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Utilización de redes energéticas inteligentes para mitigar la huella de carbono de los puertos marítimos inteligentes en aras de la sostenibilidad
Utilizing smart energy networks to mitigate the carbon footprint of smart seaports in the interest of sustainability

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Resumen-- **Según el programa «Aeropuertos y puertos verdes como centros multimodales para una movilidad sostenible e inteligente» de la Plataforma MSP europea, todos los puertos deben demostrar una producción y suministro integrados de energía de bajas emisiones en puertos y sistemas de abastecimiento, con infraestructuras de almacenamiento, distribución y repostaje sostenible de combustibles alternativos para buques, otros vehículos y otros usos. Los puertos marítimos inteligentes también equilibran la demanda y el suministro de energía mediante una gestión inteligente basada en IoT.**

A continuación, los puertos marítimos deben reducir el consumo de energía en las fronteras interiores del puerto o utilizar energías renovables en cumplimiento de la sostenibilidad, la norma ISO 50001 y los planes de gestión de la energía portuaria (PeMP). Este estudio examina los procedimientos de generación, transferencia y distribución de energía y su aplicación para reducir la huella de carbono (H.C.) del puerto marítimo. La técnica incluye una «revisión del alcance» y una amplia investigación de recursos vinculados. El impacto del SME en la reducción de las emisiones de carbono de los puertos inteligentes es objeto de debate. Y por último, la conclusión contiene ideas científicas, reflexiones y propuestas para mejorar el SGA de los puertos en un tema relevante.

Palabras clave— puerto marítimo inteligente; huella de carbono; sostenibilidad; internet de las cosas; cinchas inteligentes.

Abstract— **According to the European MSP Platform's "Green airports and ports as multimodal hubs for sustainable and intelligent mobility" program, all ports must demonstrate integrated low-emission energy production and supply at ports and supply systems, with storage, distribution, and sustainable alternative fuel refuelling infrastructure for ships, other vehicles, and other uses. Smart seaports also balance energy demand and supply via IoT-based intelligent management.**

Next, seaports must reduce internal port border energy consumption or use renewable energy in compliance with sustainability, ISO 50001, and Port Energy Management Plans (PeMP). This study examines energy generation, transfer, distribution procedures and implementation to lower the seaport's carbon footprint (C.F). The technique includes a "scoping review" and extensive linked resource investigation. EMS impact in smart ports lower carbon emissions is in the discussion. And finally, the conclusion contains scientific insights, thoughts, and proposals for enhancing the ports' EMS in a relevant subject.

Index Terms— smart seaport; carbon footprint; sustainability; internet of things; intelligent girds.

I. INTRODUCTION

In technological settings, smart refers to automated computational systems which can make self-configuration, self-protection, self-healing, and self-optimization (Spangler et al., 2010).

In urban planning, smart growth emerged during the 1990s

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as a state of course and focus in response to the increasing trend of destruction of people's living environment, noise, air pollution, destruction of historical sites, traffic congestion, and the increase in the cost of public facilities (UNESCO, 2019).

The term "smart growth" refers to a prospective (public or private) to managing developments that lead to managerial, economic, and environmental improvements Progress without congestion and environmental degradation. (Lacalle et al., 2020)

A smart city maximizes services to citizens while monitoring and integrating critical infrastructure, planning preventive maintenance measures, optimizing resources, and increasing security aspects' monitoring ("The vision of a smart city," n.d.).

The smart seaport is also gained from the smart city by the same concept but with a smaller scale and distinguished missions such as sustainability and profit. (Min, 2022)

One of the main objectives of sustainability is about energy issues and new systems and initiatives in energy generation, distribution, and consumption. An Energy Management System (EMS) is a new system in this field commonly used in all smart seaports. (Othman et al., 2022)

Conversely, a substantial proportion exists between the energy management system and C.F reduction. Like other industrial sites, smart port authorities have started to perform new initiatives in the mentioned issue to use intelligent management with intelligent infrastructures and equipment to mitigate carbon emissions and reduce the C.F in maritime ports. (Yau et al., 2020)

This study will illustrate and modify the C.F mitigation in smart maritime ports aligned with the UN Sustainable Development Goals (SDG) by managing energy production, distribution, and consumption via a smart grid system. Then the results are to be discussed in a literature review manner.

II. LITERATURE REVIEW

. Multiple digital departments linked to digital infrastructure and intelligent management make up an intelligent set. The connection port combines broadband communication, flexible and service-oriented computing infrastructure, and quick and cutting-edge services to meet demands through effective communication. A smart port has access to the most recent telecommunications, electronics, and mechanical technologies, as well as all necessary infrastructure and information technology (Lacalle et al., 2020).

A smart port has intelligent management, transportation, economy, healthcare system, energy, communication, grid, buildings, better-educated people, skilled workforces, intelligent infrastructure, and automation. Additionally, improving port operations and resilience results in stable and assured development and safe and secure port activities. (Lacalle et al., 2020).

Also, Intelligent infrastructure, intelligent traffic management, and intelligent logistics are the three main elements of a smart port and each has more minor parts (Min, 2022) as shown in Fig. 1.

On the other hand, the range of tasks performed by each smart port fall into the following categories, as it's shown in figure 2 (Lacalle et al., 2020):

i) operation.
ii) environment.
iii) energy.
iv) safety.
v) security.

Figure 2 depicts the activities classification in a smart port, along with its details.

However, every one of them can also be considered a smaller branch.

- Operational: the operation can categorize as follows:

Productivity: it can be illustrated as balancing demands and supplying primary port services, including loading/unloading cargo, shifting cargo inside the port territory, managing traffic density inside ports, port clearance operation, etc. (Lamberti et al., 2015).

Automation: utilizing different methods of using machinery instead of human force, but with their supervision, it can increase service efficacy and save time (Battino & Muñoz Leonisio, 2022).

Intelligent infrastructure means utilizing intelligent departments of a smart port that can collaborate intelligently using intelligent communication and IoT (Spangler et al., 2010).

- Environment: the following categories apply to the environment:
  - Environmental management system: any activity that can illustrate ports activity's goal to align with the protecting

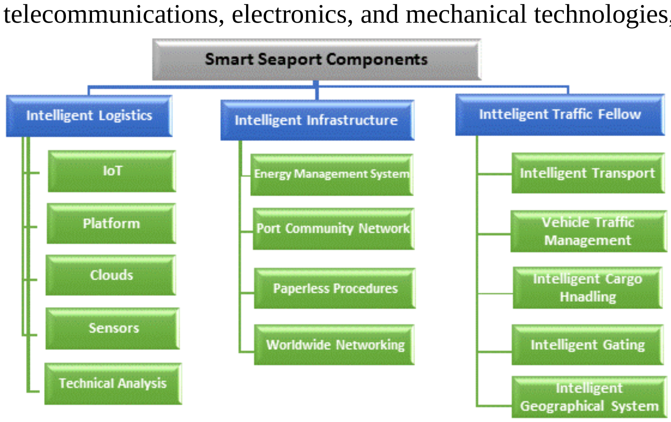

Fig. 1 Key Component of Smart Seaport

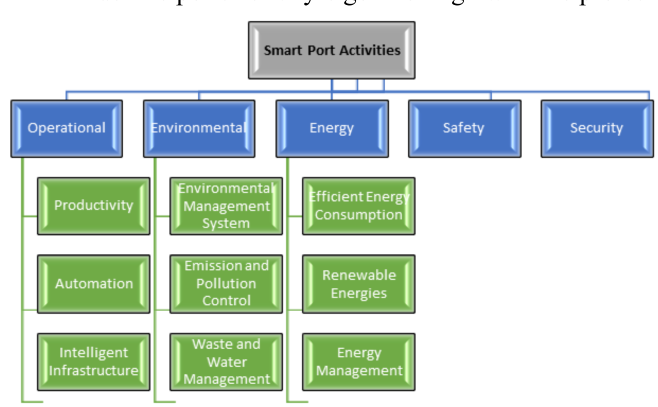

Fig. 2. Categorizing of Operation in a Smart Port

environment management in this domain (Lacalle et al., 2020).

- Emission and pollution control: all activities to control and mitigate emissions inside port territories governed by port authorities or public authority according to the national and international regulations can be illustrated as control initiatives in ports (Othman et al., 2022).
- Waste and water management: it includes all activities for balancing demand and supply for water management as a vital substance in the world and then moves for controlling and receiving waste materials and then using them in case of possibility for other industries like renewable energies, etc.(Lin et al., 2022).

- Energy: it splits into:
  - Efficient energy consumption: numerous guidelines and international and national regulations concern the efficient energy use of ships, vehicles, equipment and buildings, factories, and generators within seaports, and they are all aligned to achieve efficient energy consumption in seaports (Smith et al., 2021).
  - Renewable energies and their production: the second step in reducing the use of fossil fuels is to produce renewable energies such as wind energy, solar energy, earth thermal energy, and sea energy, and then to prepare them for use within seaports; this can be one of the primary goals of smart seaport authorities and policymakers(Doe & Roe, 2020).
  - Energy management: all activities and responsibilities of the port authorities relating to developing port-wide strategies for efficiently using energy and related activities (Lacalle et al., 2020).
- Safety: It includes all activities to maintain port safety in public and private operations that must be monitored and supervised in smart seaports using intelligent facilities (Yau et al., 2020).
- Security: It encompasses all initiatives, operations, and seaport security activities requiring intelligent infrastructure alongside technologies and monitoring; these procedures are called smart port security activities (Green et al., 2021) (Brown, 2020).

As mentioned in previous sections, each smart port has components that work together to create an intelligent form and wise policy; To put it another way and by another view of analyzing, each smart port has an intelligent management system that directs its initiatives, operations, and policies (Yau et al., 2020). The smart port management system requires intelligence in vessel traffic, cargo handling, port management, energy, and resources (Yau et al., 2020). Figure 3 depicts the critical components of a smart port management system.

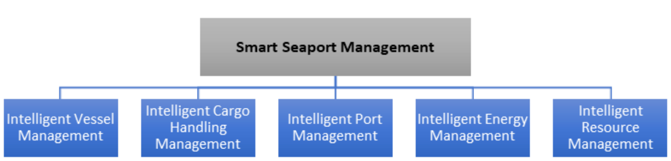

Fig. 3. Smart Seaport Management Sections

- Intelligent vessel management can manage vessel traffic management (VTS) and vessel traffic management services (VTMS), pilotage operation, and other maritime services for all vessels in the port territory.
- Intelligent cargo handling management system, including all loading, discharging, shifting, and striping warehousing in/from a smart port which can be delivered intelligently and using intelligent infrastructures and equipment.
- Intelligent port management includes innovatively implementing all decisions and policies and their application system and utilizing intelligent automation systems.
- Intelligent energy management involves balancing energy supply and demand inside the port, regulating efficient energy use, and attempting to replace renewable and green energies instead of fossil fuels.
- Intelligent resource management schedules and allocates resources, including equipment and infrastructures, to reduce congestion and identify the sources of congestion to optimize resource procurement and allocation in terms of time and cost. It helps to reduce resource wastage and waiting and inactivity time (Yau et al., 2020).

The primary goal of this study is to conduct a systematic scoping review to analyze the carbon footprint reduction effort in smart ports. These reviews can generally be divided into five critical scopes:

1-Power generation (energy supply).

2-Energy distribution,

3-Energy supplying systems

4-Energy consumption (energy demand), and

5-Moving toward renewable energies and replacing them instead fossil fuel energies (Lacalle et al., 2020), which this research will cover in the subsequent chapter.

III. Methodolody

This study is a "cross-sectional descriptive scoping review" of relevant resources, such as articles, eBooks, official websites, etc., about mitigating C.F in smart ports by utilizing smart energy networks.

A well-documented guide conducted the critical scoping review for creating PRISMA literature review protocols. There were five main steps, as shown in figure 3, illustrating the selection process with a number further refined at each stage as follows.

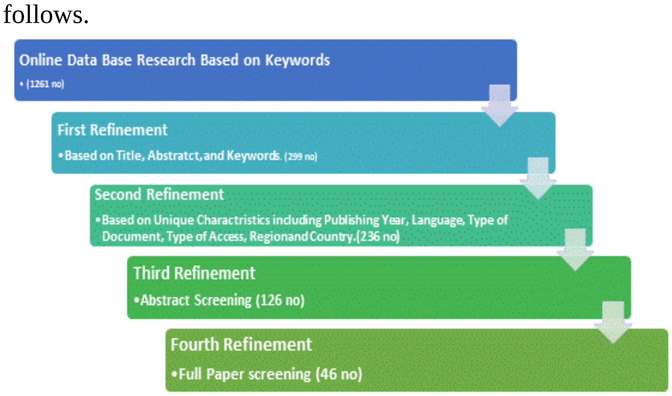

Fig. 4. Refining procedures in methodology

Online databases can be searched for using the following refinement:

- Keyword search in internet databases (Science Direct, Web of Sciences, Scopus, IEEE); "Green ports", "port carbon footprint mitigation", "maritime, renewable energy", "port carbon footprint reduction", and "smart seaport" were chosen to cover the study literature on greening ports, which rated top in 1261 results.
- Further refinement based on keywords.
- Abstract screening; and
- Full-text review.

Finally, forty-nine sources have been chosen, including thirty-three journal articles, four IEEE papers, five conference papers, three eBooks, and four official websites with content expressed in the work-study.

IV. RESULTS AND DISCUSSION

A. *Energy management system*

The rising potential of Information and Communication Technology (ICT) applications to create automation systems has increased the viability of employing intelligent energy systems to emphasize the environmental implications of energy generation and consumption (Blue & Gray, 2020).

The industry section outlined to raise its energy demand by 40% by 2040 [16].

Environmental Impact Energy Management System (EMS) is a capability that can reduce energy use in fabrications and productions by implementing several effective techniques to mitigate energy use, as indicated by the global energy requirements prediction[17].

This method primarily pertains to four issues:

- Energy generation.
- Energy distribution.
- Energy consumption.
- Development of renewable energy.

Energy generation refers to port-based activities that turn energy into electricity.

Energy distribution refers to the system, infrastructure, and rules for intelligent power distribution. Energy use is the term used to describe electricity use in ports and activities connected to ports, such as cargo handling, industrial processes, logistical operations, and administrative responsibilities. The renewable energy segment encompasses all issues about the investigation, management, and supervision of the possibility and installation of renewable energy facilities. Energy use can be divided into(Lacalle et al., 2020)

1. All direct port operations require energy, including operating terminals, locks, bridges, office buildings, buoys, and lighting.
2. The energy needed for ship propulsion (fuel consumed and electricity provided to ships).
3. Energy is required for activities that are influenced or related to ports, such as refineries, railroads, the steel and metal sector, or tourism.

On the other hand, Because ports are frequently situated in regions that are particularly suited for power generation from wind and wave (e.g., Rotterdam, 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). In addition, storage areas and warehouses, which are frequently available in ports, provide broad flat surfaces that can be used for solar panel installation (e.g., the Tokyo Ohi Terminal or the Port of San Diego administration buildings).

Although managing energy in seaports needs management tools which are policies, technological and Operational Measures, as follows :(Min, 2022)

Policy side: National and international rules and standards for EMS in marine ports are centred on optimizing EMS objectives. 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 (EMS).
- Port Environmental Management Plans (PEMP) and Green Port Policies.

Adopted Operational and Technological Measures to Improve Energy Efficiency:

- Categorization of activities inside the port (direct and indirect or land-based and maritime-based).
- Key operational measures.
- Main technological options for vehicles and port/terminal equipment.
- Energy-Efficient Port Buildings.
- Additional Facilities and Infrastructure Promoting Port Energy Efficiency

In addition, it is essential to pay attention to the new perspective that manages energy consumption through distributed energy resources (DERs), which includes the intelligent network, virtual power plant, Information and Communication Technology (ICT), Internet of Things (IoT), microgrid, Artificial Intelligence (AI), and finally distribution of production, which are explored in greater detail in the following sections. Figure 4 illustrates parts of DER in the energy management system.

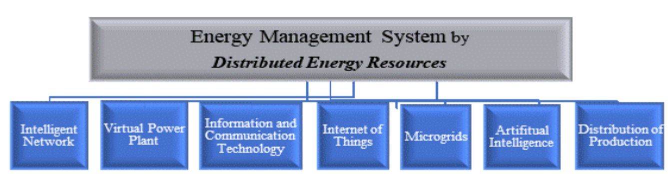

Fig. 5. Components of the Energy Management System's Distribution of Energy Resources

B. *Virtual Power plant*

The increasing deployment of Distributed generation (DG) and the lack of a passive viewpoint highlight the need for investments made throughout DG governance. There is an immediate need to develop a structure that facilitates DG's participation in the energy industry [18].

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

A VPP may control the flow of electricity between multiple units. It can optimise energy consumption and improve system efficiency [20].

The three essential tasks of VPPs are organization and control, distribution and optimization, and DG and renewable energy sources combined[21].

C. Artificial intelligence

Multiple complicated systems, such as intelligent control, timing, optimization, and complex mapping, are used, optimized, simulated, supervised, and monitored by artificial intelligence techniques [22].

Intelligent energy management systems for maritime ports can improve the power output of their systems using artificial intelligence [23].

Additionally, Artificial Intelligence can improve power supply dependability and minimize electricity expenditures [24].

D. Information and communication technologies

Information and communication technology (ICT) is required to develop a realistic, adaptable, and secure communication infrastructure and to enable protocols that facilitate real-time producer-user interactions in an intelligent grid[25]. The most common communication approach involves a smart meter and a data cloud via a power line connection (PLC). In the second perspective, a data cloud and a data meter management system are combined, and GPS or GPRS is the most prevalent system.[25].

E. Internet of Things

The Internet of Things (IoT) enables the secure and safe exchange of operational data between non-visible, embedded, and unique, recognizable devices using radio frequency identification (RFID) and Wireless Sensor Networks (WSN) with sensor devices and multiple processors to optimize decision-making in support of automation [26].

Sarabia-Jacome asserts the use of IoT for maritime port operations and enhanced a marine port data cloud that prohibits interoperability across stakeholder information systems [27]

The findings showed that the marine port data clouds enhance the choices made by several port departments. An additional investigation into using an automatic mooring system (AMS), which enables ships to berth and undock without using their mooring equipment, found that it can lower carbon emissions [28].

F. Intelligence network

The intelligent grid issue has aided in the identification of high-quality, compatible production and storage units. The objective of an intelligent grid is to allow stakeholders and policymakers to concentrate on identifying the optimal operating environment for electrical energy and customers [29].

This transition emphasizes intelligent, eco-friendly, cost-effective, innovative electrical system solutions [30].

Figure 6 illustrates how integrating many local energy sources with renewable energy sources via an intelligent grid enhances the efficiency and reliability of the power system [31].

It provides an intelligent grid layout at the smart seaport, a cargo terminal, which includes buildings, an onshore power supply, an in-port crane and stowage equipment, and cranes for handling goods.

Figure 6 illustrates how reducing electricity prices and generating revenue from energy sales during peak hours might benefit users through intelligent networks[32].

An intelligent grid uses digital technology to increase the electrical system's dependability, stability, and efficiency (in terms of energy and economics)[33].

Additionally, intelligent grids rely on intermittent and unreliable renewable energy sources like marine, solar, thermal, and wind [32].

It may be seen in several technologies, such as the use of artificial intelligence to forecast how much energy will be produced in the following days and then store or convert it, that go a long way toward providing stability and adaptability in the distribution of electrical energy[34].

G. Microgrids

A microgrid is a small-scale local energy system composed of energy generators, electricity storage devices, loads, a grid control system, and other distributed energy resources (DERs). The US Department of Energy defines a microgrid as "a

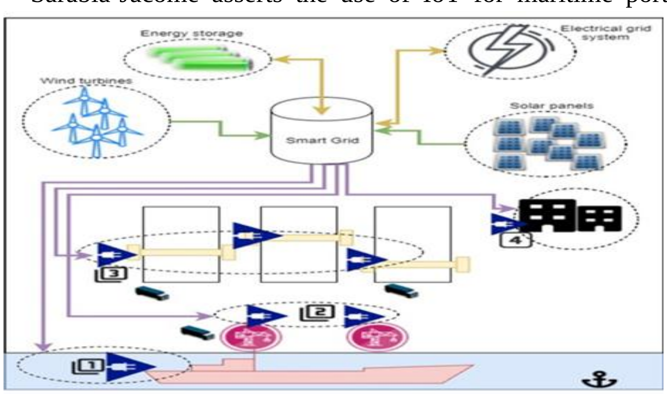

Fig. 6. Layout of the Intelligence Grid in the Smart Seaport [31]

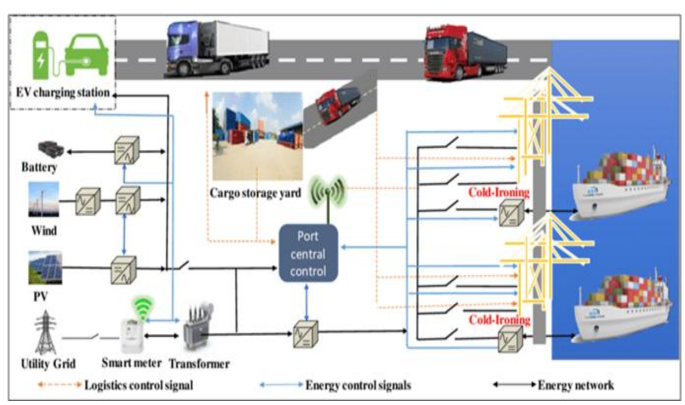

Fig. 7. Microgrid System in Smart Seaport [43].

community of interconnected loads and distributed generation at defined electrical boundaries that depend on a controllable entity connected to the grid." Due to its grid connectivity and detachment, a microgrid can function in either an isolated or linked state [35].

DER, energy-exchanging technology, communication links, control systems, and EMS are all components of microgrids in maritime ports that allow for effective energy management between parties and users[36].

Consequently, A microgrid combines renewable energy resources with power storage, management systems, and consumers. It may also be a system that spans generations and is linked to grids[37].

Renewable energy sources (RES) lean on wind and tide, weather conditions, and Photovoltaic (PV) fragmentary resources [38].

On the other hand, 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. [39].

Collaboration, control, and microgrid performance are crucial factors affecting system performance[40].

Two studies employed optimization skills to mitigate errors and enlarge efficiency and profits for the system and its consumers [41] [42].

Figure 7 shows an overview of a microgrid system in a smart seaport[43]:

H. Distribution of product

Energy laws and policies have seen a striking change during the last few years. Some countries have started employing modest energy-producing systems to strengthen the security of supplying and satisfying energy demands.[44]

This technology is a decentralized energy system or distributed generation (DG) (DES). By deploying smaller energy facilities and more skilled generation, DG must provide flexibility and security to the system. [45]

As per a study by P. Paliwal and his team [46], Energy production needs to transition faster from centralized to decentralized.

The definition of DG varies depending on geographical perspective; however, T. Ackermann and his colleagues provided the first one, defining it as a "power source inside distribution networks or on the meter's user side"[47]

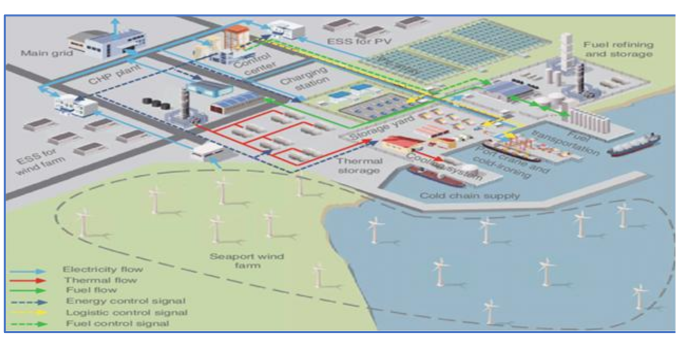

Fig. 8. Schematic of the Seaport Multi Energy Distribution. [49]

Considering the research of L. Mehigan and his team, three DG classifications exist; distribution generation options include: [48]

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.

DG has both a conventional and unconventional production system. Conventional production: This system utilizes components like microturbines. Figure 8 depicts energy allocation in a smart maritime port that utilizes various energy sources.

V. CONCLUSIONS

According to the conclusions of this study, there is a considerable correlation between the EMS and the amount of air pollution created globally. On larger dimensions, such as industrial sites, the effect of this relationship is more prominent. Seaports may be one of the industrial and service sites. In these areas, the connection between the energy management system and air pollution is inversely established, which indicates that the more influential the energy management system in a seaport is, the more efficient the energy consumption is, and the higher

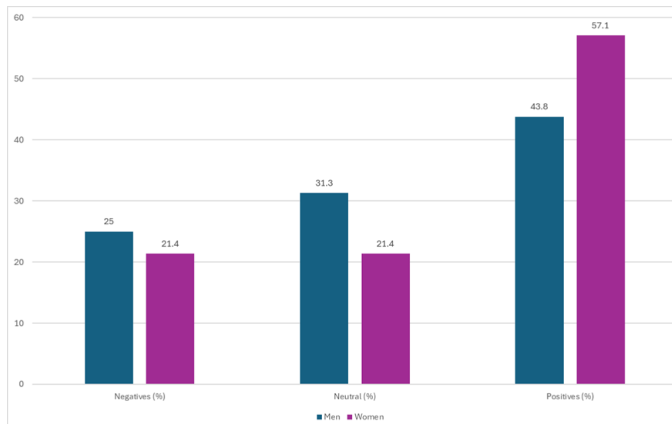

Fig. 6 Gender polarity.
(Source: Own elaboration)

the production and service performance. The reduced energy consumption will result in fewer pollutants released into the atmosphere, with carbon accounting for a significant proportion of these pollutants.

As a result, the improvement of a management system Energy makes the best use of energy, resulting in less air pollution and a lower C.F. Aside from minimizing C.F., this issue can substantially impact cost savings, affecting the industry's cost in both domestic and foreign markets. Figure 9 demonstrates how EMS and smart seaports collaborate to lower C.F. in that region.

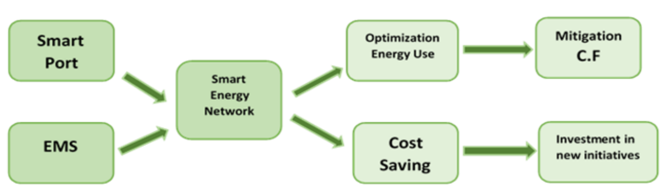

Fig. 9. Interrelation between Smart Network System and Mitigation Carbon Footprint.

Figure 9 depicts the interaction of EMS and a smart seaport to reduce C.F. The creation of intelligent infrastructures connected via the internet or intranet networks, on the other hand, is one of the components of smart ports. It can prevent repeating or parallelizing processes within the port by aligning them. It will decrease superfluous actions and, as a result, the C.F. Nonetheless, by combining the definitions of smart ports and energy management system, an essential concept can be derived: the energy management system attempts to manage energy generation, transfers, and consumption by utilizing the smart port's infrastructure and components, such as the Internet of Things, databases, artificially intelligent networks, etc., and, when necessary, the storage system or direct connection between production and consumption, thereby optimizing energy use which leads less fossil fuel use to generate energy and this reduction in fuel consumption will reduce the emission of pollutants and reduce the C.F.

In ports that use renewable energies as effective sources of energy production, the energy management system utilizing smart energy networks increases the efficiency of balancing energy supply and demand, so if the amount of energy generated by renewable resources is greater than the demand, they can reserve the excess energy for later consumption. However, suppose the energy generated by renewable sources in smart ports is less than the energy demanded; then, the excess energy will be used to offset the deficit. Hence, the production of energy from fossil fuels will be compensated. The smart energy management system and smart energy network will lower the output of fossil fuels and the port's carbon footprint.

Therefore, this work-study focused on the relationship between using smart energy networks to optimize energy consumption, mitigate energy generation, which results in less resource use to produce electricity, and finally mitigate C.F., which results in more sustainable seaports. New technologies will eventually help EMS to manage the current supply system more effectively and assist in deploying more renewable energies, which is an excellent topic to concentrate on in future work studies.

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