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Review

Optimizing Smart Energy Infrastructure in Smart Ports: A Systematic Scoping Review of Carbon Footprint Reduction

Seyed Behbood Issa Zadeh [1,*], Maria Dolores Esteban Perez [2,*], José-Santos López-Gutiérrez [2] and Gonzalo Fernández-Sánchez [3]

1 Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, 28040 Madrid, Spain
2 Environment, Coast and Ocean Research Laboratory—ECOREL, Universidad Politécnica de Madrid, 28040 Madrid, Spain
3 Civil Engineering Department, Universidad Europea, 28005 Madrid, Spain
* Correspondence: behbood.issazadeh@alumnos.upm.es (S.B.I.Z.); mariadolores.esteban@upm.es (M.D.E.P.)

Abstract: To lessen the environmental impact of the maritime industry, ports must decarbonize in conformity with various standards such as the European Green Deal and the Sustainable Development Goals (SDGs). In this regard, they must demonstrate integrated low-emission energy production, distribution, and supply, as well as sustainable alternative infrastructure for refueling ships, cargo handling equipment, and other vehicles inside port boundaries. To address this issue, ports must progress toward smartening their operations. This requires intelligent infrastructure and components, with smart energy infrastructure being one of the most crucial ones. It is a part of port energy management systems (EMSs) and works based on modern technology to balance energy demand, distributions, and supply while transitioning to renewable energies. This study investigates the "scoping review" of "smart energy infrastructure" deployment and its efficiency in seaport EMSs to reduce the port's carbon footprint (C.F). The "Introduction" section discusses the subject's significance. The "Materials and Methods" section explains the process of selecting and revising references and relevant material. The "Findings" section then examines the several aspects and sections of a smart port and smart energy infrastructure, as well as how they function. The "Discussion" section explains the interpretation based on the present situation. Finally, the "Conclusion" part gives scientific thoughts and comments on the work-study debate and ideas for future research in the same field to help port authorities achieve sustainability.

Keywords: smart seaport; carbon footprint; sustainability; energy management systems; intelligent energy infrastructure

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1. Introduction

Automated computational systems that can self-configure, self-protect, self-heal, and optimize themselves are considered smart in technical contexts [1].

An approach (public or private) to controlling growth that results in managerial, economic, and environmental gains is called "smart growth". Without congestion and environmental deterioration, this progress would be impossible [2].

In addition, in urban planning, as a result of the growing trend of noise pollution, air pollution, the destruction of historical monuments, traffic congestion, and the rise in the expense of public infrastructure, smart development evolved throughout the 1990s as a state of course and concentration [3].

A smart city optimizes services for residents while keeping an eye on and integrating crucial infrastructure, planning proactive maintenance procedures, making the best use of resources, and boosting the monitoring of security issues [4].

Using the same principle but on a smaller scale and with distinct goals like sustainability and profit, the smart seaport also benefits from the smart city [5].

To lessen the environmental impact of the maritime industry, ports must decarbonize in conformity with various standards such as the European Green Deal and the Sustainable Development Goals (SDGs). In this regard, they must demonstrate integrated low-emission energy production, distribution, supply, and sustainable alternative infrastructure for refueling ships, cargo handling equipment, and other vehicles inside port boundaries. They are key hubs for international trade and transportation, and reducing carbon emissions there can significantly impact improving air quality, lowering greenhouse gas emissions, and ensuring the sustainability of our planet's future.

Furthermore, with the introduction of new technologies in Industry 4.0, smart port development is recognized as a strategic path for several ports toward sustainable growth, increasing concern about smart ports in both academic and practical contexts [6].

Accordingly, all smart seaports use an Energy Management System (EMS), a novel technology in the field of energy-related issues that employs intelligent methods and efforts for energy production, distribution, and consumption, as well as moving toward replacing renewables rather than fossil fuels to achieve sustainability [7].

Conversely, smart port authorities, like other industrial sites, have started to develop new programs to utilize intelligent management with intelligent infrastructures and technology to progress toward sustainability, which will reduce greenhouse gas (GHG) emissions and the C.F in marine ports [7].

Considering the concerns highlighted above, this study attempts to demonstrate how C.F mitigation in smart seaports can be accomplished using smart energy infrastructure, which is a crucial component of the EMS.

This scoping review study fills the "research gap" by synthesizing the smart seaport C.F reduction literature on energy infrastructure optimization. There are several strategies to reduce emissions in the maritime-based marine industry, such as international maritime organization GHG strategies, low-sulfur guidelines, energy-related CO_2 emission reduction, port-to-ship pathway review, cold ironing, and a clean and green framework for shipbuilding toward zero emissions.

As land-based marine industry parts, this research wants to survive in smart ports. Smart seaports and sustainable energy management are on the rise, but a thorough study landscape is needed to identify trends, methods, and knowledge gaps. This scoping study analyzes current research to better understand marine sector environmental sustainability strategies and technology.

Furthermore, this review's "main objective" is to thoroughly analyze and map the academic literature on smart energy infrastructure optimization strategies and technologies in smart ports. As global demand for efficient and sustainable port operations rises, this study seeks to identify major research issues, approaches, and gaps in smart energy infrastructure in the smart port's literature. This analytical scoping assessment summarizes existing information and identifies future research and development opportunities to maximize energy usage, environmental sustainability, and smart port performance.

The "novelty of this review" is its comprehensive assessment of strategic and technological improvements in smarts EMS at seaports. This review not only categorizes the difficulties associated with developing smart energy infrastructure at smart ports but also synthesizes the most recent discoveries to offer a complete picture of how advanced infrastructure and sustainable practices combined with intelligent management can be connected to boost seaport energy efficiency.

Because of the issue's importance, initiatives, technological strategies, activities, and infrastructures are present worldwide, and the difference between this research and the other literature is the analysis and classification of the smart infrastructures with combinations of smart port components and management attributes. Because it integrates multiple sources and perspectives, it can benefit policymakers and industry experts navigating seaport smart energy solutions.

This research study is analytical, and its analysis begins by introducing various aspects and features of smart seaport activities, responsibilities, and attributes before focusing on smart grid system performance, elements, and activities that are aligned with reducing emissions and are a fundamental component of an intelligent EMS, particularly in seaports as an industrial zone.

The data are then reviewed, separated into categories, and presented in an approachable manner so that academics, stakeholders, and policymakers may better understand various EMS-related issues in the context of a literature review.

The following section outlines the techniques for locating and evaluating literature.

2. Materials and Methods

This analysis was conducted as a scoping review of optimizing smart energy infrastructure at smart ports. In other words, it analyzes the efficiency of deploying smart energy infrastructure in smart ports using literature evaluations and certain pertinent cases. This research included a study and review of the background and recent literature on this research work's main issue, developed through preferred reporting items for systematic reviews and meta-analyses in scoping reviews (PRISMA-ScR). It intends to help readers better understand the relevant terminology, core concepts, and critical items to report for scoping reviews. These phases and procedures include "Identification", "Screening", and "Eligibility", as shown in Figure 1. These phases involved the following tasks:

- Identification: Searching for databases, including "Scopus" and "Google Scholar", based on the combination of a few keywords, including "smart seaports" AND "energy management system" AND "smart energy" AND "climate change" OR "carbon footprint" OR "GHG emission" OR "CO_2 emission" in the first step, which results in 543 findings in total.
- Screening and eligibility: These processes are linked because a single or mixture of eligibility concerns are raised at each screening stage. Eligibility categories included the paper's title, abstract, and keywords in the first refinement; the first keywords defined in the last stages were supposed to be applied only in the title, abstract, and keywords of the 299 found relevant sources. The second refinement was based on the year of publication from 2008 to the end of 2022 (15 years); language (only in English); and type of material (articles, conference papers, books, and conference reviews). The subsequent refinement based on access and registration was that only open access articles were refined due to accessibility, and 236 research works were identified. Subsequently, abstract screening was performed, and all resource abstracts were studied to find the articles with the relevant issues to the work-study, and refinement and adjustment were performed to account for important topics. Thus, 126 resources were found.
- In the final stage, after screening and revisions to determine the total number of studies that would be discussed in this review, 70 studies were selected for use, including 61 journal articles, 6 conference proceedings papers, and 3 books.
- The transparent procedures followed in this PRISMA-ScR allow future researchers to replicate and update the review. The flowchart of the PRISMA-ScR steps and the filtering results are shown in Figure 1.

Based on the refinement and selection process of Figure 1, 73 sources were chosen to be used and discussed in this research study, including 61 journal articles (9 review articles, 17 case study articles on installations and equipment relevant to EMS in seaports, and 35 framework articles, some of which included simulations and modeling too), 6 conference proceeding papers, 3 books, and 1 additional official website with helpful information.

In the following sections, the reports, and data, as well as the results in the resources on the issue, are stated, which include initial explanations of the smart seaports' characteristics and components, and then smart infrastructures are classified and briefly discussed. These categories are based on the efficiency and location of smart infrastructure in seaports.

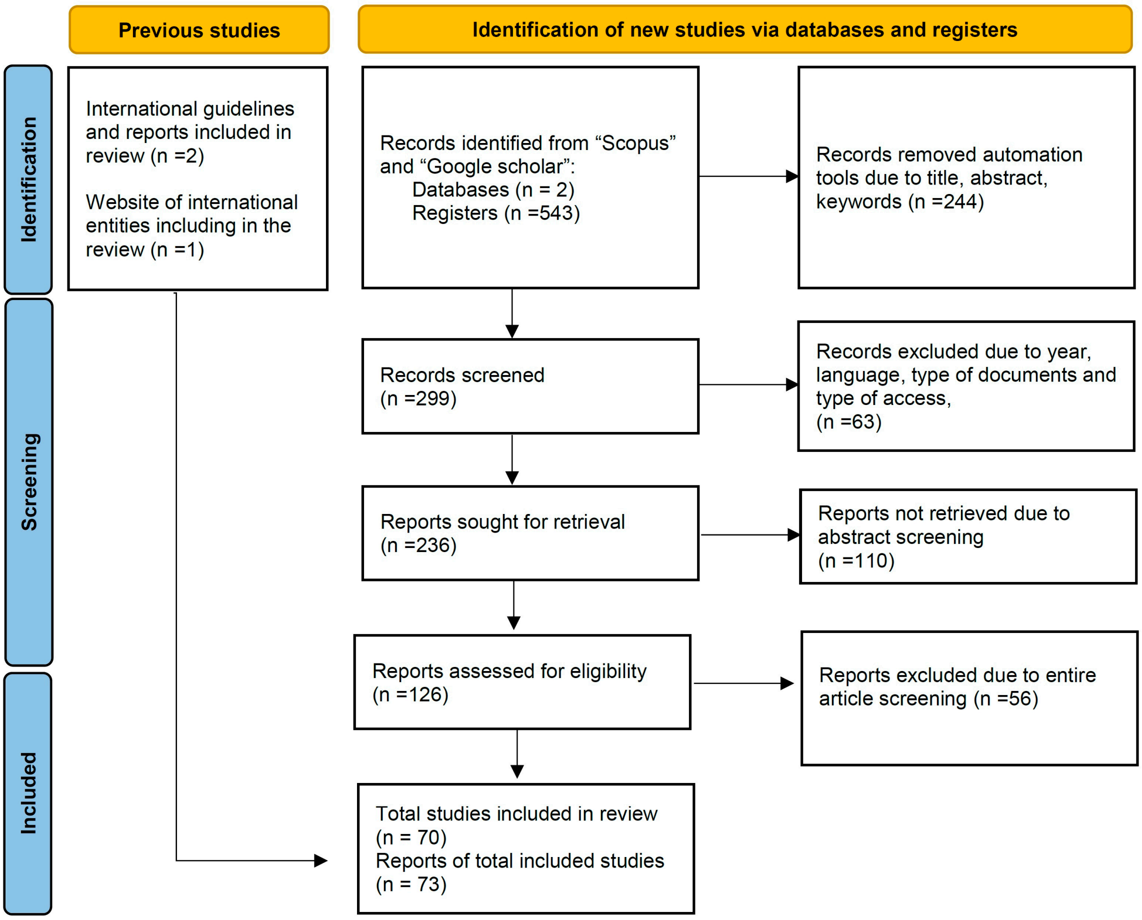

Figure 1. Literature review methodology phases based on the PRISMA-SCR review.

3. Findings

A smart set is made up of many intelligent components that are linked to digital infrastructure and intelligent management. The smart port combines broadband connections, adaptive and service-oriented computer infrastructure, and quick and cutting-edge services to meet demands via efficient communication. It has access to the most advanced information technology, infrastructural, mechanical, electrical, and telecommunications advances [2]. The components, duties, and characteristics of the smart port and its management are briefly assessed in the parts that follow.

3.1. Smart Seaport Components

Considering studies due to the nature and performance of the port, a smart port has three intelligent sectors: intelligent logistics, intelligent infrastructure, and intelligent traffic. Each of these sectors can be further divided into smaller intelligent components, including intelligent management, intelligent transportation, intelligent economy, intelligent energy, intelligent communication, an intelligent energy network, intelligent buildings, intelligent workforces, etc.

Additionally, enhanced port resilience and operations lead to a steady and guaranteed development and safe and secure port operations [2]. Figure 2 displays the three mentioned core sectors of a smart port, as well as their subcategorization [5]. A port can only function well when the three sectors cooperate effectively. This research study later examines how these three parts may be branched.

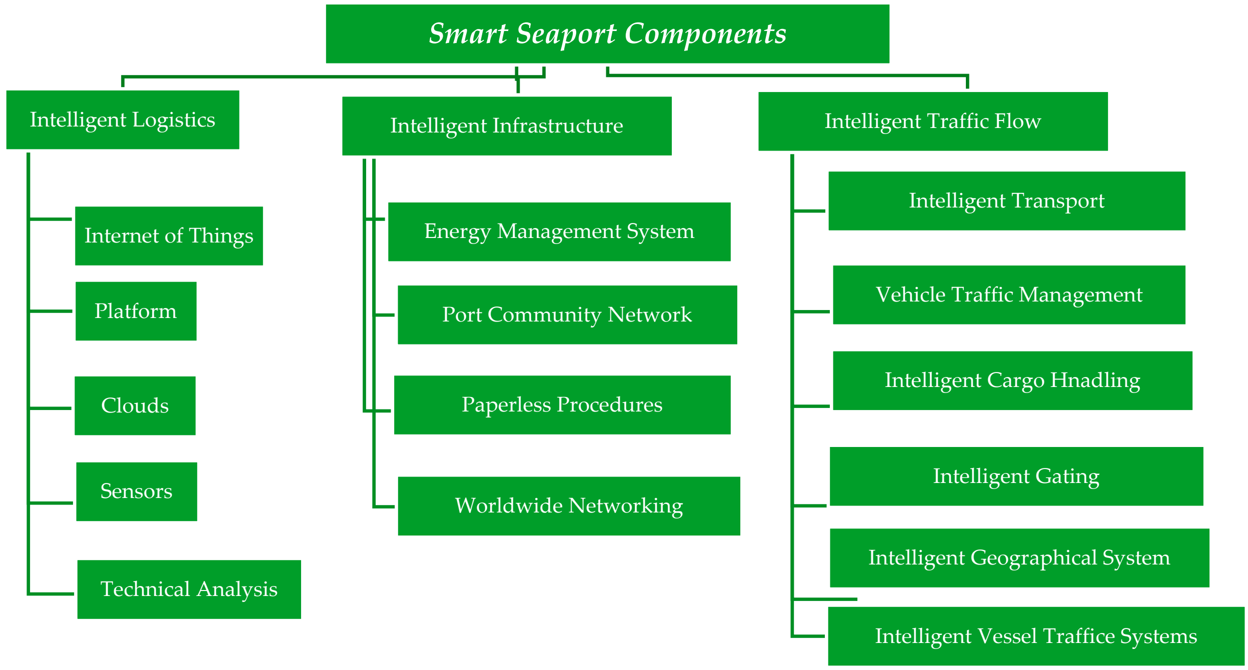

Figure 2. Key component of smart seaport based on [5].

According to Figure 2, the intelligent logistics sector in the smart port consists of the internet of things (IoT), platforms, clouds, sensors, and technical analysis. This sector serves as the brain of the whole system, directing all other components to operate as efficiently as possible.

The major components of the smart port infrastructure are the EMS, port community network, paperless processes, and global networking, which are four fundamental sectors that operate in a loop to improve port performance. Finally, as a transportation node, a smart port must have intelligent traffic flow, which is divided into land-based traffic and maritime-based traffic and consists of intelligent transport (land-based), intelligent cargo handling, vehicle traffic management systems, intelligent gating, and intelligent vessel traffic management systems.

On the other hand, according to research by Makkawan et al., a smart port is a step up from being a digital port. This means that a smart port is a port that can manage its entire operation through intelligent components that cause a smartening procedure and can subsequently provide efficiency in fuel consumption that leads to sustainability [8].

According to this viewpoint, the process of smartening a port may be as depicted in Figure 3, which can optimally contribute to the global supply chain.

Figure 3. Process of developing a smart port based on [8].

Furthermore, according to other studies, smartening is a phase that precedes digitalization, which in turn leads to the digital supply chain in Industry 4.0, and preparing the digital supply chain is necessary to achieve sustainability, which is one of the primary goals of creating smart seaports [9].

3.2. Smart Port Activities

On the other hand, the aspects of duties carried out by each smart port, however, may be divided into the following groups, as illustrated in Figure 4. Mentioning these aspects highlights the significance of current smart energy infrastructures because all components require the use of energy, and the energy supply chain undoubtedly has a significant impact on how each component operates. On the other hand, it appears that there is no other way to control energy use without making it more intelligent [2]:

(i) Operation;
(ii) Environment;
(iii) Energy;
(iv) Safety;
(v) Security.

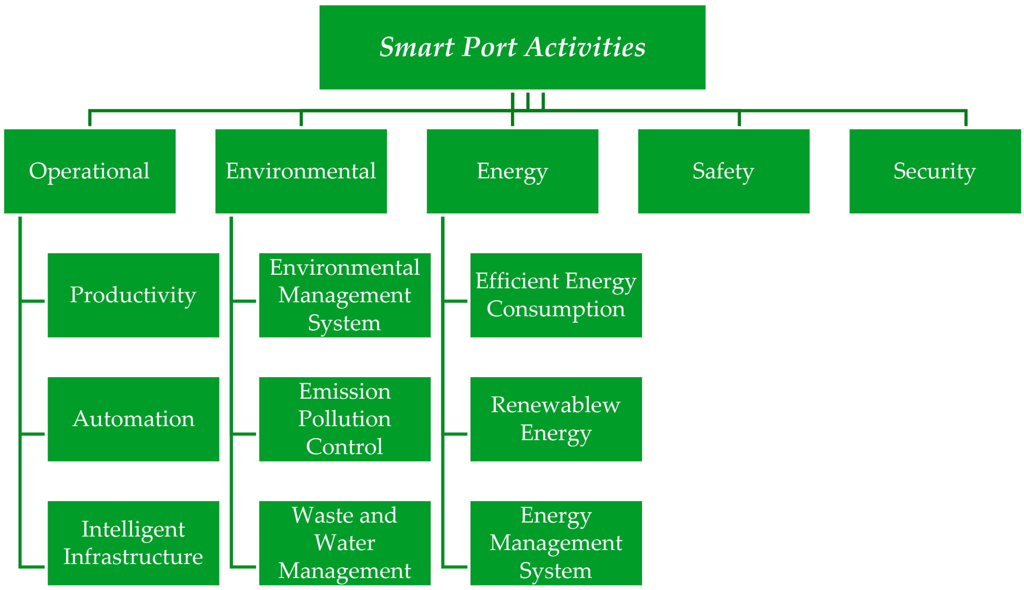

Figure 4. Categorizing operation in a smart port based on [2].

According to the research of Lacalle et al., these tasks may be divided into a few smaller groups. Figure 4 illustrates this categorization in more detail [2].

However, the classifications of the aspects are as follows:

I. Operation. The operation can be categorized as follows:
   (a) Productivity: this may be represented by balancing needs and providing essential port services, such as cargo loading and unloading, cargo movement inside the port, traffic density management, and port clearance operations [10].
   (b) Automation: under their supervision, different techniques for replacing human labor with automation may improve service effectiveness and reduce waiting times [11].
   (c) Intelligent infrastructure: this refers to utilizing an intelligent port's departments, capable of intelligent collaboration via intelligent communication and IoT [1].

II. Environment. The following categories apply to the environment:
   (a) Environmental management system: this domain may be used to demonstrate any action that helps port activities fit with managing environmental protection [2].
   (b) Emission and pollution control: this refers to any national and international regulations-compliant actions taken to reduce and control emissions within the port territory under the supervision of port authorities or public authorities [7].
   (c) Waste and water management: this comprises all actions for balancing supply and demand for the management of water, a resource that is essential to the planet,

and then goes to managing and accepting waste materials and then utilizing them, if possible, for other sectors like renewable energy [12].

III. Energy. This can be divided into:
   (a) Efficient energy consumption: to achieve optimal energy consumption in seaports, there are several guidelines and international and national rules relating to the efficient energy usage of ships, vehicles, equipment, buildings, industries, and generators [13].
   (b) Renewable energies and their production: Preparing renewable energy sources for use at seaports, such as wind, solar, earth thermal, and marine energy, is the second stage in minimizing the usage of fossil fuels. This might be one of the main objectives of smart seaport authorities and policymakers [14].
   (c) Energy management: all tasks and duties the port authorities have to do with creating port-wide plans for energy efficiency and other relevant things [2].

IV. Safety. In smart seaports with intelligent infrastructure, all port safety operations must be monitored [15].

V. Security. The term "smart port security activities" refers to all programs, projects, and seaport security operations that demand sophisticated infrastructure, technology, and oversight [16,17]. And now, with the deployment of artificial intelligence (AI) and intelligent energy network systems for smartly enhancing and controlling ports, cyber security is one of the most essential operations in the field of port security [18].

By quantifying these factors, it is possible to assert that smart energy infrastructures at ports are crucial for boosting operational efficiency using IoT and AI technologies. Sustainable energy sources, such as solar and wind, minimize emissions and prices, hence enhancing environmental and energy aspects. These infrastructures also enhance safety and security by providing comprehensive surveillance and monitoring capabilities, allowing for the quick discovery and elimination of threats. The interaction between smart energy systems and marine sector operations enhances sustainability, efficiency, and safety [19].

3.3. Smart Port Management

The implementation of smart energy infrastructures is closely tied to the integration of intelligent management systems in ports. These management systems, powered by innovative technology, allow for optimal resource allocation while optimizing energy consumption and cargo handling procedures. In tandem, intelligent energy infrastructures complement these efforts by delivering renewable and cost-effective power sources, thereby improving the overall operating efficiency. The interplay between intelligent port management and smart energy solutions promotes sustainability and competitiveness in the maritime industry [20].

Then, in this regard, and according to another perspective, each smart port has an intelligent management system that guides its initiatives, operations, and policies. Each smart port contains components that work together to produce an intelligent form and sensible approach, as was previously indicated. The smart port management system consists of intelligence in vessel traffic, cargo handling, port administration, energy, and resources [15]. Figure 5 depicts the critical components of a smart port management system.

- All vessels in the port area may have vessel traffic management (VTM), vessel traffic management services (VTMSs), pilotage operation, and other maritime services managed by intelligent vessel management.
- Intelligent infrastructure and equipment may offer an intelligent cargo handling management system, including all loading, discharging, moving, and stripping storage in or out of a smart port.
- Intelligent port management uses cutting-edge decision-making processes, intelligent automation systems, and application systems for all choices, policies, and procedures.

- Intelligent energy management includes balancing energy supply and demand within the port, controlling efficient energy usage, and switching from fossil fuels to renewable and green energy sources.

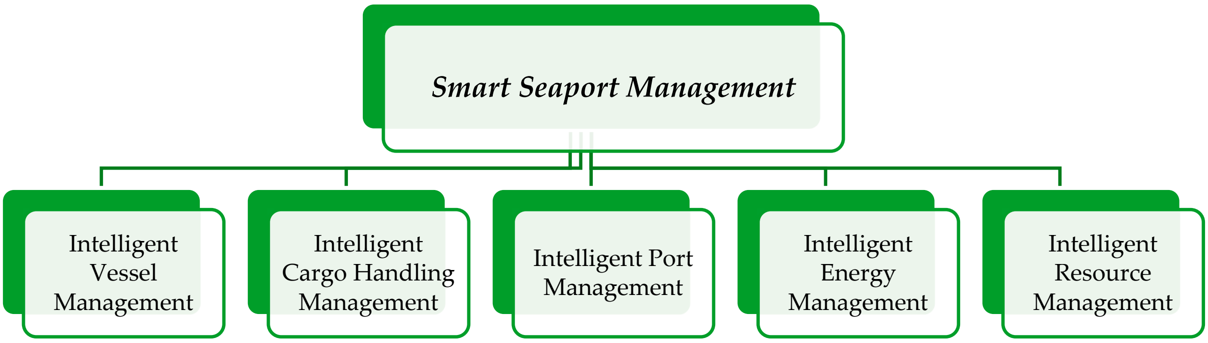

Figure 5. Smart seaport management sections based on [15].

However, recent research by Othman et al. suggests that in 2022, smart seaport management will enable sustainable seaports to deliver sustainable performance across three dimensions: environmental, economic, and social. From this perspective, a smart port can manage all activities in these three dimensions [7].

Additionally, according to the debate in an article by Chen et al., smartening and greening a port must be integrated to achieve sustainability; otherwise, the visions of 2030 and 2050 of the Sustainable Development Goals (SDGs) cannot be met alone through smartening [21].

3.4. Energy Management System

It is obvious that an EMS for seaports must be based on collaborating and integrating all their components in a continuous loop to achieve the best performance when all issues regarding smart seaport components, smart port duties aspects, and intelligent port management are considered.

Figure 6 depicts the main responsibilities of the EMS in smart ports, demonstrating that smart energy infrastructure is a crucial component that relates to all of them. Responsibilities may change depending on the design and type of port activities [22].

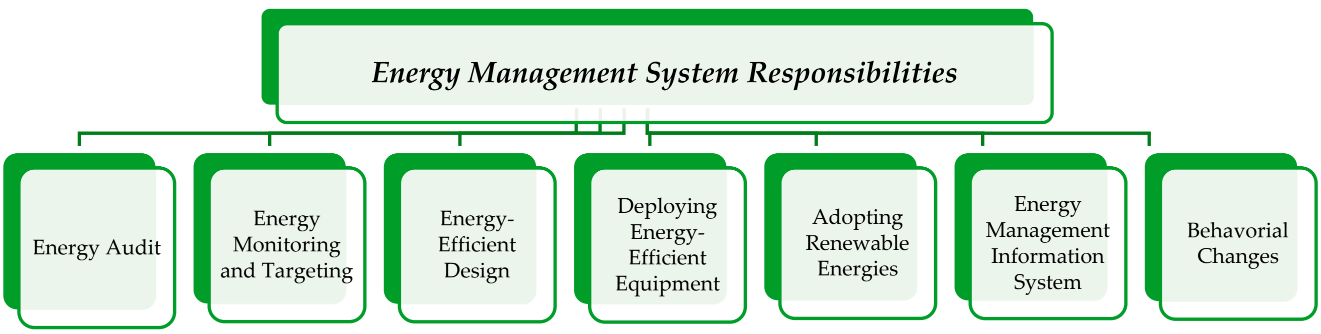

Figure 6. Energy management system responsibilities based on [22].

i. Energy audit: The first step in creating an energy management strategy is conducting an energy audit. An energy audit finds places where energy is being squandered and suggests ways to use less energy.
ii. Energy monitoring and targeting (M and T): Tracking energy use and identifying potential areas for energy savings are known as "energy monitoring and targeting". It entails establishing energy consumption goals for specific spaces or pieces of equipment and then monitoring energy use to spot any deviations from those goals.

iii. Deploying energy-efficient equipment: Energy use at seaports may decrease with energy-efficient equipment. Lighting, heating, ventilation, and air-conditioning systems, and other energy-consuming equipment are all included in the category of energy-efficient equipment.
iv. Energy-efficient design: Energy-saving architecture may aid in lowering port energy use. Insulation, natural lighting, and optimal building orientation are design components that decrease energy use.
v. Adopting renewable energy: Seaports' energy demand may decrease by using renewable energy sources like solar and wind power. Renewable energy may lower GHG emissions and offset energy costs [23].
vi. Energy management information system (EMIS): Analysis and monitoring of energy use throughout the port may be aided by a complete EMIS. It can spot patterns in energy consumption and support efficient energy management.
vii. Behavioral changes: Energy usage at seaports may be significantly reduced by altering personnel behavior. Employees may be taught to use energy-efficient equipment and adopt energy-saving habits, such as turning off lights and equipment when not in use.

Intelligent resource management plans and distributes resources, such as machinery and infrastructure, to lessen congestion, discover its causes, and buy and allocate resources as efficiently and affordably as possible. Reduced waiting, idleness, and resource waste are all benefits [15].

The responsibilities will change to be included in the system of one port, as was previously mentioned, according to the performance and specifications of the port.

However, the major goal of this study is to conduct a systematic scoping review to analyze the efforts being made to reduce the C.F of smart ports by smart energy infrastructures, which is why understanding the fundamental description and roles of energy and port management was necessary.

Based on Bilgen's study, by 2040, the industrial division projected a 40% increase in energy consumption [24]. According to the projection of the world's energy needs, the environmental impact of EMSs is a capacity that may lower energy use in fabrication and production by adopting some efficient approaches to mitigate energy usage [25]. An EMS needs to manage the energy supply chain, including these steps [26]:

1. Energy generation (energy supply);
2. Energy distribution;
3. Energy supply;
4. Energy consumption (energy demand);
5. Moving toward renewable energies and replacing them instead of fossil fuel energies.

Port-based operations that convert energy into electricity are referred to as "energy generation". The system, settings, and regulations for intelligent power distribution are called "energy distribution". The "energy supply" is the source of energy that feeds electricity into the grid for distribution. The word "energy consumption" describes how power is utilized at ports and activities related to ports, such as logistics, industrial processes, cargo handling, and administrative duties. Energy use in the port may be categorized into [2]:

1. Energy is needed for all direct port activities, including running terminals, locks, bridges, office buildings, buoys, and lights.
2. The energy needed for the ship's operation (fuel consumed and electricity provided to ships).
3. Refineries, railways, the steel and metal industry, tourism, and other industries impacted by or associated with ports all need energy.

The exploration, administration, and monitoring of the potential for and construction of renewable energy facilities are all included in the "renewable energy sector".

On the other hand, since ports are frequently located in areas that are well suited for the generation of power from wind and wave (such as Rotterdam and Kitakyushu, Japan), tide differentials (under study, for example, in Dover, UK; and the Port of Digby, Nova

Scotia), and in some cases, geothermal energy, renewable energy sources play a crucial role in the port industry (see the Hamburg case).

Additionally, vast flat surfaces may be found in storage spaces and warehouses, typically at ports, that can be used to install solar panels (e.g., the Tokyo Ohi Terminal or the Port of San Diego administration buildings).

Another critical obstacle to installing smart energy infrastructure is legislation. National and international legislation is essential in smart port EMSs because it provides the legislative framework required for the implementation of sustainable energy solutions and the integration of new technology. It guarantees that environmental, safety, and security criteria are followed, creating a robust and efficient port infrastructure. Furthermore, laws may encourage private sector investment in smart energy projects, therefore encouraging innovation and economic development in the marine industry [5].

Nonetheless, a few of the most prominent foreign policies are as follows:

- ISO 50001 "Energy Management".
- EN 16001 "Energy Management Systems".
- Port Energy Management Plans (PeMP).
- Energy Management Addressed via Environmental Management Systems (EMSs).
- Port Environmental Management Plans (PeMPs) and Green Port Policies.

On the other hand, it is also crucial to pay attention to the new perspective in EMSs that control energy consumption through distributed energy resources (DERs). Figure 7 illustrates parts of DER in the EMS.

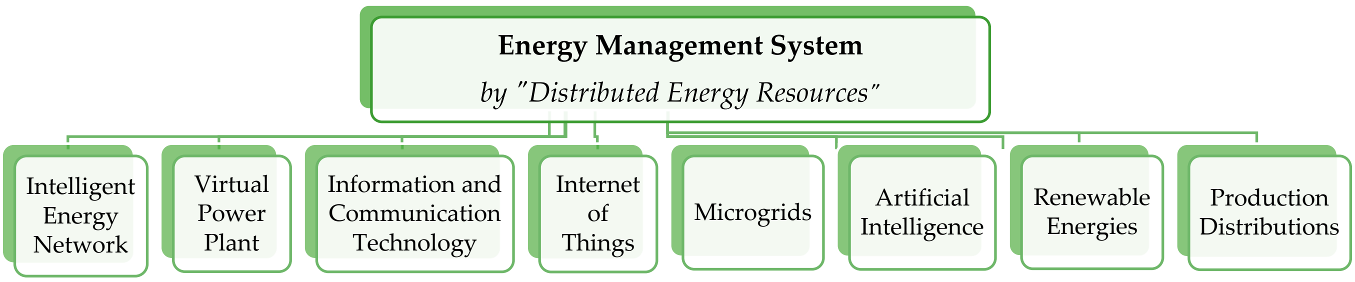

Figure 7. Components of the energy management system's distribution of energy resources retrieved from [27].

DERs consist of several components including an intelligent energy network, virtual power plant, information, and communication technology (ICT), the IoT, microgrid, AI, distribution of production, and renewable energies.

In fact, "smart energy infrastructure" in seaports, which is the major goal of this research study to be evaluated, fits into this viewpoint, and benefits a seaport by employing the specified components in Figure 7, and all of them are addressed in more depth in the following parts.

3.5. Energy Intelligence Network

The intelligent energy network is the first and most vital component of an EMS, which composes smart energy infrastructure. It enables EMSs to find high-caliber, appropriate production and storage units more easily. It frees stakeholders and policymakers to focus on finding the best conditions for using electrical energy and serving consumers [28].

This change emphasizes intelligent, economical, environmentally beneficial, and creative electrical system solutions [29].

Figure 8 shows how an intelligent energy network may improve the efficiency and dependability of the power system by combining a variety of local and renewable energy sources [27].

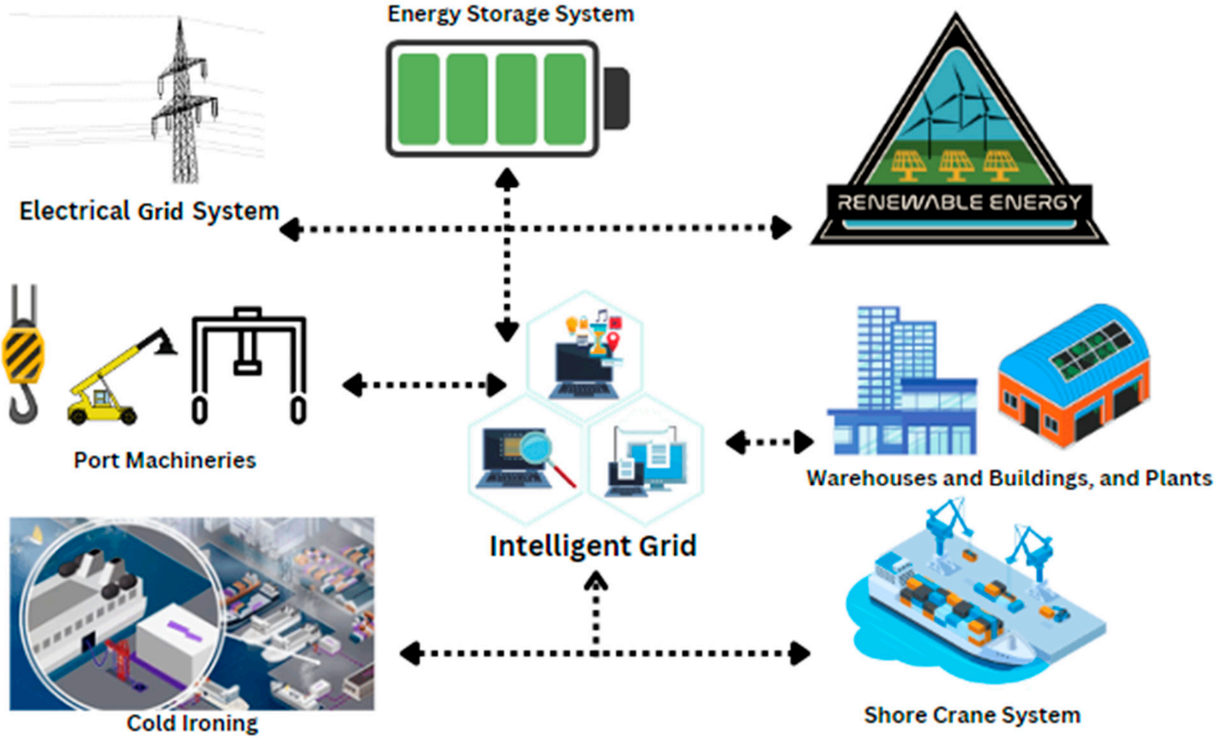

Figure 8. The layout of the energy intelligence network in the smart seaport, based on [27].

It provides a cargo terminal with buildings, an onshore power supply, an in-port crane, stowage equipment, and cranes for handling products, as well as an intelligent energy network layout at the smart seaport.

Additionally, Figure 8 shows how, via intelligent energy networks, customers may benefit from lower power costs and money from energy sales during peak hours by reserving extra energy for storage, an advantage of intelligent energy networks in modern smart seaports [30].

It may be observed in a variety of technologies, such as the use of AI to estimate how much energy will be generated in the following days and then store or convert it, which goes a long way toward supplying stability and flexibility in the distribution of electrical energy [31].

Furthermore, it illustrates that using hybrid renewable energy sources is more logical than depending only on one or two types of renewable energy in today's intelligent energy network.

In addition, as can be seen, an intelligent energy network employs digital technologies to improve the electrical system's reliability, stability, and effectiveness (in terms of energy and economics) [32].

3.6. Virtual Power Plant

The growing use of distributed generation (DG) and the absence of a passive perspective emphasize the need for long-term investments in DG governance. As a result, creating a framework that makes DG's engagement in the energy sector easier is urgently required [33].

The term Virtual Power Plant (VPP) in a smart port refers to a centralized system that integrates and controls a variety of distributed energy resources, including solar cells, wind turbines, and batteries, to optimize energy generation and distribution and increase the energy efficiency and resilience of the port.

VPP is not a real power plant, despite being defined as "a unique power station that leverages ICT to connect, monitor, and display remote generators", and it is a digital platform that aggregates and controls distributed traditional or renewable energy resources, batteries, and demand–response devices to maximize their collective power output and consumption, hence improving network stability and efficiency [34].

Electricity may be moved between different units under the direction of a VPP. It may increase system effectiveness and optimize energy use [35]. VPPs are charged with three primary functions, each of which is significant in and of itself: organization and control, distribution and optimization, and a mix of distributed generation and renewable energy sources [36].

The next DER component is ICT, which is a collaborative component between the IoT and intelligent energy networks.

3.7. Information and Communication Technology

The term ICT in smart ports refers to the integration and application of ICT solutions, such as digital systems, data analytics, sensors, and communication networks, to improve the effectiveness, security, and sustainability of port operations and management. This makes it possible for the maritime industry's logistics, cargo handling, and overall performance to be optimized [37].

ICT is needed to create protocols that allow real-time producer–user interactions in an intelligent energy network as well as to provide a practical, flexible, and secure communication infrastructure [37].

According to a study by Kara in 2020, ICT is now one of the primary and essential elements of the 5th and 6th generation of seaports, and data integrated with IoT will be sent through different programmed transmitters and receivers like personal telephones [38].

Additionally, to better present the model of the smart port system, a design was made according to a study by Douaioui in 2018; based on this study, the ICT-based smart port system consists of two pillars that include different components based on the viewpoint of using ICT as a technological and digital part of smart ports. These pillars are connectivity and automation [39].

An ICT-based smart port is "a technologically enhanced marine facility that optimizes its entire operations by using ICT". It combines sensors, automation, and data analytics to improve efficiency, safety, and sustainability in areas such as cargo handling, security, and energy management, ensuring marine competitiveness and environmental responsibility [40].

The various ICT-based smart port systems are shown in Figure 9:

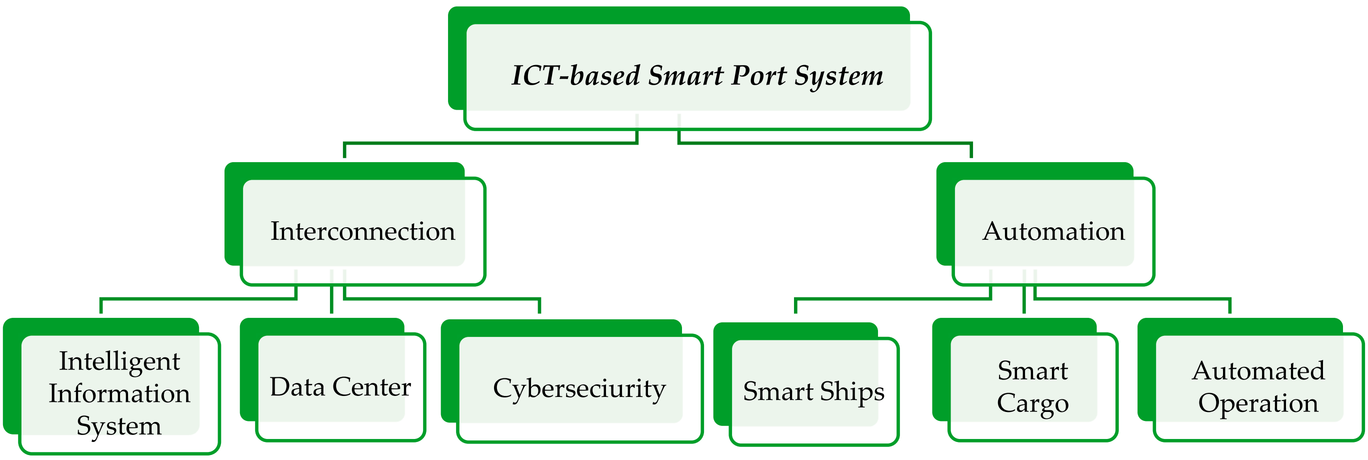

Figure 9. Smart port operation by using ICT based on [39].

According to Douaioui et al.'s research study at a smart seaport, interconnectivity consists of an intelligent information system, a data center, and cyber security, while automation consists of smart ships, smart cargo, and automated operations. Other land-based activities, such as cargo transfer at terminals or other land-based logistic operations, may be included in the smart cargo operation segment from this perspective [39].

Based on another research work by Bessid et al., the experts feel that multiple significant links exist between the connectivity and automation components. The successful performance of smart ships that employ ICT relies on the data placed in data centers, which shows the importance of deploying ICT [41].

The most frequent ICT-based system that may be used as an example is a power line connection (PLC) between a smart meter and a data cloud. The second helpful example is systems that integrate a data cloud with a data meter management system, using the global positioning system (GPS) or general packet radio services as the most common technology (GPRSs) [37].

The IoT, which is a component of a smart system, is discussed in further detail in the next section.

3.8. Internet of Things

IoT is "a network of items, including sensors and embedded systems, that are connected to the Internet and enable physical objects to gather and exchange data" [42].

The IoT facilitates the secure and safe exchange of operational data between non-visible, embedded, and unique recognized items by using wireless sensor networks (WSN) with sensor devices and multiple processors to enhance decision making in support of automation [43].

In smart ports, the IoT plays a vital role by providing real-time monitoring and control of numerous aspects of the port infrastructure. It enables the monitoring and management of cargo, equipment, and environmental conditions, improving operational efficiency. IoT also helps to increase safety and security via sensor-based monitoring and early identification of possible concerns, guaranteeing smooth and secure port operations [44].

Sarabia-Jacome argued that the IoT may be utilized to enhance maritime port operations and build a marine port data cloud that prohibits interoperability across stakeholder information systems [45].

The deployment of sensor-equipped containers is one example of how IoT is being used in smart ports. These smart containers have IoT gadgets that offer real-time data on their location, temperature, humidity, and even the condition of goods within. These data assist port managers and shipping corporations in optimizing logistics, monitoring cargo conditions, and ensuring timely delivery while decreasing losses due to spoilage or theft [46].

The results demonstrated that IoT-enabled marine port data clouds improved the decisions made by several port departments. The use of an automatic mooring system (AMS), which enables ships to berth and undock without using their mooring equipment, is the subject of further research. This case serves as another valuable illustration of how IoT and ICT can be used in smart ports [47].

The following section goes into further depth about microgrids in smart ports.

3.9. Microgrids

A microgrid is a compact local energy system comprising energy producers, electricity storage systems, loads, a grid management system, and other DERs. A microgrid is "a community of linked loads and dispersed generation at specified electrical boundaries that rely on a controlled entity connected to the grid", according to the US Department of Energy. A microgrid may operate in an isolated or connected state due to its grid connection and detachment [48].

In maritime ports, microgrids comprise DERs, energy-exchanging technologies, communication lines, control systems, and EMSs. These components allow for effective energy management between parties and users [49].

On the other hand, a microgrid in a smart port links renewable energy sources with end users, control systems, and power storage. A multigenerational system connected to grids is another possibility [50].

Moreover, for a microgrid to function well, system reliability must be fixed, power must be anticipated, and contingencies must be avoided. Utilizing energy storage devices for microgrids aids in resolving unexpected RES issues [51].

Collaboration, control, and the effectiveness of the microgrid are key elements influencing system performance [52].

Two studies used optimization methodologies to remove operational errors, increase system efficiency, and benefit the system and its users. Both show the critical importance of deploying microgrids in seaports [52,53]. An overview of a microgrid system in a smart seaport is broken up into three distinct pieces, according to Nur Najihah et al. (2021). These portions are titled "energy network", "energy control signal", and "logistic control signal", respectively. The energy network encompasses all aspects of energy production, including generation, transformation, and storage. The energy control signal acts as the system's brain, balancing the generation and supply units, and the logistic control signal includes the entire supply to vehicles, vessels, and any other equipment that can be considered end-users. These two signals comprise the entire system's supply chain [54].

This classification of microgrid operations sections has been validated by research conducted by Fang et al. (2020), which also focuses on the foreseeable future of marine transportation [55].

3.10. Artificial Intelligence

AI refers to computer systems that can learn and make judgments like humans. It is used to increase automation and problem solving in a variety of sectors, including self-driving vehicles and virtual assistants [56].

In smart ports, by inputting massive data on all port activities, AI technologies optimize, simulate, supervise, and monitor various complicated systems, including intelligent control, timing, and smart mapping [57].

Additionally, it provides high-frequency and extensive-volume data by allowing several data sources to be connected at the smart port through a well-defined open interface. Integration of the Application Programming Interface (API) with existing solutions is simple and scalable, allowing the plugging in of various modules and tools to have real-time predictions, offline non-real-time model processing, and a single point to find data for the control system to have enough information for future decision making [58].

According to Dincer et al. in their book "*Optimization of Energy Systems*", intelligent energy management systems for marine smart ports may use AI to increase the power output of their systems [59].

Furthermore, according to a scientific study by Bracke et al., three essential qualities are needed for effective IoT integration inside a port environment. These three capabilities are (i) interoperability across the wide range of wireless technologies and data formats; (ii) multi-tenancy to ensure appropriate data isolation among the various stakeholders operating within port premises; and (iii) scalability to adapt platform performance following data volume patterns and thereby guarantee stability for response time and service time (composed of the "internal streaming time" and the "internal persistence time") [60].

It implies that employing AI in smart ports provides seamless communication between various wireless devices and data types (interoperability). It also keeps data private and distinct for numerous parties (multi-tenancy), such as shipping companies and authorities. AI can also change its performance according to the quantity of data available, ensuring speedy and dependable service even during peak periods (scalability). This allows smart ports to manage operations more effectively, improve security, and react to changing needs.

Additionally, utilizing AI may increase power supply reliability and reduce electricity expenditures, particularly in smart port energy systems [61].

The section that follows discusses the different types of renewable energy and briefly explains why shifting toward renewables is important for smart ports.

3.11. Renewable Energies

In the modern period, many ports are moving toward using renewable energy to satisfy energy needs for operational reasons within port limits. This action may reduce the port's C.F and aid in the fight against climate change.

The usage of wind farms in the seaports of the UK and Spain, solar and solar-thermal plants in Singapore and Australia, maritime energy in the UK, and geothermal plants in German ports are a few examples of how renewable energies are being used to replace fossil fuels for port operations in the new era.

However, employing renewable energy requires certain infrastructure, implementation, and legal requirements. As a result, another component of this study might be devoted to using renewable energy.

Renewable energy sources (RESs) include wind, tides, waves, biomass, hydroelectric power, geothermal, advanced nuclear power, synthetic fuels (e.g., hydrogen and ammonia), and solar photovoltaic (PV) supplies [62].

However, only wind, solar, marine, and geothermal sources are now utilized at seaports; other sources still need to be.

According to research on the effect of employing renewable energies at seaports by Kandiyil et al., using marine renewable energy at ports might reduce carbon emissions at Middle Eastern ports by up to 28 million metric tons per year, or around 20 percent. This study showed, however, that implementing maritime renewable energy in the Middle East is difficult owing to high initial capital expenditures, legal and regulatory hurdles, and technical and operational restrictions [63].

In terms of using a renewable energy framework in smart ports, Wang et al. presented a study in 2019 on the use of a two-stage framework for constructing hybrid renewable energy systems at seaports. According to the findings of this research, between 2015 and 2018, this strategy might lower annual electricity expenses by 31.9 percent and carbon emissions by up to 34.7 percent. The research looks at how using renewable energy at ports may improve both economic and environmental sustainability [64].

Additionally, based on Sadek et al. (2020), a review of the renewable energy market suggested that wind and solar energy might be efficiently employed for green ports. The optimal choice, according to the findings of this study, is a hybrid renewable energy system. According to the example study, a hybrid system like this could meet around 60% of the port's total energy needs [65].

Sifakis et al. recently investigated hybrid renewable energy as one of the strategies for satisfying energy needs while reducing GHG emissions. The customer intelligence (CI) process at seaports is powered by a hydrogen fuel cell and photovoltaic (PV) panels in the proposed technology.

The research found that employing a hybrid renewable energy system may lower GHG emissions by up to 87%, giving seaports a dependable and economical energy supply. This situation falls within the category of installing EMSs alongside CI infrastructure and leveraging laws to replace ship energy with CI [23].

Furthermore, the use of renewable energy in seaports is highly linked to the port's geographical potential. As an example, in this context, Fossile et al. (2020) examined the flexible and interactive trade-off (FITradeoff) method in this context. This process allowed for implementing a linear programming model to address potentially optimal alternatives. This approach helped researchers to find the most viable renewable energy sources for Brazilian ports based on geographical location [66].

According to the report, solar and wind energy receive the highest feasibility ratings. In contrast, hydropower and biomass were ranked last. Because the researchers discovered that incorporating energy storage devices may significantly reduce energy expenditures, the study can be referenced as a wonderful example of combining multiple renewable energies, infrastructure, and laws in a project [66].

Although additional examples are needed in this area, these examples are cited in this scoping study for the obstacles and difficulties in installing renewable energy in smart ports. The last component of the EMS in a smart energy infrastructure in a smart seaport is "product distribution", which is briefly detailed in the next chapter.

3.12. Distribution of Product

The last component of the energy supply chain is distributing energy to the end user, which is briefly detailed in this section.

Over the last several years, there has been a notable shift in energy legislation and regulations. Certain nations have begun implementing minor energy-producing systems to increase the security of providing and meeting energy needs [67].

This technology is called a "decentralized energy system" (DES) or "distributed generation" (DG). By deploying smaller energy facilities and more skilled generation, DG must give flexibility and security to the system [68].

DG is defined as "small-scale power production sources situated near the point of consumption, often employing renewable energy technologies to augment or replace conventional centralized power plants". These devices may improve grid resilience, minimize transmission losses, and increase overall energy efficiency [69].

Many researchers believe that the transition from centralized to decentralized energy distribution systems must occur more quickly since a smart energy infrastructure with a decentralized distribution system is valuable [70].

Likewise, according to the Mehigan et al. study, there are three DG classes and several alternatives for distribution generation [71]:

(A) Generation associated with the distribution system.
(B) Generation connected to the receiving device's user end.
(C) Generation reliant on energy demand and unconnected to the grid.

However, such groups may be further subdivided into conventional and nonconventional categories, and deciding which classes to install for a port is dependent on the port's attributes [71].

To summarize, decentralized energy distribution at smart ports implies a fundamental shift in energy management inside maritime hubs. By integrating dispersed energy sources, both conventional and renewable, these ports lessen their dependence on centralized power grids while transitioning away from the reliance on fossil fuels and moving toward renewable energies.

This decentralization not only increases sustainability by cutting GHG emissions dramatically, but it also improves energy resilience. Smart ports become less subject to grid interruptions by producing and distributing electricity locally, guaranteeing ongoing operations even during power outages or crises [15].

Furthermore, innovative control systems, such as real-time monitoring and demand–response mechanisms, optimize energy flow and utilization throughout the port, increasing efficiency and lowering operating costs. Decentralized energy distribution at smart ports exhibits the synergy of renewable energy technology, intelligent controls, and sustainable practices, eventually transforming the energy landscape of these key maritime hubs.

4. Discussion

The purpose of this scoping assessment was to look at the different components of an EMS for maximizing smart energy infrastructure in smart seaports.

Furthermore, the results emphasize the need for smart port activities and management to guarantee the effective use of energy resources. Smart port operations need a significant amount of energy.

The EMS can monitor and optimize energy use in response to these activities by leveraging real-time data and sophisticated analytics. Smart port management is critical for coordinating and integrating the EMS with multiple stakeholders and guaranteeing a continuous flow of information and communication.

The combination of an intelligent energy network, ICT, IoT, VPP, AI, distribution production systems, and renewable energy components has enormous potential for improving energy efficiency and sustainability in smart seaports.

Intelligent energy networks play a critical role in smart energy infrastructure. These networks provide efficient power transmission while also balancing and optimizing energy flow.

By incorporating intelligent grids into smart seaports, energy may be distributed more effectively, reducing waste, and increasing efficiency. The use of sophisticated control algorithms and real-time monitoring systems enables better energy distribution management and decision making.

AI, ICT, and IoT technologies are critical to the optimization of smart energy infrastructure. It is now feasible to collect real-time data on energy usage, production, and demand by utilizing these technologies.

This information may be examined and used to find energy-saving possibilities and enhance overall energy management in smart ports. These also aid in the integration of diverse energy systems and devices, allowing for smooth communication and coordination among the many components of the energy management system.

Virtual power plants (VPPs) are gaining popularity as a means of optimizing smart energy infrastructure. Multiple dispersed energy resources, such as solar panels, wind turbines, and battery storage devices, are aggregated into a coherent, controlled entity by VPPs.

This enables more effective resource usage as well as more flexibility in addressing the energy requirements of smart seaports. Smart seaports may reap the advantages of distributed energy production and storage by incorporating VPPs into their energy management systems.

Another key component in improving smart energy infrastructure is distribution systems. These systems oversee transporting power from the source to the end users. The integration of efficient distribution systems in smart ports guarantees dependable and continuous energy delivery to diverse port facilities and activities.

Distribution systems may be modified to fulfil energy needs while avoiding losses and optimizing efficiency by studying the energy demand patterns of various locations within the port.

Incorporating renewable energy components is critical for smart port sustainability. Smart seaports may decrease dependency on fossil fuels, cut emissions, and contribute to a sustainable energy transition by utilizing all available renewable energy sources. According to the International Energy Agency, marine transport still uses 99 percent of fossil fuels; thus, ports must spend more to reduce this rate since they are the only node in touch with ships [72].

However, efficient renewable energy integration requires careful consideration of aspects like intermittent, resource availability, and demand-side management, as well as complex forecasting models and optimization algorithms.

Figure 10 displays a smart port with all of the EMS components outlined in this research study that may work together to produce a sustainable port.

Knowing about smart port components, management criteria, and actions under the control of an EMS and smart port will help the reader better grasp all the facts in this figure. This figure was obtained from a recent research study conducted by Daniel Clemente et al. in 2023 [73].

This figure illustrates marine renewable energy (MRE) in the metocean condition (understanding meteorological and oceanographic conditions in offshore coastal engineering or renewable energy projects) using all available facilities to provide energy from renewables, including wave energy converters (WECs), as well as all technological equipment like closed-circuit television (CCTV) or digital television (DT) for traffic centers, as well as all AI, cloud computing (CC), and blockchain (BC) facilities, that can collaborate to provide a sustainable smart seaport Multi-Energy Distribution system.

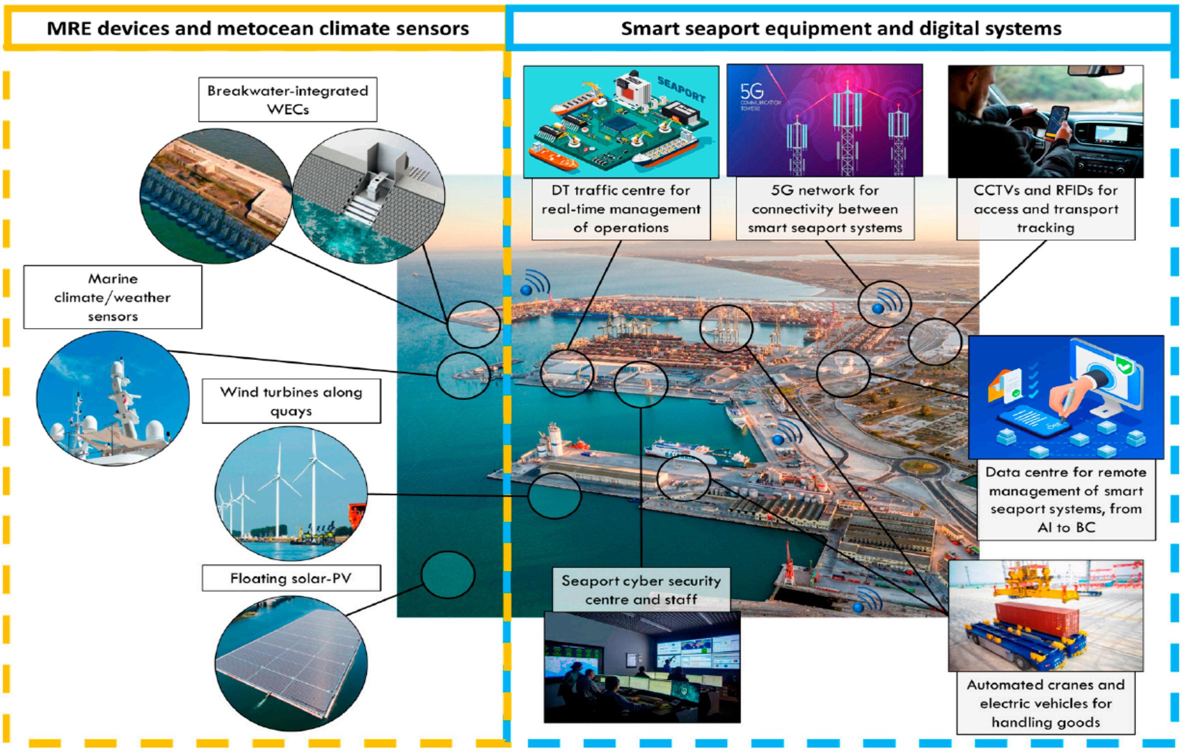

Figure 10. Schematic of the sustainable smart seaport Multi-Energy Distribution system retrieved from [73].

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5. Conclusions

In conclusion, intelligent energy networks and EMSs at seaports might support the maritime industry's efforts to cut carbon emissions and achieve sustainability goals. Smart seaports use real-time data monitoring, predictive analytics, and effective energy utilization to regulate and control energy consumption. As a result, less GHG emissions and fossil fuel utilization are required.

In this case, it is shown that there is an inverse connection between air pollution and the EMS, meaning that the more efficient the EMS in a seaport, the less energy is consumed and the better the performance of production and services.

Consequently, the development of an EMS maximizes energy use, reducing air pollution and the C.F. The industry's cost in both local and international markets may be significantly affected by this issue, in addition to lowering the C.F.

Furthermore, the deployment of an EMS is financially favorable for port operators, especially when the government and other public entities offer some financial help since the advantages are not instantaneous, and some tiny seaports that are clever too cannot afford sustainability supply costs.

However, based on this review, a key idea can be derived by combining the definitions of smart ports and EMSs: the EMS aims to manage energy generation, transfers, supply, and consumption by utilizing the smart port's infrastructure and components, such as the IoT, databases, and AI networks, and, when necessary, the storage system or direct connection between production and consumption, thereby optimizing energy use and resulting in less fossil fuel use.

Intelligent energy networks also make it possible to include renewable energy sources in the port's energy infrastructure, such as solar, marine, or wind power. Using various energy sources can further reduce the C.F and encourage eco-friendly behavior.

Additionally, intelligent elements such as sensors and smart lighting may be used in smart seaports as a part of smart infrastructure to improve energy efficiency and decrease waste.

Likewise, the EMS employing smart energy networks improves the efficiency of balancing energy supply and demand at ports that utilize renewable energies as efficient sources of energy production. If the quantity of energy produced by renewable resources exceeds the demand, they may store the extra energy for later use.

However, the surplus energy will be utilized to make up the difference if the energy produced by renewable sources at smart ports is less than the energy required. Hence, the output of energy from fossil fuels will be compensated. The port smart energy network and management system will reduce the port's C.F and fossil fuel production.

Therefore, this work-study concentrated on the interaction between employing smart energy networks to optimize energy consumption; mitigate energy generation, resulting in reduced resource usage to create power; and consequently mitigate C.F, resulting in more sustainable seaports.

This article emphasizes the importance of integrating energy management into the overall smart port strategy to achieve a greener and more sustainable maritime industry.

Smart seaports may provide a sustainable working environment that emphasizes lowering the C.F and minimizing environmental effects using EMSs and intelligent energy networks. This complies with international sustainability goals and establishes the marine sector as a pioneer in environmental management.

Future research should concentrate on the same topic as this article since new technologies are constantly emerging that will eventually assist EMS in managing the current supply system more effectively and aid with the deployment of extra renewable energy. Furthermore, ongoing research and development initiatives in this sector are critical to spurring new ideas and improvements toward a greener and more sustainable future for smart seaports.

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Abbreviations

SDG	Sustainable development goal
EMS	Energy management system
C.F	Carbon footprint
GHG	Greenhouse gas
SCR	Scoping review
IoT	Internet of things
AI	Artificial intelligence
VTM	Vessel traffic management
VTMS	Vessel traffic management services
M and T	Monitoring and targeting
EMIS	Energy management information system
PeMP	Port energy management plan
EnMS	Environmental management system
DER	Distributed energy resources
ICT	Information, and communication technology
DG	Distributed generation
VPP	Virtual Power Plant
PLC	Power line connection
GPS	Global positioning system
GPRS	General packet radio services
WSN	Wireless sensor networks
AMS	Automatic mooring system
API	Application programming interface
PV	Photovoltaic
CI	Customer intelligence
DES	Decentralized energy system
MRE	Marine renewable energy
WEC	Wave energy converters
CCTV	Closed-circuit television
DT	Digital television
CC	Cloud computing
BC	Blockchain

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