Environmental Benefits of Reducing Greenhouse Gas Emissions from Smart Ports via Implementation of Smart Energy Infrastructure

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ABSTRACT

According to the European management of marine spaces platforms "Green airports and ports as multimodal hubs for sustainable and intelligent mobility" set up, every seaport must show the incorporation of low-emission power generation and provision into its terminal and power infrastructure, including facilities for storing, distributing, and refilling vessels and other transportation with green alternative fuels., and other uses. Smart seaports also balance energy demand and supply through intelligent management based on the Internet of Things (IoTs). Furthermore, seaports must reduce internal port border energy consumption or use renewable energy in compliance with ISO 50001 and Port Energy Management Plans. As a result, smart seaports use energy management systems (EMS) to balance energy generation, transfer, distribution, and consumption principles to move toward sustainable seaports. The characteristics of minimizing the seaport's greenhouse gas (GHG) emission using EMSs are investigated in this study. The technique includes a "scoping review" and extensive linked resource investigation. The sections and various components of an EMS and their functions in smart ports are next examined in the "finding." Finally, the "conclusion" section includes scientific insights, ideas, and proposals for improving the impact and functions of the ports' energy management services toward port sustainability, as well as some recommendations for further research.

1. INTRODUCTION

In scientific contexts, "smart" implies a mechanized computer setup that can do self-configuration, safeguarding oneself, self-treatment, and self-optimizing [1].

Smart development, a concept that arose in the field of city design throughout the 1990s, was developed as a deliberate and targeted reaction to the escalating issues of environmental degradation, noise and air pollution, destruction of historical landmarks, congested roadways, and rising costs of municipal infrastructure [2].

The concept of "smart growth" pertains to a proactive approach, whether by the government or industry, to handling advances that result in enhanced governance, economic prosperity, and ecological durability—advancement without pollution and ecological deterioration [3].

A smart city aims to optimize amenities for its residents by constantly tracking and linking vital facilities, implementing proactive maintenance measures, optimizing resource allocation, and enhancing surveillance of safety concerns [4].

The idea of the smart port is derived from the smart city, although on a more modest basis and with specific objectives like as long as it is profitable [5]

One of the primary goals of sustainability is to address power issues and develop innovative Techniques and initiatives for electricity power production, distribution, and utilization. An EMS is a recently developed setup widely employed in all intelligent ports to manage power usage efficiently [6].

On the other hand, there is a significant correlation between the EMS and GHG emission reduction. Like other industrial sites, smart port authorities have implemented novel approaches to address this issue by employing intelligent approaches to leadership and utilizing intelligent facilities and systems. The goal is to minimize GHG emissions in marine ports [7].

The present research aims to demonstrate and enhance GHG emissions reduction at intelligent marine ports, following the United Nations Sustainable Development Goals (SDGs), by effectively controlling power generation, dispersion, and utilization using a smart grid setup. Subsequently, the findings will be analyzed and evaluated consistent with a literature study.

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2. LITERATURE REVIEW

An intelligent setting comprises various technological divisions interconnected with a digital framework and governed by intelligent leadership. The link to the port integrates high-speed interaction, adaptable and service-oriented computing infrastructure, and rapid and modern amenities to address requirements effectively via productive collaboration. A smart seaport has state-of-the-art connectivity, electrical and industrial innovations, and the needed facilities and digital information [3].

A smart seaport encompasses advanced systems for managing shipping, finances, medical care, energy, communication, grid, buildings, and facilities. It also promotes the development of well-educated individuals and competent personnel while incorporating mechanization technologies. Furthermore, enhancing port operations and resilience leads to consistent and guaranteed growth and ensures the safety and security of port operations [3].

The three primary components of a smart port are intelligent facilities, intelligent transportation planning, and intelligent operations. Each of these components consists of various subparts [5].

Conversely, the responsibilities of each smart port can be classified into five main groups [3]:

i) operation.

ii) environment.

iii) energy.

iv) safety.

v) security.

Nevertheless, each of these may additionally be regarded as a subordinate division.

Operation: The operation may be classified into the following categories:

Performance: It may be shown as maintaining equilibrium between the requirements and provision of port amenities, such as cargo handling, intra-port cargo movement, traffic management inside ports, port clearance operations, and more [8].

Mechanization: By employing various mechanization techniques under human oversight, customer satisfaction can be enhanced while resources can be saved [9].

Intelligent architecture: It refers to the utilization of intelligent divisions inside a smart seaport that may efficiently collaborate through intelligent interaction and the IoT [1].

Environment: It can be classified into three main groups:

Method to oversee the environment: Any endeavor that may help align the objectives of seaport activities with environmental conservation might be exemplified within this field [3].

Controlling pollutants: Management efforts in seaports encompass measures undertaken by port authorities or public entities, per local and international rules, to manage and reduce pollutants inside port boundaries [6].

Controlling water and trash: It involves the various operations in maintaining a balance between the need for and provision of water, a crucial resource worldwide. It also involves regulating and utilizing trash, potentially repurposing it into other sectors, such as green energy [10].

Energy: It splits into three groups:

Optimal power utilization: the effective utilization of power by vessels, automobiles, buildings, factories, and generators within seaports is governed by several worldwide and local frameworks and standards, all of which aim at achieving Optimal power utilization in ports [11].

Green power: producing green power sources, which include sunlight, wind, thermal energy, and marine power, and preparing them to be utilized at ports is the next step in mitigation of consumption of traditional power sources. This could potentially be a primary aim of smart marine port regulatory bodies and authorities [12].

Power administration: the entirety of the port administration's duties to creating plans for the effective use of power across the seaport and associated operations are collectively referred to as power administration [3].

Safety: It refers to every action taken to ensure seaport safety in public and private operations that needs to be constantly monitored and overseen by intelligent equipment in contemporary ports [7].

Security: It includes every program, activity, and port safety precautions that call for sophisticated technology, evaluation, and equipment; these practices are referred to as "smart seaport security systems" [13], [14].

As previously stated, each smart seaport comprises interrelated elements collaborating to establish a sophisticated and well-informed structure. Alternatively, each smart seaport has an intelligent governing framework that regulates its initiatives, operations, and policies. This framework necessitates sophistication in ship traffic, freight processing, terminal administration, power, and human resources [7]. The essential elements of a smart seaport administration framework are listed below:

Intelligent ship administration oversees the control and coordination of vessel traffic management (VTS) and vessel traffic management services (VTMS), pilotage operation, and other marine amenities for every vessel operating inside the seaport area.

An advanced setup for managing cargo operation, encompassing entire aspects of the loading process, dis-loading, moving, and labeling in a smart seaport. This system utilizes intelligent structures and technology to ensure efficient and intelligent delivery.

Advanced seaport management encompasses formulating and implementing options and rules, employing a creative strategy, and leveraging sophisticated mechanization solutions.

Creative power administration involves the careful equilibrium of energy supply and demand within the seaport, the regulation of optimal power consumption, and the endeavor to substitute modern and environmentally friendly sources for traditional ones.

Moreover, an EMS consists of the elements depicted in Figure 1, which may exhibit slight differences based on the port's layout and operations. Figure 1 illustrates the identified sections:

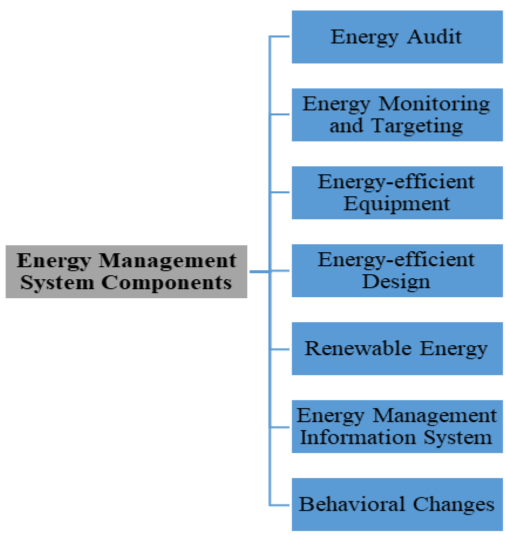

Fig. 1. Energy Management System Components.

i. Energy Audit: Conducting an energy audit serves as the initial phase in the formulation of an energy management strategy. An energy audit serves to identify areas of inefficiency in energy usage and proposes strategies to mitigate such inefficiency.

ii. Energy Monitoring and Targeting (M&T): It tracks energy usage and identifies areas where energy-saving opportunities exist. It involves setting energy usage targets for specific areas or machinery and energy consumption tracking to detect deviations from those objectives.

iii. Energy-efficient Equipment: Using power-efficient equipment can help reduce energy consumption in seaports. Energy-efficient equipment includes any device that can use excessive energy, such as thermal systems and air conditioning.

iv. Energy-efficient Design: Energy-efficient designs can help reduce energy consumption in ports. Design elements that help reduce energy consumption include efficient building orientation, insulation, and natural lighting.

v. Renewable Energy: Utilizing green power sources, such as solar and wind power, can effectively diminish the power use of marine ports. Utilizing these sources may successfully counterbalance power expenses and mitigate the release of GHG.

vi. Energy Management Information System: A comprehensive energy management information system (EMIS) can assist in analyzing and monitoring energy usage throughout the port. EMIS can identify trends in energy usage and help manage energy use effectively.

vii. Behavioral Changes: Changing employees' behavior can significantly impact energy consumption in seaports. Employees can be trained to implement energy-saving habits and utilize energy-efficient machineries, for example, implementing energy-saving practices like switching off lamps and appliances while not being used.

Effective resource administration efficiently plans and assigns assets, such as machinery and facilities, to minimize bottlenecks and discover their causes. This approach seeks to improve the acquisition and distribution of resources regarding time and expense. It aids in reducing the squandering of resources and the duration of delay and inaction [7].

However, as previously stated, due to the nature of port authority, these components will change to be adopted into the system of one port.

On the other hand, the main objective of this research is to perform a comprehensive feasibility analysis to examine the initiatives undertaken to mitigate the environmental impact of modern seaports by reducing their GHG emissions. The evaluations can typically be categorized into five essential aspects:

- Power generation (energy supply).
- Energy distribution,
- Energy supply systems.
- Energy consumption (energy demand), and
- Moving toward renewable energies and replacing them with fossil fuel energies [3], which will be covered in the subsequent chapter.

3. METHOD

The present research is a comprehensive assessment that examines several materials, including papers, eBooks, official websites, and more, to explore the strategies for reducing greenhouse gas emissions in modern seaports using intelligent power systems.

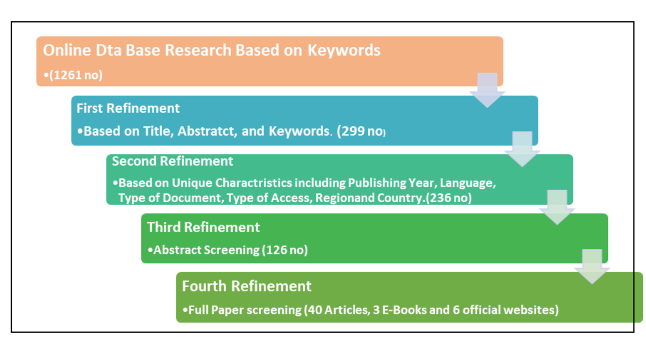

Fig. 2. Refining Procedures in Methodology.

A meticulously detailed manual conducted the essential scoping examination to develop PRISMA-SCR guidelines for scoping research reviews. The selection process is depicted in Figure 2 and consists of five key processes. At each level, the number of candidates is progressively narrowed down.

viii. Databases on the web might be accessed by employing the subsequent method of refining:

ix. Keyword search in internet databases (Science Direct, Web of Sciences, Scopus, IEEE); "Green ports," "port GHG emission mitigation," "marine renewable energy," "port GHG emissions reduction," and "smart seaport" were chosen to cover the study literature on greening ports, which rated top in 1261 results.

x. Additional improvement using specific key terms.

xi. Abstract screening; and

xii. Full-text review.

xiii. A total of forty-nine sources have been selected, comprising thirty-three journal articles, four IEEE papers, three conference papers, three eBooks, and six official websites containing information relevant to the research.

4. DISCUSSION AND RESULT

4.1 Energy Management System

The increasing capacity of Information and Communication Technology (ICT) technologies to develop automated processes has enhanced the feasibility of utilizing intelligent power sets to prioritize the ecological impacts of power production and usage [15].

Based on the scientific anticipation and evaluation, the industrial division proposed a 40% augmentation of electrical usage by 2040 [16].

An environmental impact of EMS is an ability to decrease energy consumption in deceptions and manufactures by using various successful approaches to reduce power consumption, according to the worldwide demand for energy estimate [17].

This strategy relates explicitly to four challenges:

- Power production.
- Power distribution.
- Power utilization.
- Development of renewable energy.

Power generating encompasses the actions conducted at ports that convert various forms of power into electrical power.

Power distribution includes the arrangement, facilities, and regulations for efficient electricity allocation. Energy utilization refers to electricity consumption in seaports and related operations, including cargo operation, manufacturing steps, transportation, and managerial duties.

The renewable energy industry comprises entire aspects related to the exploration, administration, and oversight of the feasibility and implementation of green power infrastructure. Energy consumption may be categorized into [3]:

1. Energy is necessary for direct port activities, which encompass machines, gates, roads, workplaces, buoys, illumination, etc.
2. The electricity required for vessel propulsion encompasses fuel consumption and ship power provision.
3. Electricity is necessary for operations associated with ports, including factories, railways, the iron and metallurgy industry, and ecotourism.

Ports located in regions with favorable conditions for wind, wave, tide, and geothermal energy generation, such as Rotterdam and Kitakyushu, Japan, as well as Dover, United Kingdom, and the Digby port in Canada, are particularly well-suited for utilizing renewable energy sources. These sources, including wind, wave, tide, and geothermal energy, are of great importance in the port industry, as demonstrated by the case of Hamburg.

Furthermore, the storage spaces and warehouses commonly found in ports offer expensive and level surfaces suitable for installing solar panels. Such locations include the Ohi Terminal in Tokyo, Japan, and the San Diego seaport administration buildings.

Energy management in marine ports requires the implementation of several tools, including policies, technological measures, and operational measures [5]:

Policy side: local and international regulations and standards for EMS in marine ports are centered on optimizing EMS objectives. Nonetheless, a few of the most prominent foreign policies are as follows:

- Energy Management (ISO 50001).
- Energy Management Systems (EN 16001)
- Port Energy Management Plans (PeMP).
- Energy Management, which is addressed via environmental management systems (EMS).
- Port Environmental Management Plans (PEMP) and Green Port Policies.

Implemented organizational and technological approaches to enhance power conservation:

- The classification of activities within the port can be divided into two categories: direct and indirect, or land-based and maritime-based.
- Main operational measures.
- Primary technical choices for automobiles and equipment at ports and terminals.
- Energy-conserving port structures.
- Infrastructure and other resources to support seaport energy conservation.

Furthermore, it is crucial to consider the novel approach of overseeing energy usage via distributed energy resources (DERs), encompassing the intelligent network, virtual power plant, ICT, IoT, microgrid, Artificial Intelligence (AI), and production delivery. These concepts will be examined more extensively in the subsequent paragraphs.

4.2 Virtual Power Plant

The growing implementation of Distributed Generation (DG) and the absence of an impartial perspective emphasize the necessity for sustained investments in DG administration. There is an urgent requirement to establish a framework that enables Distributed Generation's involvement in the power sector [18].

Nevertheless, a virtual power plant (VPP) is outlined as "a distinctive power station that uses information and communication technology (ICT) to connect, monitor, and visualize remote generators" [19].

The electrical flow across numerous devices may be managed by a VPP.in this regard, system functionality could potentially be enhanced and minimize power use [20].

Administration and control, transmission and optimization, and the combination of DG and green power sources are the three primary responsibilities of VPPs [21].

4.3 Artificial Intelligence

AI approaches are employed to optimize, emulate, regulate, and control a variety of complex structures, including intelligent control, execution, optimization, and complex cartography [22].

Intelligent power administrative systems may use artificial intelligence for marine seaports to increase their systems' energy production. [23].

Moreover, AI can enhance the electrical grid's reliability and reduce electricity costs [24].

4.4 Information and Communication Technology

ICT is necessary to create a practical, flexible, safe network of connections and implement standards that support immediate exchanges between producers and users in an intelligent grid [25].

A prevalent communication method entails using an intelligent meter and a data cloud connected by a power line connection (PLC). The second viewpoint involves the integration of a data stream and a data metering control system, with GPS or GPRS being the most used technology [25].

4.5 Internet of Things

IoT facilitates the secure and reliable transfer of information about operation among concealed, integrated, and distinct objects using radio frequency identification (RFID) and Wireless Sensor Networks (WSN). These systems incorporate devices that sense and multiple processing units to enhance making choices and permit automation [26].

Sarabia-Jacome proposes the utilization of IoT in marine seaport activities and the development of a port data infrastructure that hinders the exchange of information between different participant platforms [27].

Results demonstrated that maritime port data platforms significantly improve decision-making across many port sectors. A further inquiry into utilizing an automated mooring system (AMS), which allows vessels to dock and remove without employing their own mooring apparatus, revealed that it can effectively reduce GHG emissions [28].

4.6 Intelligence Network

The intelligent network (grid) helped detect superior, suitable manufacturing and storage units. Its primary goal is to enable policymakers and other interested parties to focus on determining the most advantageous circumstances for the efficient operation of electricity and the satisfaction of clients [29].

This shift prioritizes intelligent, environmentally conscious, cost-efficient, and cutting-edge power system technologies [30].

Figure 3 demonstrates whether integrating many regional power plants with green energy sources through an intelligent grid improves the effectiveness and dependability of the electrical network [31].

The smart seaport features an advanced grid plan encompassing many components, such as structures, an ashore generator, in-port cranes, and warehousing technology. Additionally, it incorporates specialized lifts for the efficient handling of commodities.

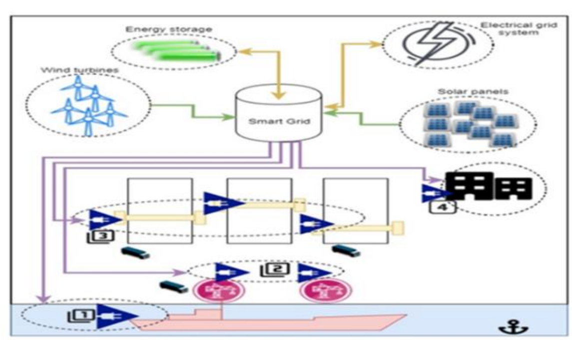

Fig. 3. Intelligence Grid configuration in a modern seaport [31].

Figure 3 demonstrates the potential advantages of intelligent network users by lowering electricity costs and producing income from power sales throughout peak hours [32].

An intelligent grid employs technological advances to enhance the power system's reliability, resilience, and efficacy (in terms of power and finance) [33].

Furthermore, intelligent grids depend on sporadic and unpredictable green energy resources such as marine, solar, thermal, and wind power [32].

Multiple methods, including the application of AI, are utilized to predict and manage production, storage, and conversion. These innovations significantly contribute to the reliability and flexibility of electrical power transmission [34].

4.7 Microgrids

A microgrid refers to a compact and localized energy system comprising energy generators, electrical storage units for deliveries, a grid management structure, and other distributed energy resources (DERs). According to the US ministry of energy, a microgrid is a network of linked power consumers that share power sources within specific electrical limits that rely on a manageable entity related to the power grid. A microgrid can operate independently and interconnected, thanks to its electrical network and ability to detach [35].

DER refers to technology that allows for energy exchange. Communication linkages, administrative systems, and EMS are all elements of microgrids in seaports. These components enable efficient energy management among stakeholders and customers [36].

Thus, a microgrid integrates green energy sources with power backup, management tools, and end-users. Additionally, it could be a multi-generational network interconnected with networks [37].

Renewable energy sources (RES) rely on wind and tidal power, as well as climate variability and fragmented Photovoltaic (PV) supplies [38].

Conversely, to enable a microgrid to operate effectively, it is imperative to address system resilience, accurately forecast power supply, and proactively prevent potential crises. Using batteries for microgrids helps to address unforeseen renewable energy source (RES) challenges [39].

Coordination, oversight, and microgrid efficiency are essential variables significantly impacting the system's efficiency [40].

Two investigations utilized optimization methods to reduce faults and enhance the network's and its clients' profitability and effectiveness [41], [42].

Figure 4 provides a comprehensive depiction of a microgrid network within a technologically advanced marine port [43]:

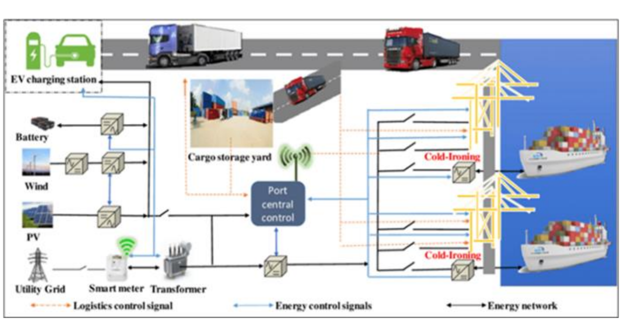

Fig. 4. Smart Port Microgrid Systems [43].

4.7. Distribution of Product

A discernible transition in power regulation and practices has occurred over the past few years. Specific countries have initiated the deployment of compact electricity-generating devices to improve the dependability of electricity provision and completion [44].

This technique is distributed generation (DG) or decentralized energy system (DES). DG must give versatility and safety to the network by using higher-quality production and lighter electricity plants [45].

According to research by P. Paliwal and colleagues, there needs to be a quicker shift in electricity generation from centralized to decentralized [46].

Regional viewpoints influence the concept of distributed generation (DG); T. Ackermann and associates offered the first description, characterizing it as an "energy source inside the distribution system or on the meter's client-side"[47].

Based on the studies conducted by L. Mehigan and his colleagues, three types of DG exist. The available alternatives for dispersion production are as follows [48]:

A) The production process is linked to the supply network.

B) Production linked to the customer's end of the device that receives it.

C) Production that is independent of the grid and dependent on electricity consumption.

DG employs both a traditional and non-traditional manufacturing process. Traditional manufacture: this method employs elements such as microturbines. Figure 5 illustrates power distribution at a smart seaport that uses diverse energy sources.

Fig. 5. Diagram of the Multi Energy Delivery System at a modern port [49].

5. CONCLUSION

The results of the research indicate that there is a strong relationship between the quantity of air pollution produced worldwide and the EMS. This link has a more substantial impact on bigger scales, including industrial sites. One of the economic and service areas might be marine ports.

Air pollution and the EMS in these areas are negatively correlated. This means that the more influential the system is in a seaport, the better the electricity utilization performance and the better the production and service efficiency.

Because of the decreased energy use, fewer emissions will be discharged into the environment, with carbon making up a substantial portion of that pollution.

Consequently, implementing an EMS optimizes electricity utilization, reducing emissions and decreasing CF. In addition to reducing emissions, this problem can significantly influence monetary savings, impacting the market's expenses in both home and international business. Figure 6 illustrates the collaborative efforts between EMS and modern ports to reduce GHG emissions in the specified area.

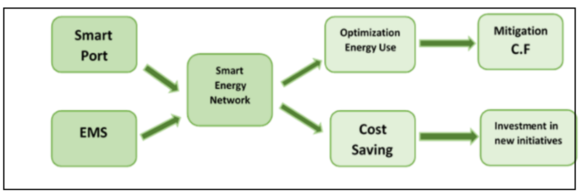

Fig. 6. Smart network systems' GHG emissions and CF reduction are related.

Figure 6 illustrates the collaboration between EMS and a modern port to mitigate CF, a consequence of emission reduction. Smart ports encompass the development of intelligent structures interconnected by internet or intranet systems. It may avoid repetitive or parallel actions within the port by aligning operations. It will reduce unneeded behavior and, thus, the emissions.

Furthermore, this research comprehensively analyzed existing literature to examine the financial implications and advantages of implementing EMS at port facilities. Port operators may get financial benefits from the implementation of EMS, as shown by a discrete event analysis conducted in this research study and the methodology outlined in Figure 6. This is particularly true when the government and public organizations provide financial assistance. Solar energy and other forms of renewable energy have significant environmental advantages.

However, by integrating the concepts of smart ports and EMS, we can extract a fundamental idea: the EMS aims to control energy product, transfers, and use by leveraging the infrastructure and elements of a smart port, such as the IOT, databases, networks, etc. Additionally, it utilizes a storage facility or direct connection among production and consumption when needed. This optimization of energy usage results in decreased reliance on fossil fuels for energy generation, reducing fuel consumption and lowering pollutant emissions.

In ports that employ green power as effective forms of energy for production. The utilization of smart energy networks in the EMS enhances its effectiveness in balancing the demand and supply of energy. Consequently, if the quantity of electricity produced by green resources exceeds the market, the surplus energy can be stored for future use.

If the energy produced by environmentally friendly sources in sophisticated ports is insufficient to meet the energy demand, any extra power will compensate for the shortfall. Therefore, the generation of electricity from traditional resources will be offset. Implementing the intelligent EMS and intelligent energy network would effectively reduce the use of fossil fuels and thus decrease the GHG emissions associated with the port.

Hence, this research aimed to examine the correlation between employing intelligent electrical systems to enhance energy use and reduce energy production, minimizing the usage of resources for power generation and ultimately curbing emissions, leading to establishing more environmentally friendly seaports. Emerging technologies will eventually enhance the efficiency of EMS in aiding in the administration of the existing power infrastructure and promoting the integration of supplementary renewable energy sources. This is a promising area of focus for future research investigations.

In conclusion, deploying smart energy infrastructure in ports is a promising approach to reducing GHG emissions and promoting environmental sustainability. It offers a range of benefits, including increased energy efficiency, improved operational performance, and reduced operational costs. However, its successful implementation requires collaboration and coordination between various stakeholders and significant investment in infrastructure, technology, and human resources. With the right policies and regulations, the shipping industry can become more sustainable, resilient, and eco-friendly, leading to a cleaner and greener future for all.

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