Revamping Seaport Operations with Renewable Energy: A Sustainable Approach to Reducing Carbon Footprint

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ABSTRACT

Objective seven of the Sustainable Development Goals states that everyone needs sustainable energy to reach 2050. As stated in Goal 13, global climate change reduction actions are crucial. A recent health board investigation indicated that seaport and ship emissions cause 19000 lung cancer cases and nearly 60,000 pollution-related deaths. The UN's annual maritime transport study predicts 961 million tons of CO2eq from maritime transport. However, less fossil fuel consumption leads to less air pollution and climate change, so a stable relationship exists between managing energy use and reducing air pollution, which mitigates climate change. Seaports, as essential nodes of global transport and a critical part of the maritime industry, began to deploy Energy Management Systems to manage energy use and move toward replacing fossil fuel energies with renewables. This study is a thorough scoping review of utilizing renewable energy in ports, as well as an evaluation of the strategy for achieving this goal and the impact of this goal on lowering the carbon footprint in seaports. The finding describes recent research by category and policy trends toward port sustainability via renewable energy. Finally, in conclusion, the data presented is used to analyze the process of establishing and increasing this phenomenon and to make relevant recommendations.

1. INTRODUCTION

Since Seventy percent of all ship emissions globally occur in coastal areas within 400 km, coastal cities are the globe's most polluted metropolitan areas. A recent study conducted by a health board indicated that around 19,000 lung cancer cases per year are reported annually worldwide because of seaport emissions [1]. Approximately 2.7 percent of all CO_2 emissions are estimated to be attributable to ship emissions, which have increased progressively over time [2].

Furthermore, in seaports, maritime activities contribute roughly three percent of all global emissions of CO_2, causing an abundance of efforts, including preparing wind farms and solar farms in ports or near them to supply sustainable energy, decarbonizing and greening up ports and their energy infrastructure [3].

On the other hand, as stated in Objective 13 of the Sustainable Development Goals (SDGs) about climate change, addressing and identifying world climate change reduction actions is an essential issue, and ports, as an intersection of maritime and other modes of transport with different types of transport, play a crucial role in this issue. Additionally, the greenhouse gas (GHG) emissions produced by port operations and fossil fuel utilization are among the most significant environmental factors contributing to climate change [4].

Innovation in the production, consumption, and distribution of energy and the development of systems are significant energy-related issues and addressing them is one of the main goals of sustainability. Nowadays, a new comprehensive framework for the management of energy usage known as the Energy Management System (EMS) is usually used in most ports [5]. Moreover, renewable energies can have a substantial impact on producing energy.

Examples of international regulations and initiatives aiming to mitigate carbon emissions in ports include the International Maritime Organization's (IMO) Maritime Pollution Regulation (MARPOL) Annex IV (2005) [5], the “World Ports Climate Initiative” (WPCI) by the “International Association of Ports and Harbours” (IAPH) (2008) [6], the green port philosophy guidelines by the “World Association for Waterborne Transport Infrastructure” (PIANC) (2014), and the European Green Deal by the “European Sea Ports Organization” (ESPO) (2020) [7].

These initiatives and measures are moving towards sustainable energy and combating air pollution by emphasizing the integration of objectives seven and 13 of the SDGs [8]-[9].

Then, in the findings of this study, the authors attempt to evaluate the literature on the use of renewable energies in

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ports as important transport hubs worldwide. They also provide a scientific interpretation of the recently reviewed literature and suggest future research in the relevant field in the conclusion.

2. RESEARCH METHODOLOGY

Following an extensive review process in Science Direct, IEEE, Scopus, Web of Sciences, and Google Scholar search engines to identify articles and books on the topic of "renewable energies and carbon footprint (C.F) mitigation measures in seaports" around the world, the initial and preliminary keywords list was chosen to provide a suitable and relevant perspective for answering the research questions.

The selected keywords included to cover the research literature comprehensively are "sustainable energy"," green ports", "carbon footprint", and "marine renewable energy".

This conceptual and descriptive paper is based on a cross-sectional deep-scoping literature review of articles about renewable energies in maritime ports, including reducing C.F by renewable energies, etc. Five main steps were followed in conducting the critical literature review: (i) online database search based on keywords (Scopus and Web of Science); (ii) first refinement based on selection criteria including title, abstract, and keywords of that paper; (iii) Other unique features such as language, publication year, country and region, access type, document type, etc, for further refinement; (iv) focusing on the main topic by abstract screening as third refinement; and (v) the last step is full-text review. The procedures for refinements with the number of refined resources are shown in Figure 1.

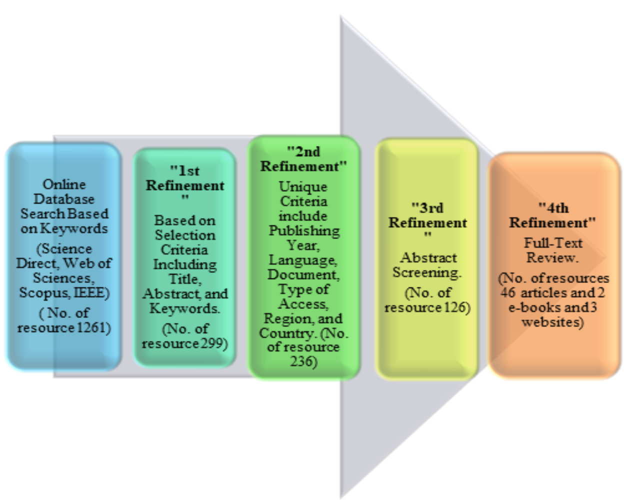

Fig. 1. Refinement Procedures.

Finally, the articles on the practical utilization of renewable energies are divided into six different categories according to the used renewables:

- Solar energies.
- Wind energies.
- Marine energies.
- Geothermal energies.
- Hydropower and bioenergy.
- Hybrid use of renewables.

Although each of these categories could be divided into some subcategories, this research study focuses on using renewable energies in EMS, as presented in the following sections.

3. RESULTS AND FINDINGS

Mitigation of C.F and Renewable Energies

At the end of the search and after several stages of filtering, 47 related articles, one book, and three official websites of international organizations were found that were wholly focused on new energies and carbon reduction measures in ports.

The literature concerning the main research work issue is divided into three categories, as shown in Figure 2.

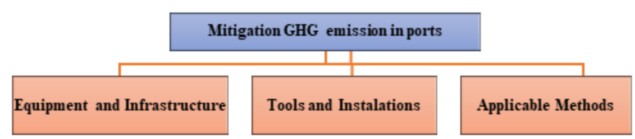

Fig. 2. GHG emission reduction initiatives in ports

The first category focuses on equipping and installing facilities and infrastructure directly using different types of renewable energies to mitigate carbon emissions in ports.

The second category examines the impact of installing equipment and infrastructure in the first category and focuses on the impact of EMS due to the use of equipment.

The third category suggests methods that have the potential to reduce carbon dioxide emissions via the utilization of new energies and criticizes how to implement these methods.

However, as explored in the following chapters, employing renewable energies in ports is a move toward sustainability, minimizes climate change, and is a fusion of all three classifications mentioned above.

3.1. Supply and Use of Renewable Energies

In this study, the review analysis is conducted based on the ways and methods to use or supply renewable energy as the most common topic, which are shown in Table 1; several scientific research studies have discussed the supply and utilization of renewable energy in the seaports and significant role of this action to mitigate GHG emissions by changing the utilization of these energy sources in place of relying on fossil fuels. The most relevant articles in the field are as follows.

Table 1. Use of Renewable Energy for Seaports

No	Major theme	Author	Type	Research Method
1	Integrity and electricity structures: electricity generation for an environmentally friendly future [11].	Andren et al., 2012	Wind energy	Case study
2	An offshore wind turbine GIS to evaluate the offshore possibility of wind power in the United Kingdom [12].	Cavazzi et al., 2016	Wind energy	Case study
3	Management of power consumption in port facilities [13].	Acciaro et al., 2014	Wind energy	Framework
4	Planning of environmentally friendly port operations considering all aspects of sustainability [14].	W. Wang, Huang, et al, 2019	Wind energy	Framework
5	Deploying cold ironing in seaports [15].	Gutierrez-Romero et al, 2019	Wind energy	Framework
6	Researching the potential wave power across the offshore and terrestrial maritime region of Oman [38].	Motlagh, 2019	Wave energy	Case study
7	A discussion on the use of solar energy in commercial settings [16].	Mekhilef et al., 2011	Solar energy	Framework
8	The Global Energy Assessment for 2016, with Forecasts Extending to 2040 [17].	Conti et al., 2016	Solar energy	Framework
9	Architecture of a Solar Processes Thermal System for Certain Low-Temperature Activities in the Manufacturing Market [18].	Hess et al., 2011	Solar energy	Framework
10	The possibilities for using clean energy for different types of industrial purposes [19].	Taibi et al., 2012	Solar energy	Framework
11	A photovoltaic battery made of polymer that is both self-recharging and adaptable [20].	Dennler et al., 2007	Solar energy	Case study
12	A Comprehensive Analysis of the Average Cost of Solar Photovoltaic Electricity [22].	Branker et al., 2011	Solar energy	Case study
13	A discussion on solar energy production that combines photovoltaic and thermal elements [23].	Chow et al., 2010	Solar energy	Framework
14	Market expansion and outlook for the photovoltaic solar power economy [24].	Hoffman, 2006	Solar energy	Modeling and simulation
15	Active house installation paradigm for a flexible relationship between the distributed energy system and home electricity customers [26].	Stoll et al., 2013	Solar energy	Case study
16	CO_2 mitigation through the utilization of Renewable Energy Sources (RES) for the charging of Electric Vehicles (EV) [27].	Brenna et al., 2017	Solar energy	Case study
17	An investigation into energy conservation in seaports, including business plans, technological advancements, and energy oversight technologies [28].	Lam et al., 2018	Solar energy	Framework
18	The simulation and installation of smart electrical grids for the fish manufacturing industry [29].	Al-zahrani et al, 2019	Solar energy	Case study
19	An assessment and modeling of intelligent energy hubs and the electricity supply chain for fish processing firms [4].	Al-zahrani, 2020	Solar energy	Implementation
20	Effect Analysis for PV and ESS Integration in the Transmission Network of Jurong Seaport [30].	Verma et al., 2018	Solar energy	Case study
21	Smart Incorporation for CO_2 Pollution Mitigation in Eco-Ports Employing Integrated Particle Swarm Optimization Methodology [31].	Balbaa et al., 2019	Solar energy	Case study
22	A comparative analysis of the seaport of Chennai: GHG pollution monitoring and reduction initiatives that decrease the C.F	Misra et al., 2017	Solar energy	Framework

	in regular terminal operations [3].			
23	A Survey of Energy Conservation Innovations and Renewable Energy Availability [34].	Abolhosseini et al, 2014	Marine energy	Framework
24	Irish sea current power appliances: Existing condition and prospective future possibilities [33].	Rourke et al., 2010	Marine energy	Framework
25	A wave-driven electricity port targeting power self-sufficiency. [35]	Ramos et al., 2014	Marine energy	Case study
26	A Journey Beyond Sustainable seaports: The Deployment of Offshore green power generation in Middle Eastern seaports [40].	Kandiyil et al., 2022	Marine energy, hydropower, and bioenergy	Framework.
27	Green power generation from marine currents in the Aviles seaport: unique amenities provided to the society [36].	Alvarez et al., 2013	Marine energy	Case study
28	Examine How the Marine Energy Administration Can Help the Oman Marine Industry Meet Goal 7 of the UN SDGs [39].	Motlagh, H. 2021	Hybrid energy	Case study
29	The Marine Wave Electricity Converter: An environmentally friendly Seaport [37].	Lazaroiu et al., 2017	Marine energy	Case study
30	The introduction of the cold-ironing methodology and an alternative renewable energy network that utilizes hydrogen throughout seaports [43].	Sifakis et al., 2022	Hybrid energy	Framework.
31	Composite decision-making techniques for enhancing heterogeneous green energy networks: Port of Takoradi as an example study" (Composite decision-making techniques for applying a combination energy platforms) [44].	Odoi-Yorke et al. 2022	Hybrid energy	Case study
32	Hybrid green power infrastructure with the best possible structure and intelligence [46].	Sifakis et al., 2021	Hybrid energy	Framework
33	A Two-Stage Approach for the Efficient Architecture of a Mixed Green Energy Infrastructure for Seaport Operation [45].	Wang W et al., 2019	Hybrid energy	Framework
34	Evaluation of Clean Power Production for Sustainable seaports through a Research Model [47].	Sadek et al., 2020	Hybrid energy	Framework and Case Study
35	Using the "FITradeoff" technique, determine the best feasible green power supply for Brazilian seaports [32].	Karolina Fossile et al., 2020	Hybrid energy	Framework

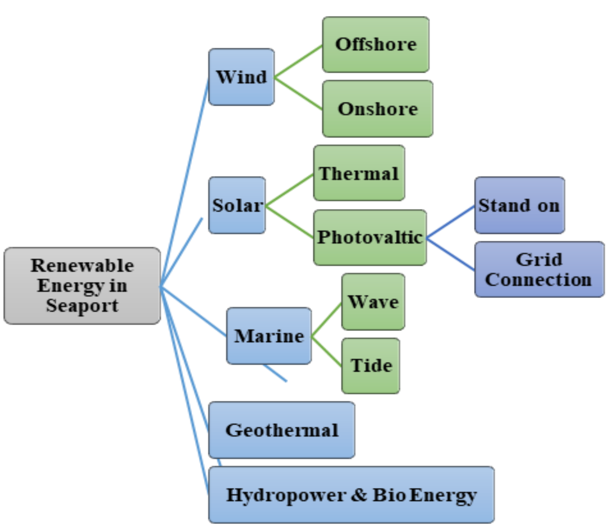

Fig. 3. Renewable Energies for Use in Seaports.

According to recent studies and the status of renewable energy usage around the globe, renewables can be categorized into the five categories shown in Figure 3. It should be noted, however, that the emergence of new forms of renewable energy is not unexpected as technology advances in a new era. Figure 3 classifies the types of renewable energy employed in ports; each type is subdivided, and each category is briefly explained concerning recent research.

Each of them in the following section is briefly reviewed with the help of some related literature.

3.2. Wind Energy

The most promising renewable energy source is wind energy due to its accessibility, cleanness, and abundance. As stated in the studies of Dinser et al., wind energy occurs due to the earth's rotation along with the temperature difference, which causes a change in the atmospheric pressure and ultimately leads to the movement of a large amount of air mass. Wind energy installations worldwide have grown significantly [10].

In 2010, the total number of installed farms to generate electricity from wind energy was 274 in the UK. The report notes that the installed wind energy capacity in the UK has increased significantly since 2010, reaching 24.1 GW by the end of 2020. A wind turbine consists of several components: a turbine, an electric generator, a tower, a drive train system, a speed control unit, and a deflection mechanism [11].

Wind energy is an attractive energy source due to its easy implementation, substantial reduction in GHG emissions, and exceptional performance. An important feature of wind power is that it is clean and reliable; however, wind turbines must be improved to reduce their noise emissions. Compared with other renewable energy sources, wind turbines are not visually pleasing and very expensive [12].

Cavazzi and Dutton examined both onshore and offshore wind power generation and concluded that offshore wind power could be more efficient and environmentally friendly than onshore. By 2020, the UK hopes to produce thirty-five per cent more electricity using renewable energy sources (RES). To meet this goal, the UK has made an ambitious effort to generate 22 gigawatts of electricity from offshore sources, which has also been achieved. [13].

Furthermore, 16.2 gigawatts of electricity were produced by offshore wind throughout Europe, primarily in the North Sea, where offshore wind turbines are expected to be located. Most offshore renewable energy projects are complicated to install and maintain, expensive, and time-consuming. By 2020, the UK, for instance, plans to have 18 gigawatts of operating offshore wind turbines.

However, only some studies have examined wind energy's potential for generating electricity for seaports because suitable port locations for installing offshore or onshore wind turbines are limited. The size of wind farms is significant, and their installation often requires more space near ports. Since 2012, the Port Authority in Hamburg has invested in energy extraction from renewable resources. It has constructed 126 wind turbines, each rated at 6000 kW, as indicated by Acciaro et al. [14].

An article by Wang et al. in 2019 provides a suitable and optimal framework for identifying seaports' hybrid renewable energy systems. In this method, the generated power by wind is incorporated into a subsystem designed to provide the energy requirements of the port [15].

Gutierrez-Romero et al. examined the feasibility of using renewable energy to supply the electricity needs of a port site, particularly for cold ironing (CI). The study demonstrated that wind energy may successfully meet port officials' onsite energy requirements [16].

3.3. Solar Energy

Solar energy has become an appealing energy source in the modern world despite the competition between big energy giants in the industrial sector. Solar energy is clean, abundant, and pollution-free [17].

Energy from renewable sources contributed about 10% of total consumption in 2016 [18].

On a global scale, a significant increase has been noted in the capturing and installing of solar energy from 2001 through 2018. Solar thermal and photovoltaic (PV) are two methods of harnessing solar energy. Globally, solar thermal industrial applications have a share of 10% of industrial processes at high temperatures [19].

There is a wide range of thermal applications, including dehydration, steam, hot water, preheating, chemical reactions, sterilization, concentration, washing and cleaning, commercial uses, buildings, plastic, food, industrial textiles, and even the heating of industrial spaces [20].

Nevertheless, in the case of PV, direct irradiated light (solar or otherwise) is converted into electrical power and refers to generating electricity from light [21].

It is estimated that around 25% of all PV panels 2015 were monocrystalline silicon panels, which is the most efficient. Monocrystalline silicon solar cells can achieve an efficiency of 15 to 20% [22].

For different types of PV systems, manufacturers usually provide a 25-year warranty. Solar PV cells generally have a simple component design, making maintenance affordable and competitive [23].

Due to the increasing demand for and production of PV panels, installation costs may gradually decrease as PV panels can work effectively in various weather conditions. [24].

A grid-connected PV system and a stand-alone PV system are the two primary categories of PV systems. Moreover, PV systems can be built in a variety of sized locations. Without a connection to the grid, a stand-alone system will rely on locally produced electricity to meet its energy requirements. To meet the nighttime electrical needs, like a system requires reserve. Solar energy's commercial uses include cooling, heating, ventilation, air conditioning, and power generation employing PV systems. By storing it in rechargeable battery structures, solar energy may be utilized instantly for various purposes [25].

However, grid-connected systems are linked to the regional or municipal grid to deliver extra electricity produced into the grid, preserve it, and fulfill needs when PV system energy is inadequate [26].

The usage of a spring house for the stability of the Royal Port of Stockholm was covered in another study by Stoll et al. in 2013. This study investigated the integration of solar PV systems with intelligent equipment and batteries for creating a demand response integration system for building automation systems by implementing local energy storage. [27].

Brenna et al. also examined incorporating a national PV system for recharging battery-powered cars in metropolitan areas, airports, and, notably, maritime ports [28].

Another Lam et al. 2018 research looks at using an EMS for a maritime port location to lower expenses and carbon dioxide emissions. According to this investigation, solar energy systems can be incorporated to satisfy the power requirements of port authorities [29].

Moreover, a study conducted by Al-Zahrani et al. in 2019 concerning implementing an intelligent microgrid in a fishing port site involved using a PV system on the roofs of buildings or solar farms to comply with the port administrators' power requirements [30].

Al-Zahrani et al. also, in a 2020 study, proposed the development of a regional solar farm to supply nearby power requirements in addition to the energy requirements of the nearby community by the usage of simulation modeling with the analysis programs and then examined the effect of decreasing carbon dioxide emissions in that territory [4].

Additionally, the usage of EMSs for maritime ports has been examined among Hamburg ports and the Genoa seaside in a separate investigation conducted by Acciaro et al., indicating the relevant relationship between implementing renewables and EMS in maritime ports [14].

The Port Environmental Energy Plan (PEEP), developed for the seaport of Genoa, was utilized to enhance the port's energy utilization and manufacturing operations. Three solar power plants are installed as part of the PEEP plan, which aims to cut the port's annual carbon dioxide emissions by more than 20,000 tons of CO_{2eq}.

On the other hand, according to a case study by Verma et al., installing a solar power plant with a 3.3-megawatt generating capability to aid Jurong Port's unstable electricity supply was examined and condemned [31].

Like this, a 2019 study project by Balbaa et al. examined the creation of creative power network administration among multiple ports in Egypt. According to this research, a PV system may provide all the local electrical requirements for the port site and export any excess energy to nearby ports, promoting the growth of sustainable seaports and ecological seaports. Implementing an intelligent EMS for a tourist port employing renewable energy sources was also suggested during this research paper. A PV system would supply the electrical requirements of terminals in terminals [32].

Furthermore, Misra et al. recommended a microgrid system for addressing the demands of the energy of a port authority in their research. It uses several renewable energy supplies (For example, wind and solar.). According to the findings of this study, a five-megawatt solar photovoltaic system with fluctuating power sources may help address regional electricity demand [3].

Furthermore, Fossile et al. 2020 utilized the "FIT trade-off" (Feed-In Tariff trade-off) method to evaluate the renewable energy sources that are most practical for ports in Brazil. The research findings revealed that solar and wind energy received the highest scores, suggesting their strong viability. In contrast, biomass and hydropower ranked the lowest. Additionally, the study identified that energy storage systems can potentially decrease energy expenses substantially [33].

The following section will cover the usage of marine energy and the conversion of its mechanical energy to electricity.

3.4. Marine Energy

Seventy-five percent of the globe's surface comprises oceans and seas, which can produce energy. Generating electricity by converting marine mechanical renewable energy caused by the movement of sea tides and ocean circulation is one of the cheapest and cleanest ways to produce electricity. Numerous maritime sources of clean energy, such as wind, tides, and waves, can produce power [34].

As per the 2007 World Offshore Renewable Energy Report, tidal energy is expected to reach a capacity of 3000 gigawatts, with a little over three percent of it located in places suitable for generating electricity [35].

Marine renewable energy offers greater accessibility than renewable resources dependent on wind and solar exposure. However, the problem is that connecting marine renewable energy to the national grid is more complicated and expensive than connecting other energies.

It has been claimed in a study by Rourke et al. that the marine energy setting up costs are significantly exceeding those of all other sustainable energy sources. Additionally, these machines, turbines, and equipment for maritime renewable energy resources demand routine maintenance by qualified experts. Only three papers, based on our investigation and numerous reviews, suggest using marine energy to supply the maritime organization's energy requirements [34].

The use of tidal mechanical energy to supply port authorities' energy needs was examined in Ramos et al.'s study. It demonstrated that in 2013, roughly 25 tidal energy turbines could provide all the energy required in the port of Ribadeo, Spain. It also indicated that the port's size and condition are connected to the quantity and efficiency of turbines and the number of operations performed there [36].

Alvarez et al. developed a tide-operated turbine during the subsequent inquiry. In 2013, they assessed the planned tidal turbine viability to satisfy the significant port site energy demands in Aviles Port, Spain [37].

Moreover, Lazaroiu et al. explored using the mechanical power exchanger of ocean waves to generate electricity for port uses in 2017. This is the initial and widely used method of converting mechanical energy via seawater into power and preserving it for multiple purposes. The current investigation used the Resonant wave energy exchanger (Rewec3) and the Inertial Sea wave energy generator (ISWEC) to convert waves into energy. Rewec3 was argued to be the optimal system from a scientific and academic standpoint [38].

On the other hand, in 2019, a study was conducted by Motlagh to investigate the wave energy potential extraction in Oman using numerical modeling. The study found that the regions of "Al Ashkharah" and "Raysut Port" had the highest wave power capacities, with 18.8 kW/m and 17.2 kW/m, respectively, at a depth of 50 meters. The study highlights the significant potential of Oman's coastal and terrestrial waters for wave energy extraction, providing a promising renewable energy source for the country [39].

Additionally, based on a 2021 study by the same author, Motlagh, Oman has a tremendous potential for renewable energy, particularly solar and wind energy, that can have a crucial impact on achieving the United Nations Sustainable Development Goals (UN SDGs). This paper emphasizes the significance of maritime energy management for Oman's sustainable growth and proposes integrating renewable energy sources to improve the marine sector's efficiency in using energy [40].

Finally, according to studies conducted in the ports of the Middle East, utilizing marine renewable energy in harbors could lead to an annual decrease in carbon dioxide emissions of approximately 28 million tons, equivalent to around 20% of the total emissions. Nevertheless, this research showed that adopting marine renewable energy in this region is challenging due to high initial capital expenditures, legal and legislative hurdles, and technical and operational limitations [41].

The following section surveys the literature on geothermal energy, a novel technique of energy production that has the potential to be employed in ports.

3.5. Geothermal Energy

Geothermal power makes use of the Earth's attainable thermal energy. Using wells or other methods, geothermal reservoirs are tapped for their heat. Hydrothermal reservoirs are inherently sufficiently hot and permeable reservoirs, whereas enhanced geothermal systems are adequately hot ponds that have been improved through hydraulic stimulation.

Once fluids of varying temperatures reach the surface, it is possible to produce electrical power, and the technique for generating electricity from hydrothermal lakes is well-established. It has been operational for more than a century. [6].

Based on K. W. Tan et al. 2018.'s research, use multiple renewable energy sources, such as energy obtained from sunlight, converting mechanical wind energy into electricity, and geothermal energy in an EMS of ports and all enterprises within the port can originate in uncertain circumstances due to fluctuating quantities of production [5].

Two other types of renewable energies are in use nowadays: hydropower and bioenergy.

Hydropower utilizes the kinetic energy of water as it flows downhill from higher to lower elevations. It can be produced through the utilization of both reservoirs and rivers. Reservoir-based hydropower facilities use stored water within a designated pool, whereas run-of-river hydropower installations capture the energy from the river's natural flow.

Hydropower reservoirs commonly serve various purposes, such as supplying drinking water, supporting irrigation, managing floods and droughts, facilitating navigation, and providing energy. Hydroelectric power is the primary renewable energy source for electricity generation. It depends on generally consistent rainfall patterns, yet it can potentially exacerbate climate-induced droughts or alterations in ecosystems that influence these rainfall patterns.

The construction required for hydroelectric power can likewise have adverse effects on ecosystems. Consequently, numerous individuals consider small-scale hydro a more environmentally sound choice, particularly well-suited for remote communities [43].

Bioenergy is derived from various organic materials known as biomass, including charcoal, wood, dung, and other organic fertilizers used to produce heat and generate power and crops for liquid biofuels. Most biomass is used for lighting, cooking, and space heating in rural areas, primarily by impoverished populations in developing nations.

Modern biomass systems comprise dedicated trees or crops, agricultural and forestry residues, and diverse organic waste streams. Biomass combustion produces fewer GHG emissions than fossil fuel combustion, such as oil, coal, or gas. Given the potential adverse environmental effects of the substantial expansion of forest and bioenergy plantations, which leads to deforestation and changes in land use, bioenergy should be restricted to specific, limited uses [41].

Nowadays, many ports combine two or more types of renewable energies to generate as much electricity as feasible. The following section is about literature on the hybrid usage of renewables in ports to generate power.

3.6. Hybrid renewable energy system

Most ports have begun transitioning toward the fusion of renewable energy to satisfy their needs, considering the benefits of employing renewable energies and the difficulties and expenses of constructing their infrastructure. Consequently, this part will conduct a literature review about using hybrid renewable energy systems.

According to a study by Sifakis et al. (2022), in the suggested setup, a combination of hydrogen fuel cells and photovoltaic panels is harnessed to generate electricity and supply energy for the cold-ironing process at ports. As the research indicates, employing this hybrid renewable energy system could lead to an impressive reduction of up to eighty-seven percent in GHG emissions, creating a dependable and cost-effective energy source for seaports.

Nevertheless, another recent study conducted by Odoi-Yorke et al. found that the most economical combination of renewable energy sources and storage technologies can boost the penetration of renewable energy by 81% while reducing CO_2 emissions by 64%. According to the study's findings and results, it is possible to construct sustainable energy systems for other seaports using the proposed optimization approach [45].

In another research paper released in 2019, Wang et al. presented a two-stage optimization scheme for hybrid renewable energy systems. Based on the research, this strategy could reduce annual electricity costs by 31.9 percent and CO_2 emissions by up to 34.4 percent. The study highlights renewable energy's ecological and financial advantages at terminals [46].

Likewise, Sifakis et al. (2021) presented an alternative hybrid renewable energy system strategy to reduce operational expenses while ensuring the seaport's energy supply. The research's suggested smart dispatch strategy entails maximizing the utilization of various energy sources according to their affordability and availability.

The findings indicated that, with a payback period of seven years, the suggested approach might increase the penetration of renewable energy sources by up to 87% [47].

Furthermore, according to Sadek and Elgohary, the renewable energy supply evaluation revealed that wind and solar energy might be effectively used for the green ports, and a hybrid renewable energy system is a feasible alternative. The case study showed that the hybrid system could meet roughly 60% of the overall port's energy needs [48].

Finally, Fossile et al. in 2020 presented a sustainable measurement model for a port in Brazil's south. The model revealed that, with a capacity factor of 26% and 44%, respectively, solar and wind energy had the most potential for deployment in that region. According to the findings, employing wind and solar energy can reduce CO_2 emissions by 84% [49].

4. CONCLUSION

Utilizing various types of renewable energies can significantly reduce air pollution in cities and industrial zones, save fossil energy for future generations, and help combat climate change. Moreover, the relationship between the different objectives of the SDGs, primarily objectives seven (affordable and clean energy), thirteen (mitigation of climate change impact), and seventeen (partnership for the goals), becomes more prominent when reviewing studies on renewable energy. Concerning the use of new energies to mitigate C.F in seaports, the following points can be considered:

- There are two significant models regarding wind energy and its conversion into electricity: land turbines and marine turbines. Both have high installation and maintenance costs. Turbines should be used where the average annual wind speed is sufficient for electricity production. Due to the high water depth in some port areas, installing marine turbines may not be cost-effective. Using hybrid renewable energies is more cost-benefit, according to many studies [50], [51].
- For solar energy as a renewable energy source, the lifecycle of energy transmission and retrofitting costs are essential. The financial aspects, such as system prices, lifetime, and loan period, can significantly impact energy production and transfer. Additionally, storing energy in batteries and transmission sources should be considered based on a cost-benefit analysis.
- Sea energy is another new source of energy production that can be exploited in two forms: wave energy and tidal energy. These mechanical energies can be converted into electrical power. Because this energy is taken from the sea, its transportation cost to ports is meager, making it an emerging energy resource for the next generation of ports.
- Geothermal and marine energy have two significant advantages over wind and solar energy. It is always available, and due to the possibility of exploitation in all lands, geothermal energy can be a desirable option for accessible energy.

Moreover, there is a question at the end of the conclusion: Is there any light at the end of the tunnel to prepare clean and affordable energy for all seaports worldwide? The answer could be more straightforward. If ports are vital economic points for regions and countries, their costly material benefits may have priority over other issues. Practical and financial support is needed to implement renewable energy production, transfer, and usage in ports, which are generally expensive initially.

In conclusion, the potential of renewable energies in seaports to mitigate climate change is enormous. Using renewable energies in seaports can significantly reduce carbon emissions and ensure a more sustainable future for our planet. It is essential to realize that the challenges of climate change require a collective effort, and every individual and organization has a role to play in reducing emissions. Using renewable energies can help seaports achieve their sustainability goals while improving their competitiveness and resilience. It is time to embrace renewable energies as a viable and effective solution to mitigate climate change in seaports worldwide.

As we move forward, let us all work towards creating a more sustainable, cleaner, and healthier world for us and future generations. By harnessing the power of renewable energies, we can build a brighter future for ourselves, our communities, and our planet.

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