shaving for QCs using twin lift and dual hoist technology was discussed by Parise et al. [20]. Indeed, the combination of crane job cycles with a strong optimisation tool, as well as an energy storage system, were two of the main operational and technological approaches suggested for peak shaving. In addition, Parise et al. [20] disclosed that, during peak times, the saved energy could be utilised, reducing peak energy demand from 10.22 MW to 2.63 MW. For reefer containers, they required variable electricity depending on the month and time of day, so peak shaving approaches were critical for lowering the peak electricity demand in the reefer area because reefer containers constituted 30-45% of overall energy utilisation [49]. The period before a reefer was hooked in, the number of reefer plugs, and the sizes of the vessels, all had an impact on reefer energy needs [49]. Therefore, the dispersal of energy between reefer batches and restricted provision of electricity to reefer batches are considered as two peak-shaving techniques. According to the experiments, the highest energy demand needed for reefers was 14.8 MW in the base scenario and this was reduced by an average of 62.8%, by the first method. Meanwhile, the latter approach had a maximal limit of 14 MW, which led to a reduction in peak demand of 7.2% [49]. Nevertheless, the connection between total operating time, energy consumption, and real idling periods for each machine were not comprehensive. Therefore, integrating the management of energy and plans for real-time operations required improvement. Indeed, a better model which could evaluate the relationship between the consumption of energy and yard traffic congestion was needed for yard activities. Therefore, it was noted that energy-aware routing and equipment scheduling was thought to be a fascinating study subject. Moreover, economic, operational, and environmental studies could be used to examine how peak-shaving techniques could be integrated into smart energy management.

Energy consumption and emission management

Since GHGs emitted from port operations are known to be a function of energy utilisation, a shortage of knowledge about energy usage might result in ambiguous information about the carbon footprint of goods through the port, as well as the total GHG emissions. According to Iris et al. [50], the primary energy consumers in ports are reefer containers (accounting for 43%), QCs (constituting 37%), and yard machinery and buildings (20%). The petroleum usage for the aforementioned ports' YTs, and RTGs comprised 32% and 58% of the overall consumption, respectively. Similarly, reefer containers and QCs each consumed 40% of the overall consumption, in a low-automation container port [52][48]; whereas, horizontal containers and YCs primarily utilised 30% and 68% of the fuel, in turn. For another example, the port of Chennai was reported to consume 6.3 million litres of gasoline, of which 59.2% and 25.5% were employed by cranes and tug vessels, respectively [115]. As reported, the port sector accounted for 3% of total global GHG pollution [70]. It was noted that several variables had an effect on the shift in energy usage, including (1) – changes in handling quantities and patterns of ship calls, (2) – fluctuation in reefer container energy requirements, and (3) – variations in port stay periods for trans-shipments, imports, reefer containers, and exports [19]. For these reasons, energy management in ports is very important, with the aim of minimising the energy used and, therefore, reducing CO_2 emissions.

Indeed, to manage the energy consumption in a port efficiently, building suitable models is very necessary.

While an instrument or device was in use for measuring energy consumption, calculations and/or observations were employed to estimate the consumption of energy. A recent Sea Terminals project examined ports in Valencia and Livorno; they suggested a smart integrated strategy in energy management towards low-CO_2 emissions, as shown in Fig. 3. They concluded that using renewable energy, integrated with smart energy management, could considerably reduce energy consumption and GHG emissions [81][116]. Grundmeier et al. [117] indicated that simulating yard and berth operations could estimate energy consumption [117]. A forecast of electrical usage in the short term and an analytical technique for one electrified RTG was given in a study by Alasali et al. [118]. Regarding emissions, they included emissions from land (such as emissions from container processing in the port) and emissions from ship activities (such as emissions from the arrival and departure of a ship, berthing, and ship manoeuvring in port waterways). All of these emissions were included in the port pollution list. The technique of determining emissions was primarily based on a bottom-up strategy, in which all emission sources made an equal contribution to overall emission values. Indeed, inputs in the various studies included size of port, cargo capacity, and the quantity of equipment investigated [119], [120]. Furthermore, the kind of engine, fuel type, port stay period, and sailing pace were all factors considered in the studies regarding ship-based emissions [115], [120]–[123]. Also, research concentrating on the GHG emissions from machinery and zones took into account scheduling, gridlock, and routing in the yard. It also addressed how port selection affected CO_2 pollution [106], [124], [125]. Liao et al. [126] suggested an emission model based on the activity for measuring emissions between Taiwan's hinterlands and various towns, and demonstrated that when trans-shipped goods were moved to a new port, emissions were reduced.

Smart grid management

The working characteristics of seaports promoted the application of smart energy management methods because smart energy management approaches could supply controllability and flexibility in operation strategy. These could be efficiently used to coordinate production and load demand and, at the same time, alleviate uncertainty or volatility [56]. Aside from the development of electrification, flourishing cold chain transport and cruise ships also led to heating and cooling demands for the port. Furthermore, high-voltage shore connection devices for passenger ships and large cargo ships were used in ports [127]. In this context, future ports will have integrated transport energy systems, and energy management is considered critical in forming the future economic and environmental behaviour of marine transport [54][56]. Buiza et al. [128] investigated smart energy systems employed in ports, in order to evaluate the present scenario in terms of operation, energy, and environmental factors. The research showed how efficient energy management could play an important part in port operations, by allowing interaction

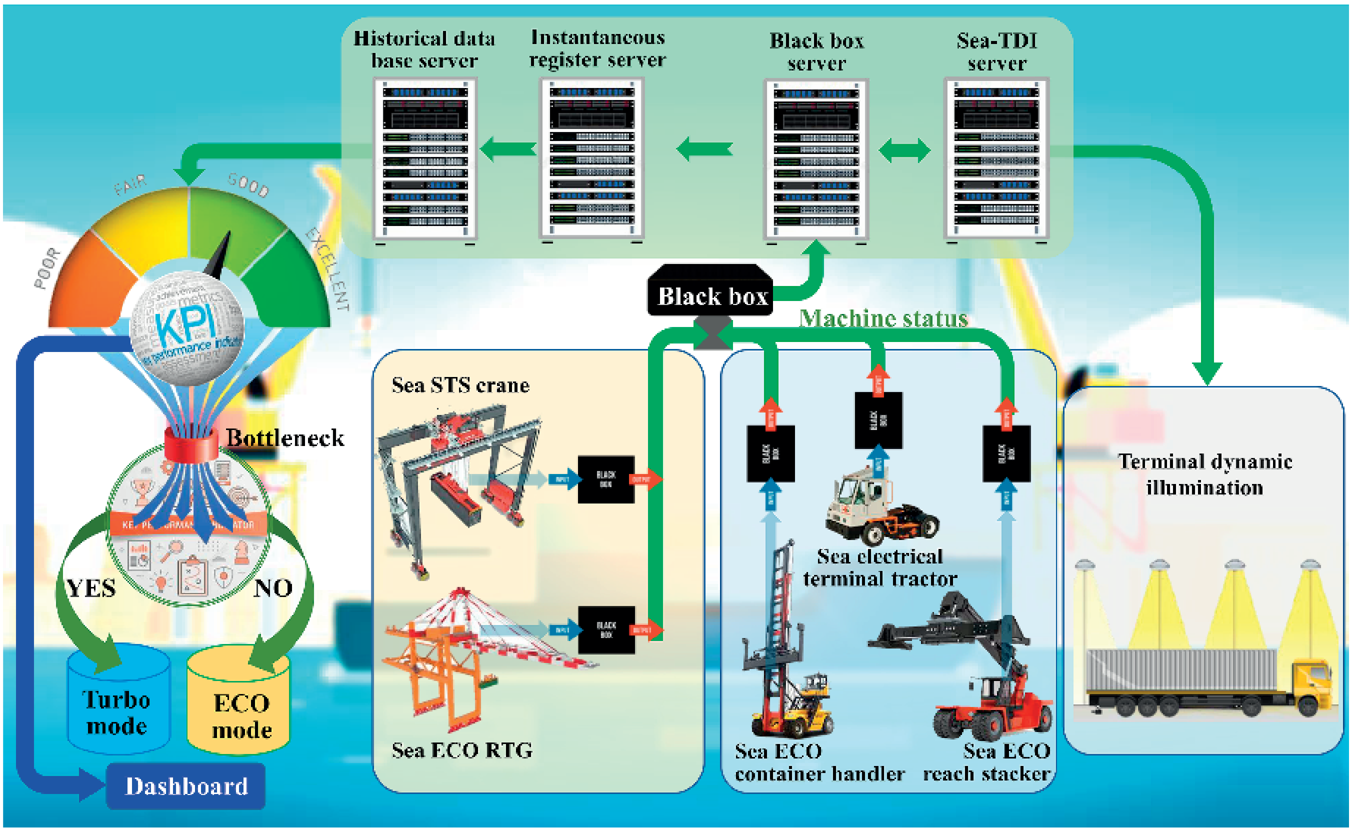

Fig. 3. Integrated energy systems smart management strategy and renewable energy [81][116]

with green sources of energy to guarantee self-consumption and decrease carbon emissions. According to comparable research by Parise et al. [129], smart grid approaches could improve the electrical efficiency of port energy management systems. Also, port authorities and stakeholders were advised to employ more informed approaches to managing energy, in order to maximise port and community benefits. The idea of a smart seaport microgrid was suggested [130], which required effective energy management techniques to handle multiple energy supplies, while satisfying port energy demand.

An energy management system could regulate, supervise, and optimise the activities of smart nanogrids and microgrids [131][132]. In fact, it comprises a high-level controller, as well as a group of lower-level controllers, linked by a communication system [133]. The motivation for developing the seaport microgrid was to use it as an energy district, so as to promote the penetration of renewable energy and grid storage capacity through selling power to the market via the main grid. Parise et al. [129] depicted an idea that was newly suggested for managing a port, called a seaport microgrid. Besides this, Lamberti et al. [134] indicated that the port region was regarded as a distinct zone with its own energy strategy. In fact, two microgrid port projects were manifested in depth in Genoa (Italy) and Hamburg (Germany), and the working data demonstrated their validity [72]. Fig. 4 shows an example of a standard seaport microgrid layout, in which the port was linked to a major grid and a variety of green energy sources were incorporated. Indeed, the seaport would provide on-shore electricity provision (cold-ironing), as well as berth location services to ships when berthing. Interestingly, the seaport's central control would send messages to each subsystem in the port for both energy and logistical management [54]. In general, a port microgrid employs microgrid techniques to enhance its operational behaviour.

The port microgrid was described as a system for managing all energy-related problems in a port area [72][129]. Because the ships were berthing in and out constantly, there would be constant plug-and-play activities, which might result in large loading pulses [135]–[137]. Port microgrids include a range of important and adaptable electrical loads such as cranes, winches, reefer systems, shore power delivery to berthed-in vessels, and electric cars, as well as the ability to incorporate local energy sources. Many studies have indicated that the increased use of electricity, with the incorporation of renewable energy and energy storage systems, will be the main factor in achieving better environmental sustainability in future ports [50], [54], [134], [138]. Nevertheless, because of the intermittent and volatile nature of non-dispatchable renewable energy systems, along with the incorporation of novel kinds of electrical loads, port area operation planning has become considerably challenging [50], [54]. In fact, with a greater prevalence of offshore renewable energy systems held by seaport owners, they would run their dispersed production and energy storage system units in order to profit economically, by selling back the energy to the main grid [139]. Thus, in this regard, the port operation differs from that of a typical grid-supported (and isolated) microgrid, with the primary goal being to handle the system's load demand by depending on power delivery from the main grid [140]. A smart grid system is needed to fulfil the requirements of four sectors: (1) QCs, (2) on-shore, (3) infrastructure and storage, and (4) equipment. As reported, energy storage systems, as well as conventional grid systems, were known as the primary components of the smart grid. Wind power and solar energy were also used to augment sustainable energy sources. Clearly, the smart grid was at the core of the system, performing functions including energy multidirectional flow centralisation distribution, control, and time data handling [54]. In general, the connections between the components of the grid control system at a seaport are depicted in Fig. 5.

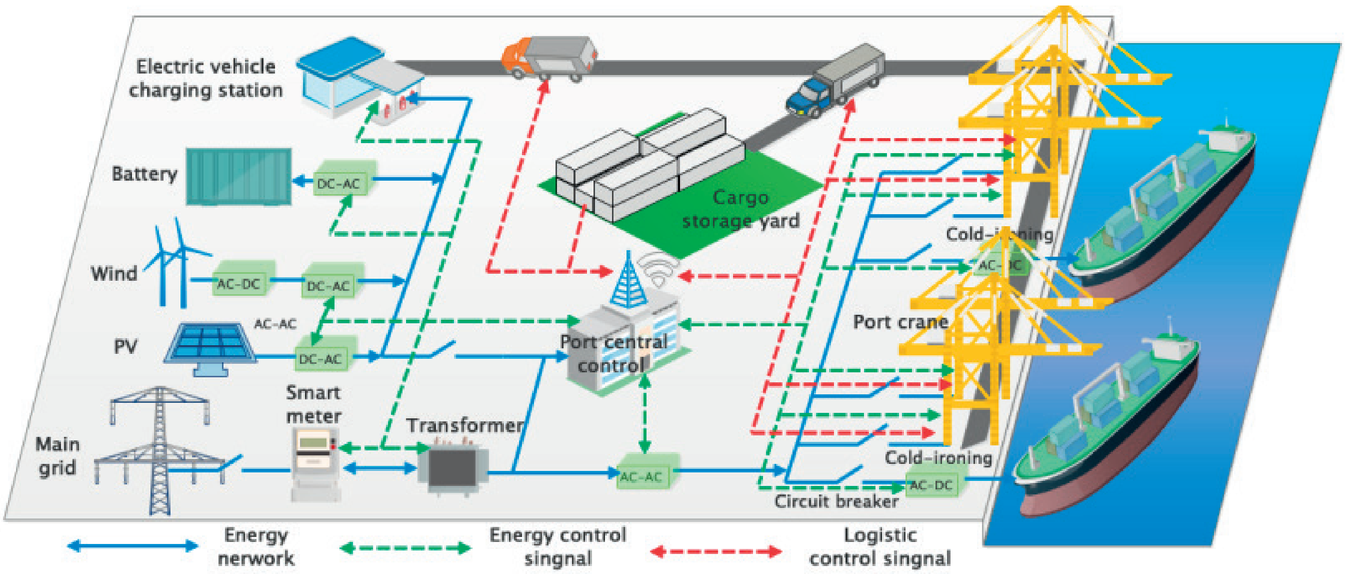

Fig. 4. Seaport grid for energy management plan [54]

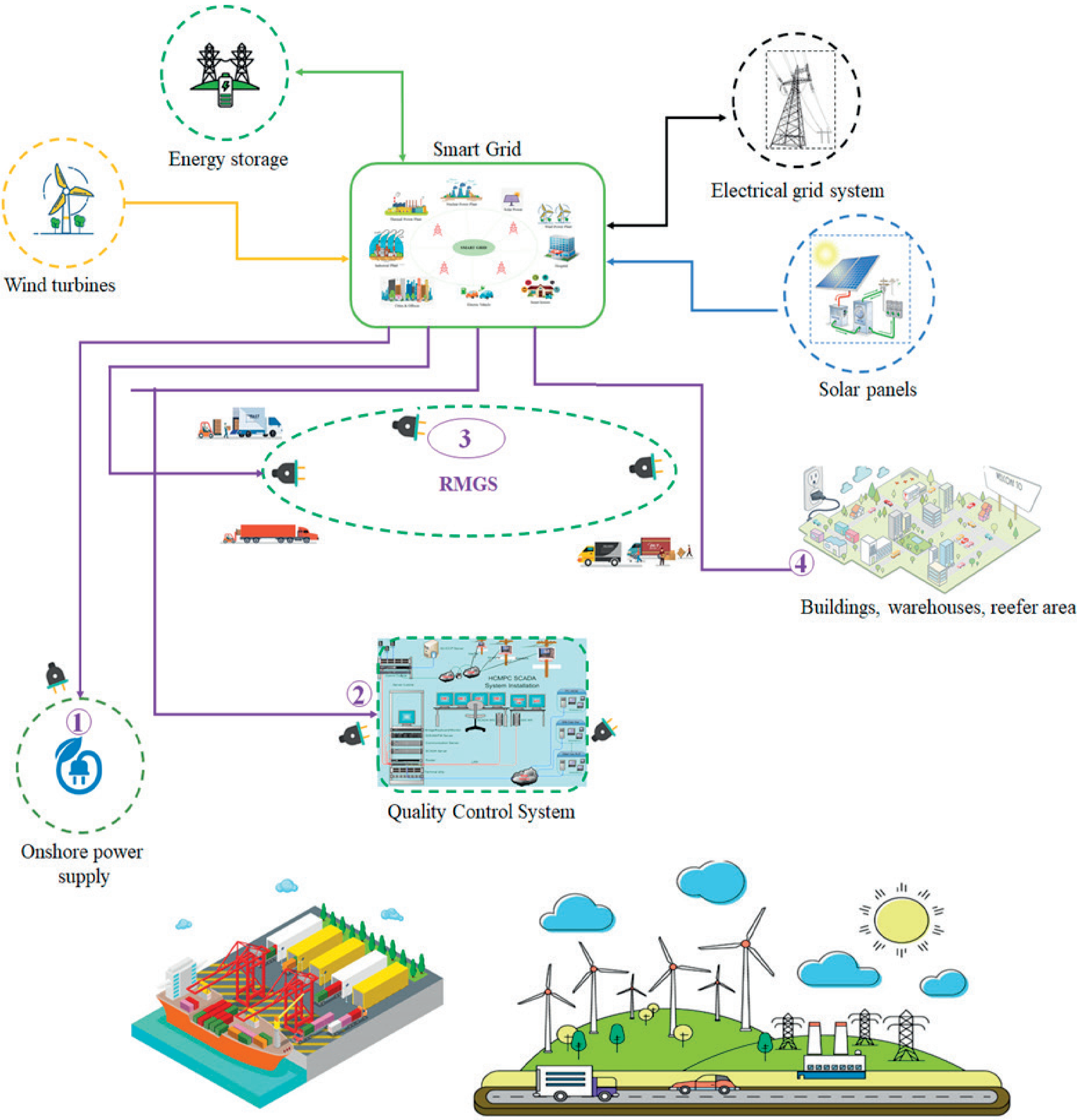

Fig. 5. Model of smart grid management at seaports [141]

POLICY FACTORS

The significance of consuming energy at ports stems from the large energy requirements of seaport activities. Energy efficiency is regarded as a problem for port authorities, since more energy usage results in more carbon emissions and higher operating expenses [52]. As a result, most seaport organisations advocate for port officials to enact port laws aiming to mitigate energy consumption, while increasing renewable sources of energy. This would also help to lower carbon pollution and energy expenses for the operating systems of ports [142]. Various innovations have sought to define and establish environmental performance metrics to assist port officials in alleviating and eliminating the influence of environmental impacts [143]–[145]. Regarding the diversity of port authorities, they were observed to differ significantly in their aims, institutional frameworks, functions, market power, financial capabilities, competencies, knowledge, and skills, as well as energy and environmental concerns, which were heavily influenced by the specific position and properties of each seaport zone [10]. Importantly, there were three levels of potential intervention from the viewpoint of environmental management by a seaport authority, with various potential effects and impacts at each level: (1) – those under the port authority's responsibility (limited effect, high influence), (2) – other interventions in the port zone (reasonable effect and influence), as well as (3) – interventions at the transportation and logistics chain levels [10]. Therefore, a model of energy management is suggested, with the aim of optimising energy consumption, thereby reducing GHG emissions, as depicted in Fig. 6.

green policies and initiatives [149][150]. A good example is the green purchasing policy, which requires ports to acquire and buy goods from ecologically favourable sectors [151], [152]. Seaports, such as the ports of Zeebrugge and Houston, purchase green dredging and towage, as well as green power generated from renewable energy [153]. Furthermore, the green travel program also promotes and incentivises port workers and residents to utilise public transportation, carpooling, biking, vanpooling, and even constructed bicycle parking and storage [151], [154]. Moreover, ports implement policies aiming to reduce freight and port vehicle idling periods via eco-driving and vessel idling times by designating quicker berths for green boats, such as the green

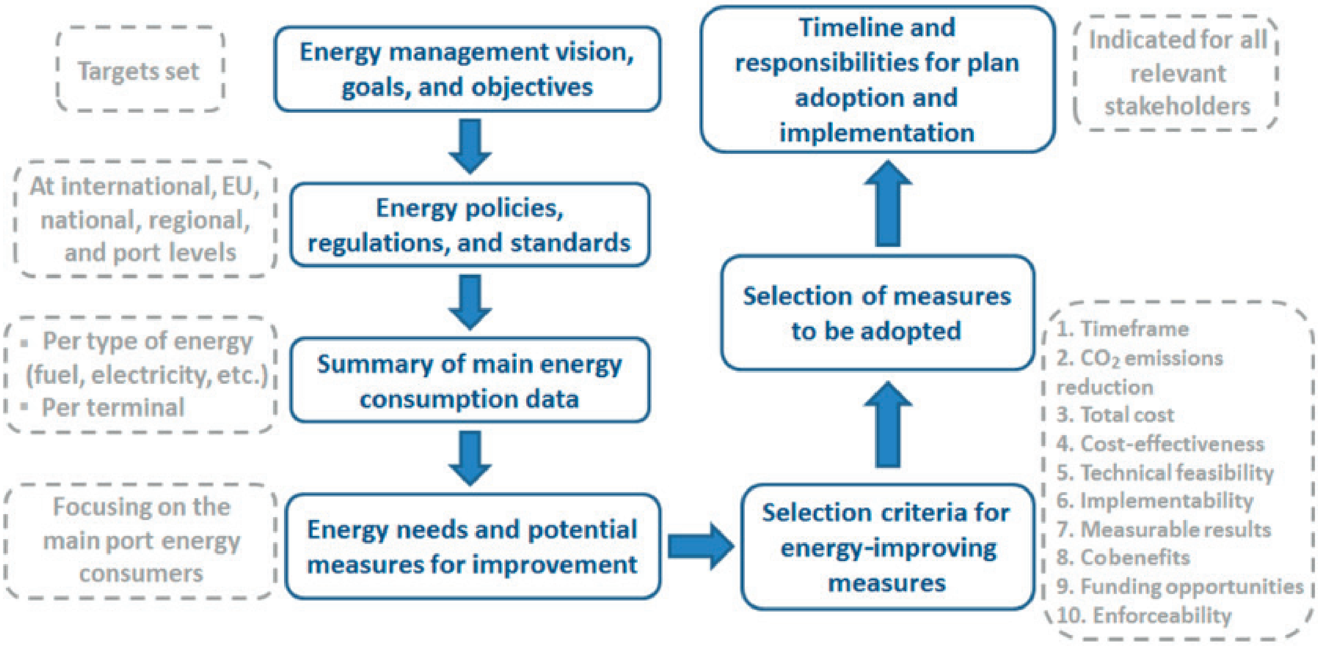

Fig. 6. Energy management planning to get low costs and low CO_2 emissions [10]

Noticeably, the impact level that a seaport authority had in taking actions for enhancing a port's energy and environmental performance differed across the three levels and was determined by the administrative structure, functions, and goals, along with the seaport authority's general competence [146]. Seaport officials, at least those of the landlord kind, took responsibility for the possible incorporation of environment-related factors in the terminal granting process to private operators, in addition to their involvement in seaport environmental management [147] [148]. Furthermore, seaport authorities might include more stringent construction guidelines for the modal split targets, infrastructure and superstructure of ports, and specific methods, such as using a minimal proportion of green energy or installing cold ironing or LNG facilities in the concession agreement [10].

In fact, seaports could go beyond technological and operational emission reduction steps by implementing various

berth allocation at the Panama Canal. More appealingly, ports recently emerged as key participants in carbon capture and storage [72]. Apart from that, ports create verdant buffer zones that enhance the look of a city; for instance, ports of Long Beach planted trees to optimise carbon sequestration [151], [154]. Thus, the carbon captured through carbon capture and utilisation could be used to supply other products [155]. Table 1 summarises the suggested policy for energy management at seaports around the world.

Tab. 1. Suggested policy for energy management plan in ports

Port and country	Input	Facilities	Policy proposal	Reference
Rotterdam, Netherlands	– The overall trans-shipment performance; – Modal split, terminal layout; – Terminal configuration (QCs, BCs, RCs, RS, ASCs, RSCs, AVGs).	Cargo handling, cranes, vehicles, trucks.	– Construct compact terminals; – Fast replacement of (diesel-powered) terminal equipment; – Blending biofuels.	[119]
Barcelona, Spain	– Consumption of electricity; – Consumption of natural gas, gasoline, diesel oil, and jet fuel; – Consumption of waste.	Cargo handling, cranes, vehicles, trucks, arrival vessel, departure vessel, hotelling, manoeuvring.	– Compatible with existing city inventories; – The consequences of GHG emissions might be more than global-scale climate change.	[156]
UK ports	– Time for staying at the port; – Type of vessel; – Type of engine; – Type of fuel.	Cargo handling, cranes, vehicles, trucks, arrival vessel, departure vessel, hotelling, manoeuvring.	– Developing both individually and collectively port working policies of reduction in emissions; – Encouraging shipping companies.	[11]
EU ports	– Number of lights, equipment, and cooling systems; – Throughput of containers; – Working time per day; – Time for staying at port.	Cargo handling, cranes, vehicles, trucks, cooling systems, lighting, and generators.	– Instead of allocating the equation of CO_2 to containers; – Handling a reference system combining weight and volume might be required;	[71]
Qingdao, Shanghai, and Tianjin terminals, China	– Container throughput; – Berth length; – Number of equipment; – Type of fuel.	Cargo handling, cranes, vehicles, trucks, heaters, water & solid waste treatment.	– Making appropriate policies for GHG emission mitigation; – A dual method to calculate GHG emissions from various sources.	[120]
Tianjin Port, China	– Type of engine, fuel; – Installed power; – Operating time; – Emission factor.	Arrival vessel, departure vessel, hotelling, manoeuvring, fairways, berth, anchorage areas.	– Emission measurement in port with both high temporal and spatial resolution is available.	[157]
Chennai Port, India	– Number of equipment; – Type of engine, fuel; – Speed of approach in port.	Cargo handling, cranes, hotelling, manoeuvring, arrival and departure vessel.	– Implementing energy conservation measures and renewable energy technologies.	[115]
Tianjin, Ningbo, Guangzhou, and Dalian ports, China	– Number of QCs, YCs, arrival vessel; – Type of fuel, vessel.	Berth, cargo handling, cranes, vehicles, trucks, hotelling, manoeuvring, arrival and departure vessel.	– Stochastic DEA can be used for future economic planning and policy evaluation.	[122]

SUGGESTIONS FOR GREEN PORTS TOWARD GREEN LOGISTICS

It is easy to see the enormous opportunities for renewable energy applications in ports, which contribute to meeting a portion, or even all, of the port's electricity consumption, thereby reducing carbon emissions. In a study by Mishra et al. [70], carbon emissions were calculated for different port activities, showing that port operations produced approximately 280,558 tons of CO_2 per year. So as to alleviate CO_2 emissions, several methods were suggested for integrating renewable sources of energy [158], [159]. However, the important issue is the desire of the port managers/owners to use renewable energy to meet their energy requirements [160]. Indeed, seaports are known as logistic nodes aiming to accommodate ships/vessels [161]. Ports, as extensively global nodes, could generate adverse effects on the climate via their logistical and industrial functions. Hence, ports play an important role in green supply chain management [162]. Indeed, the structure of green supply chain management associated with port functions can be illustrated as Fig. 7.

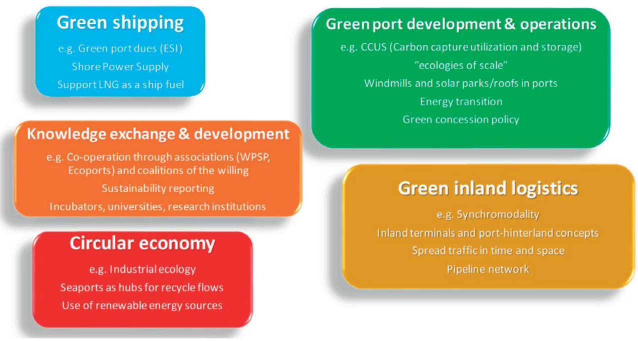

Fig. 7. Role of ports in green supply chain management [162]

As reported, the renewable sources of energy that could be advanced in ports include: the wind technology installed in electric forklifts and cranes; off-shore, photovoltaic techniques integrated into buildings to meet the energy demand of electric vehicles, offices, and garage facilities; small-scale wind power used in buildings, to fulfil the energy demand of garage facilities, offices, and electric transport; biodiesel for an internal fleet; and ocean energy for electric forklifts and cranes [163]. When the use of renewable energy is not feasible, ports could buy power from the Renewable Energy Purchase Initiative to mitigate GHG emissions [151]. Furthermore, ports engage in and collaborate with other businesses through renewable energy cooperatives, to broaden the extent of renewable energy employment. For this reason, port authorities should increase the penetration rate of renewable energy to energy systems, in order to achieve the goals of green port logistics and green maritime in the near future.

Indeed, Hentschel et al. [164] examined how to expand renewable energy cooperatives in the Port of Rotterdam. In addition, the EU's 'E-ports' initiative researched the possible use of renewable energy in EU ports [165] and a The World Association for Waterborne Transport Infrastructure described renewable energy techniques and their potential [166]. When combining renewable energies, the overall energy usage and CO_2 emissions were seen to greatly decrease. In a study by Fahdi et al. [167], diverse renewable energy was compared for various Asian ports, discovering energy savings ranging from 12-84% and CO_2 reductions ranging between 2.7-80.0%. Some studies addressed the significance of green energy sources in establishing a viable port [51]. In this context, "the proportion of energy from renewable sources" was utilised as a key performance indicator (KPI) for smart and sustainable ports [50], [168], [169]. Apart from that, the significance of RE was also emphasised in a German marine industry report [170]. In this regard, Hamburg Port erected over 20 wind turbines with a total capacity of 25.4 MW, with seven additional turbines scheduled to be installed in 2017 [171]. Although offshore turbines were usually placed in offshore wind farms, they were too large to be incorporated into the port's infrastructure, and so ports have entered into power purchase deals with wind farm operators [166]. More significantly, Li et al. [172] investigated the optimisation of offshore wind production and storage for container ports. In fact, current wind energy producers operate in the ports of San Francisco, New York/New Jersey, San Diego, Zeebrugge, Baltimore, Hamburg and Long Beach, while significant wind developments can also be found in the ports of Rotterdam (200 MW), Amsterdam (28.2 MW), and Antwerp (45 MW) [173].

Ocean energy exploits the energy generated by tides, ocean waves, salinity, and temperature variations [173], and yet it is limited because of navigational and biological challenges. The present state and potential prospects of ocean sources of energy were examined in [174]. Ocean energy could be exploited in two ways: tidal energy and wave energy. Tidal energy converters harness the kinetic energy of the tide's nearshore in passes, islands, and straits. Some investigations looked into the utilisation of tidal turbines in various ports, such as the port of New Jersey in the United States of America [175] and some ports in Spain [160][176]. Wave energy utilisation was investigated for different ports, including Port Leixes in Portugal [177] and various Italian ports [178]. Furthermore, the evolution of the conversion of wave energy in port breakwaters was examined by [179] [155]. Another study, by Alvarez et al. [180], offered a techno-economic analysis of using tidal energy to satisfy the energy requirements of ports and local communities. According to the research, utilising tidal energy was a viable choice in terms of expense and sustainability. The research also investigated tidal turbine generator design while evaluating the economic viability of implementing the system.

Solar energy is considered to be a potential renewable energy source and solar energy can be used to produce electricity or to heat water etc. [181][182]. In particular, PVs were employed in off-grid applications, including remote signals, navigation aids, and buoys. Solar panels were installed in open areas when the land was available, and on the roofs of buildings, cruise ports, cold storage warehouses, and normal warehouses, as evident at ports such as Rijeka, Venice, and West Sacramento [10][155]. Additionally, PV electricity has been utilised in the ports of Genoa, Amsterdam, Felixstowe, Tokyo, San Diego, and Antwerp [72]. Significant pollution reduction could be realised if the OPS was powered by wind turbines and PVs [183]; thus, PVs have been suggested as a low-carbon green port strategy [184]. Meanwhile, panels are placed on the rooftops of port buildings, lowering the energy expenses associated with heating canteens, buildings, warehouses, and bathrooms [185][155].

Another sustainable source of energy, under consideration for ports, is geothermal energy [72]. Geothermal energy could be employed to produce electricity and, along with cold stores, the heat can also be utilised for heating and cooling workplaces, buildings, and warehouses. Furthermore, near-surface geothermal energy is used in EU ports [173] such as Antwerp and Hamburg [72]. Combined heat and power facilities, also known as co-generation, could offer a significant opportunity for ports [129][186]. It has been noted that combined heat and power could be operated in a heat-controlled mode, employing a waste heat recovery device, from the in-house utilisation of port buildings [171]. Notably, heat exchangers, degassing systems, and water purification technologies are used by the Port of Rotterdam to save energy and collect heat [73]. Material recycling for ports also contribute to additional energy savings [72]. In addition, ports could serve as carbon capture systems in the future, with facilities collecting excess CO_2 from activities and depositing it, without discharging it into the atmosphere [72].

Moreover, Balbaa et al. [187] suggested statistical techniques for combining solar-based farms and biomass energy, with the aim of satisfying electricity requirements in port locations. The effect of such integration was found to have 50% power consumption optimisation with local renewable energy production [188]. In general, green ports should include a core principle relating to Energy-Environment-Economy (3E), as depicted in Fig. 8 [189].

In order to have a high rate of renewable energy in the energy systems of ports, Green Efforts initiatives, sponsored by the EU, recommend: (1) – external provision of regenerative energy and (2) – energy generation from sustainable resources for ports [75]. In the first case of, ports could serve as a great negotiator, grouping all minor customers around the port and negotiating with electricity providers, and then, the supply energy can be distributed to consumers [50]. Even though the use of renewable energy in ports shows a variety of supplied energy source possibilities to target the green port goals, it should take account into the efficiency of using which green energy that is considered the most potential at those ports. Table 2 illustrates various capabilities of renewable energies [155].

Tab. 2. Power capabilities of various renewable energy sources [190][155]

Renewable energy sources	Power produced
Wind turbine	Max 6 MW
Solar PV – rooftop	Max 2 MW
Solar PV – on-ground	Max 50 MW
Tidal energy converters	Max 750 kW
Wave energy converters	Max 250 MW

Fig. 8. Energy-Environment-Economy principle for green ports [189]

In addition to renewable energy applications in ports, sustainability and energy economy goals are encouraged when choosing port machinery; this will cause fewer pollutants to be discharged [4], [5]. In this regard, renewable fuels, such as LNG-based dual-fuel, biodiesel, hydrogen, and fuel cells, and others, are critical in shipping and ports [191]–[193]. Ports can have an impact on reducing pollutants and GHGs by employing renewable fuels in their machinery. As part of the EU-sponsored Green Crane initiative [50], a number of European ports assessed LNG fuel-powered terminal tractors, LNG dual-fuel RSs, dual-fuel RTGs, and LNG. With NOx emissions, the projected CO_2 decrease for terminal tractors based on LNG was 16%. In contrast to fossil fuels, the use of LNG was expected to decrease CO_2 emissions by 25% [122]. In addition, as part of the EU-funded SEA ports initiative [50], hybrid, as well as LNG dual-fuel RTGs, were tested as prototypes. The port at Valencia will eventually employ LNG-fueled engines, along with other 'green' efforts [71]. Because of the growing demand for LNG as a fuel, it is observed that LNG bunkering infrastructure, LNG delivery network, and LNG storage sites all play important parts in ports [50][72]. In addition to LNG, biodiesel is one of the efficient alternatives that could be used in vehicles in ports. For example, the Port of Rotterdam, which obtained a biofuel yield of 4.8 million tons in 2016 and became the top import and export centre, presents clean fuels that are a blend of bio-derived fuels (30%) and diesel fuel. Interestingly, port wastes are used to produce biofuel from natural sources [194]. Furthermore, utilising H_2 fuel cells in terminal machinery is a brand-new method and has been studied in recent years. According to McDowall et al. [195], the Port of Hamburg examined H_2 generated from green resources for fuel cells in forklifts, and the Port of Bremerhaven analysed upgrading engines to H_2-powered combustion engines. Whereas, the Port of Los Angeles and the Port of Long Beach, have evaluated the commercial fuel cell in conjunction with H_2 acting as a clean source of energy for a range of machinery [196].

CONCLUSION

In this work, operational approaches, energy management methods, and technologies for seaport green energy efficacy were all examined. Furthermore, all techniques, measures, and technologies were also analysed and contrasted in this paper. The findings highlighted that, in addition to electrifying the equipment, the employment of renewable energy and biofuels could be investigated in future green ports. Besides this, seaports could improve energy distribution, create better power strategies, and employ a variety of other techniques for reefer containers. In addition, the ports could save energy and reduce emissions by implementing energy management, operational enhancements, and state-of-the-art technologies. Nonetheless, port authorities should make significant efforts in this regard, establishing suitable policy frameworks, implementing novel operational practices, and investing in modern techniques, in order to realise additional energy savings and promote their present energy performance. Moreover, studies in the literature clarify the employment of green energy, although there are no studies on its economic impact, best practices, feasibility, or applicability. Hence, further investigations should assess existing renewable energy initiatives in ports around the world; this would significantly contribute to the literature. In this respect, port areas with renewable energy possibilities could be highlighted. In addition, hydrogen fuel cells are employed in many vehicles in the transportation sector, including yard trucks and other port machinery. Ports might benefit from future advancements in this technology. Therefore, further studies should examine the technical, operational, environmental, and economic factors of hydrogen fuel cells in this context. Last but not least, greater commitments to energy saving are required and an appropriate voluntary certification system might be able to effectively advance the process of shifting to green energy, green logistics and maritime.

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