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Article

A Framework for Accurate Carbon Footprint Calculation in Seaports: Methodology Proposal

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Abstract: According to the 2020 European Sea Ports Organization Environmental Report, ports are the second biggest environmental concern for climate change due to greenhouse gas emissions. Furthermore, the International Association of Ports and Harbors determined that seaports are carbon-intensive and environmentally harmful because of increased commercial and non-commercial activities surrounding them. Due to the urgent concern to address solutions in this research line, this study aims to present a frame of reference to estimate the Carbon Footprint in ports through an innovative method. The study design presents a Meta-Analyses Scoping Review based on the PRISMA-ScR methodology to analyse the current articles, normativity and primary resources related to the Carbon Footprint estimation approach in seaports. Then, a categorization for the new method of Carbon Footprint and scopes description calculation is presented. Besides, the Port of Valencia, a famous Spanish port, provides the case study to apply and confirm the approach. Findings state that this new approach, with the designation of new boundaries and factors affecting ports' emissions would lead to an accurate estimation of the carbon footprint of ports. The originality and value of this work-study deliver scientific interpretations, reflections, and suggestions for future research and validation.

Keywords: greenhouse effect; international association of ports and harbors; carbon footprint; European sea ports organization

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1. Introduction

According to WMO Greenhouse Gas (GHG) Bulletin of 2020 which published on October 2021, the primary Greenhouse Gases (GHG) that human activity releases on a global scale includes [1]: (1) Carbon dioxide (CO_2), produced mainly by the burning of fossil fuels; (2) Methane (CH_4), produced because of various human activities, including farming, waste management, and energy consumption; (3) Nitrous oxide (N_2O), produced by burning fossil fuels and using fertilizers in agriculture, and (4) Fluorinated gases (F-gases), produced by industrial operations, refrigeration, and other factors, including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Figure 1 shows the four main gases that cause GHG, with CO_2 accounting for 66% of global GHG overall and divided into two sections.

Furthermore, based on the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report, carbon dioxide (CO_2) emitted because of industrial operations in the GHG contributes the most to climate change [2]. However, carbon footprint (CF) is nearly used to state CO_2 emissions. The CF, according to research by Lombardi et al., *"represents CO_2 and other GHG gases over the whole life cycle of a process or product"* [3], and Equation (1) describes it as follows:

$$CF = CO_2 + GHG \quad (1)$$

CF represents the carbon footprint amount in CO_2 equivalent (Co_{2eq}).

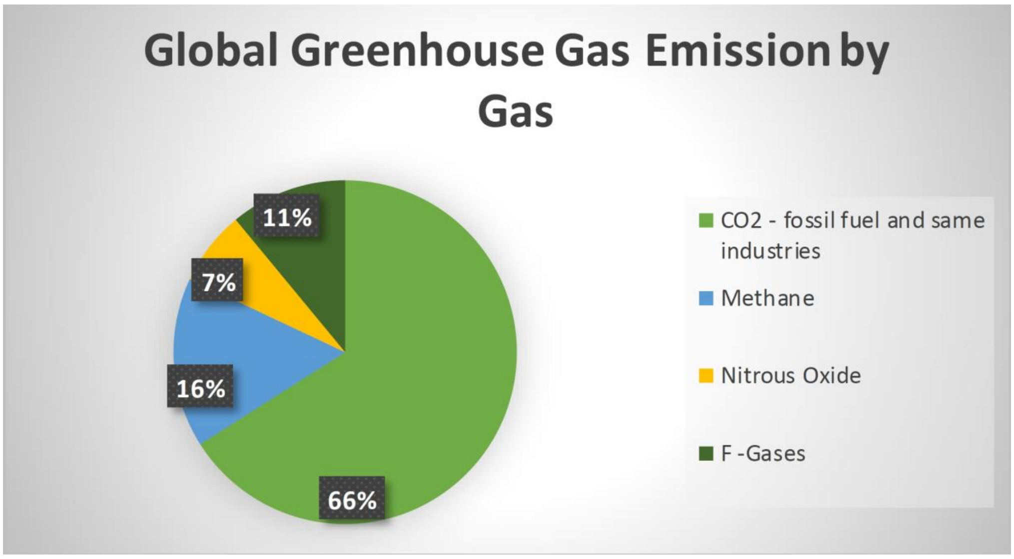

Figure 1. Global GHG Emissions based on [1].

Understanding Co_{2eq} can be made simpler by keeping these two terms in mind. The two most important variables affecting the atmosphere are the radiative forcing or "radiation intensity" and the "average time" a gas molecule spends in it. The total of these two factors, measured in kilograms of Co_{2eq}, is each gas's Global Warming Potential (GWP). In other words, each gas is converted into kg of CO_2 units using the formula described above [4].

Regarding the existence of CO_2 emission challenges in civil and industrial areas, one of the most important factors distinguishing cities is the presence of airports or seaports, both of which have the potential to increase a city's total inventory of emissions significantly; thus, reducing carbon dioxide emissions is a significant step toward mitigating the harmful effects of climate change [5].

Indeed, the existence of seaports is critical since they are crucial nodes in the global network in today's globalized society, serving as vital centers for the transnational movement of goods. In addition, international shipping accounts for over 80% of global trade by volume and 70% by value [6].

CF estimates must be more accurate to improve reduction measures and maximize seaport utilization. So, ideas and techniques for accounting CF at seaports are becoming more popular, and several projects are underway to reach an agreement on how to account for GHG emissions in specific cities and industrial sites like ports. This isn't easy, and miscommunication may occur.

The initiatives for accounting CF in seaports that are of concern in this research are typically divided into international and national accounting systems, both of which are in the same framework and localized due to area criteria but cannot breach the standard framework issued by international guidelines and entities. Table 1 lists the most popular and full standards.

Table 1. The most well-known and comprehensive standard guidelines.

CF Accounting Standard	Organization	Year
EMEP/EEA Air Pollutant Emission Inventory Guidebook [7]	European environmental agency	1996
Greenhouse Gas Protocol [8]	World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD)	Late 1990
ISO 14064, 14065, 14066, 14067, 14068, 14069 [9–14]	International Organization for Standard	—-
Guidelines for National Greenhouse Gas Inventories [15]	Intergovernmental Panel on Climate Change (IPCC)	2003
Guidelines for Calculating Carbon Footprints by the Ministry of Environmental Transition from the Spanish Government [16]	Ministry for the Ecological Transition and the Demographic Challenge (MITECO) of the Spanish	2007
Practical Guide for Calculation Greenhouse Gas (GHG) Emissions [17]	Catalan Office for Climate Change (Oficina Catalana del Canvi Climatic)	2008
Carbon footprint inventory and management guideline [18]	International Association of Ports and Harbors (IAPH) World Port Climate Initiative (WPCI)	2010
US Environmental Protection Agency Guidelines [19]	US Environmental Protection Agency's Centre for Corporate Climate Leadership	2012
European Standard EN 16,258 [20]	German Institute Standardization (DIN) and British Standards Institute (BSI)	2012
publicly available specification–PAS 2395 [21]	British Standards Institution (BSI)	2014
Clean Cargo Working Group Carbon Emissions Accounting Methodology [22]	Business for Social Responsibility (BSR) UK	2015
Spain Methodological Guide for Calculating the Carbon Footprint in Ports [23]	Spain Center for Studies and Experimentation of Public Works	2016
The Global Logistics Emissions Council (GLEC) [24]	The Global Logistics Emissions Council (GLEC)	2016
A guide to carbon footprinting for businesses [25]	Carbon Trust (UK-based company)	2017
Ship Emissions Toolkit Guide No.3: Development of a national ship emissions reduction strategy [26]	International maritime organization, Institute of Marine Engineering, Science and Technology (IMarEST)	2018

It should be noted that this study incorporates a new approach for CF calculation in ports based on international standards and describes new boundaries, and it applies the proposed technique to a Spanish port for verification using formal inventories released by local authorities and with the assistance of national and international records and databases.

Section 2 presents Materials and Methods as a Scoping Review and the system boundaries and data. In addition to the international and national standards mentioned in Table 1, only a few studies have been conducted on CF estimations' techniques and methodologies; and some are discussed in Section 2.1. In Section 3 authors stage the new methodology for CF calculation to perform in Section 4, the Case of Study of the Valencia port. In closing, Sections 5 and 6 create a discussion and conclusions.

Moreover, it should be noted that the objective of this study is to promote a novel approach for estimating the carbon footprint of seaports with more precision, verify it with a port of significant traffic volumes, and then discuss, evaluate, and draw useful findings from the results discussion, conclusion, and future work.

2. Materials and Methods

This section is divided into two main parts. The first part is about the scoping review of relevant literature review that will be presented in the following section about the previous related studies of CF mitigation in seaports and CF estimation.

The second part explains data that needs to be collected and categorized for the new methodology of CF calculation that will be presented, followed by its evaluation in a seaport as a case of study and discuss its outcomes in Sections 2.1 and 2.2.

A study and survey of the background and recent literature on the main issue of the research was prepared by using Preferred Reporting Items for Systematic Reviews and

Meta-Analyses in Scoping Review (PRISMA-ScR); The PRISMA-ScR intents to help readers develop a greater understanding of relevant terminology, core concepts, and key items to report for scoping reviews. This procedure includes Identification, Screening, Eligibility, and included as shown in Figure 2.

- Identification: Keyword search in internet databases (Science Direct, Web of Sciences, Scopus, google scholar); "seaport carbon footprint", "port carbon footprint calculation", and "seaport CO_2 emission", which rated top in 261 results.
- Screening and eligibility: These two processes are intertwined because, at each screening stage, single eligibility or a combination of eligibility issues are raised. These eligibilities include the paper's title, abstract, and keywords in the first refinement, which identified 99 resources; year of publication, language, type of material (articles, conference papers, e-books, and conference reviews), access, and the region in the second step of refinement, which identified 72 research works. A third refinement was applied based on an abstract screening refinement, and an adjustment was made to account for the critical topic of 72 resources, yielding 53 resources.
- Included: this is the final stage after screening and refinements, which gives us the total number of research discussed in a review. The entire work included 28 publications, comprising 19 indexed journal articles, seven conference and workshop papers and reviews, and 1 M.Sc. thesis report.

Thus, 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 results of filtration are illustrated in Figure 2.

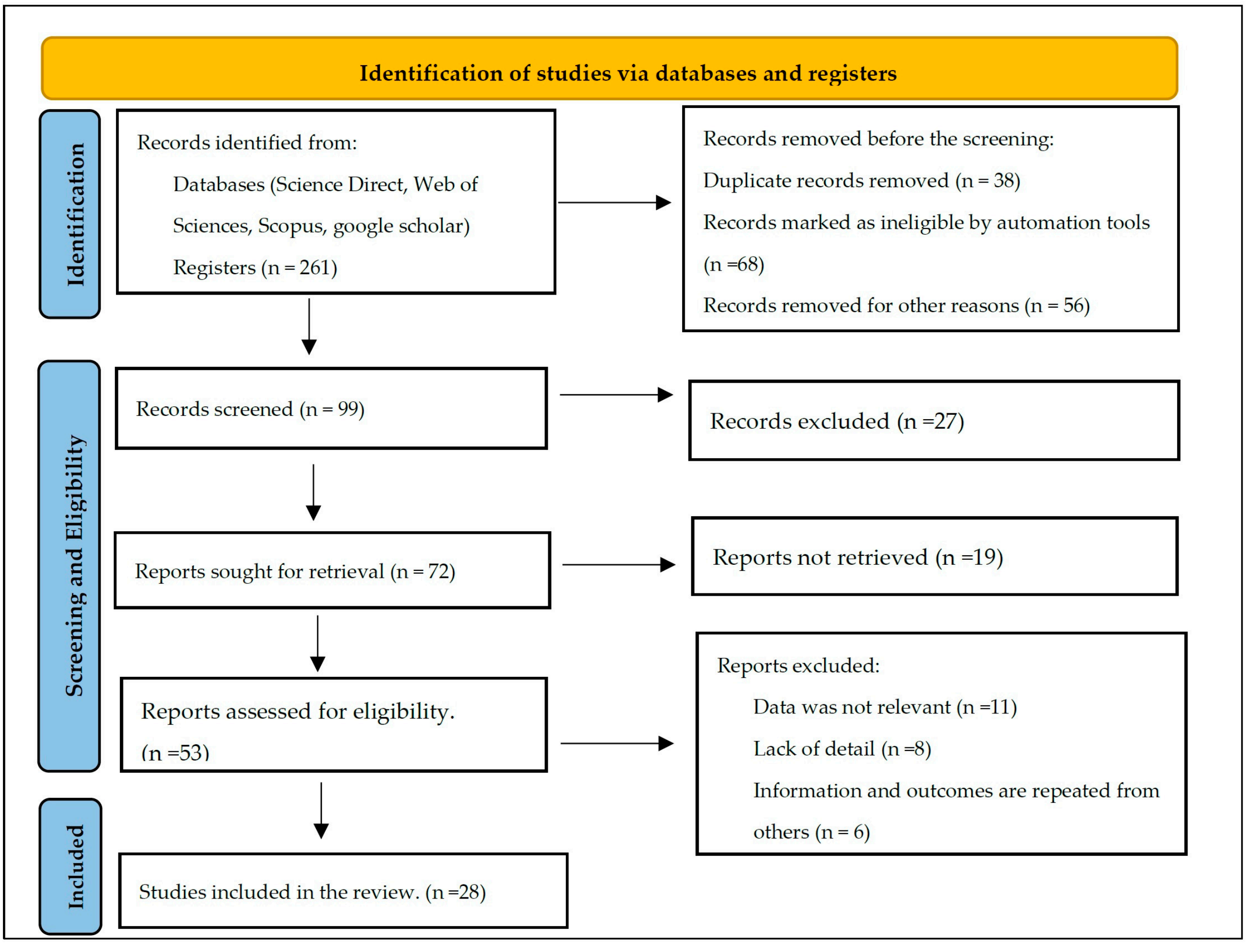

Figure 2. PRISMA-ScR Literature Review steps.

2.1. Scoping Review

After a thorough search in authorized databases including Scopus, Web of Science (Clarivate), Science Direct, and Google Scholar, and after a precise selection of the most relevant papers about CF estimation methodology in seaports from 2011 to 2023, due to the novelty of the subject, it can be said that there is a lack of diversity in presented methodologies.

Most research focuses on mitigation policies and activities or tries to adapt previous methodologies to the geographical area of the port and region rather than working on methods. Finding research falls into two primary categories: (1) *seaport* CF *estimation procedures* and *methodologies*, and (2) *seaport* CF mitigation measures, standards, *and* guidelines. As indicated in Figure 3, CF estimation studies may be separated into two primary categories: whole port or a part of it (such as terminals) and CF mitigation measures and standards that can be classified into initiatives, projects and standards, rules, and guidelines.

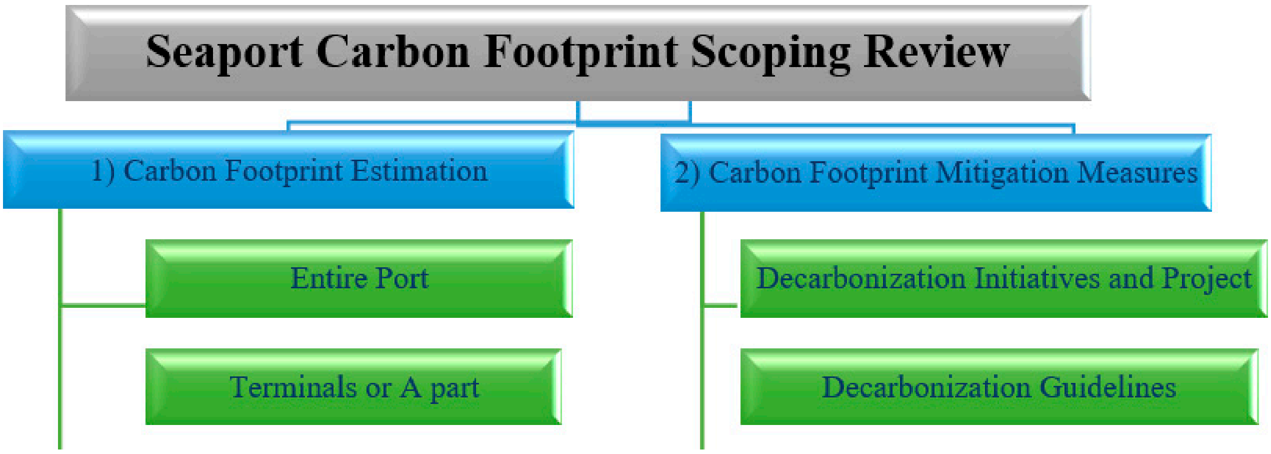

Figure 3. Scoping Review Classification from 2011 to 2023 (authors' work).

Table 2 summarizes the main comprehensive literature; this was done after classifying all the most common literature related to the research's primary topic.

Table 2. Identifies all the most widely-read literature pertinent to the main subject of the study.

Title	Authors	Year
Estimating GHG emissions of marine ports—the case of Barcelona [27].	Gara Villalba, Eskinder Demisse Gemechu	2011
Measurement of the ecological and carbon footprint of port authorities [28].	Mateo-Mantecón I., Coto-Millán P., Doménech J., Pesquera-González M.	2011
From the motorways of the sea to the green corridors' carbon footprint: The case of a port in Spain [29].	Carballo-Penela A., Mateo-Mantecón I., Doménech J.L., Coto-Millán P.	2012
Studies of the Carbon Footprint for a Port in the Panama Canal [30].	Luis Rabelo, Sayli Bhide, John Pastrana, Alfonso T. Sarmiento	2014
A Carbon Footprint Assessment on Construction and Maintenance Operations for the Port of Gothenburg [31].	Anna Sarbring	2014
Greening ports and maritime logistics: A review [32].	Hoda Davarzani, Behnam Fahimnia, Michael Bell b, Joseph Sarkis	2015
The carbon footprint by scopes applied to a Port [33].	Ingrid Mateo-Mantecón and Pablo Coto-Millán	2016
Operating strategies of CO_2 reduction for a container terminal based on carbon footprint perspective [34].	Yi-Chih Yang	2016
An integrated framework for carbon footprinting at container seaports: the case study of a Chinese port [35].	Mamatok Y., Jin C.	2017

Table 2. *Cont.*

Title	Authors	Year
A Carbon Emission Evaluation for an Integrated Logistics System—A Case Study of the Port of Shenzhen [36].	Lei Yang, Yiji Cai, Xiaozhe Zhong, Yongqiang Shi and Zhiyong Zhang	2017
GHG emission accounting and mitigation strategies to reduce the carbon footprint in conventional port activities–a case of the Port of Chennai [37].	Atulya Misra, Karthik Panchabikesan, Senthil Kumar Gowrishankar, Elayaperumal Ayyasamy and Velraj Ramalingam	2017
Reduction in CO_2 emissions in RoRo/Pax ports equipped with automatic mooring systems [38].	Díaz-Ruiz-Navamuel E., Ortega Piris A., Pérez-Labajos C.A.	2018
A carbon emission evaluation model for a container terminal [39].	Jaehun Sim	2018
Waste management and determination of carbon footprint of a marine port: A case study from Izmir, Turkey [40].	Baycan N., Pehlivan Y.	2019
The Carbon Footprint of Valencia Port: A Case Study of the Port Authority of Valencia (Spain) [41].	Víctor Cloquell Ballester, Vanesa G. Lo-Iacono-Ferreira,	2020
Calculating the Carbon Footprint in ports by using a standardized tool [42].	Sahar Azarkamand, Guillem Ferré, R.M. Darbra	2020
Carbon Footprint of a Port Infrastructure from a Life Cycle Approach [43].	Rodrigo Saravia de los Reyes, Gonzalo Fernández-Sánchez, María Dolores Esteban, and Raúl Rubén Rodríguez	2020
Review of Initiatives and Methodologies to Reduce CO_2 Emissions and Climate Change Effects in Ports [44].	Sahar Azarkamand, Chris Wooldridge, and R. M. Darbra	2020
Decarbonization of Maritime Transport: Is There Light at the End of the Tunnel? [45]	Harilaos N. Psaraftis and Christos A. Kontovas	2021
Decarbonization of seaports: A review and directions for future research [46].	Ateyah Alzahrani, Ioan Petri, Yacine Rezgui, Ali Ghoroghi	2021
Port greenhouse gas emission reduction: Port and public authorities implementation schemes [47].	Anas S. Alamoush, Aykut I. Olçer, Fabio Ballini	2021
Ports' role in shipping decarbonization: A common port incentive scheme for shipping greenhouse gas emissions reduction [48].	Anas S. Alamoush, Aykut I. Ölçer, Fabio Ballini	2021
Strategies to Reduce Carbon Footprint in Port and Terminal Operations: Evidence from a Developing Country [49].	M. R. Islam, M. G. Aziz, and M. B. Khan	2022
A Review of Carbon Footprint Reduction Measures in Seaports [50].	S. Behbood Issa Zadeh, Jose Santos López Gutiérrez. M. Dolores Esteban, Gonzalo Fernandez-Sanchez	2022
Carbon and Water Footprints of Marinas in the Canary Islands (Spain) [51].	Cruz-Pérez N., Dessimoz M.-D., Rodríguez-Martín J., García C., Iora F., Santamarta J.C.	2022
The Logistic Carbon Footprint: A Dynamic Calculation Tool for an Indicator of the Sustainability of Logistic Processes with a Case Study on the Port of Trieste [52].	Gallo A.	2022
Estimation of the carbon footprint of longline and lines fisheries in the Indonesia FMA 573-Indian Ocean based at Palabuhanratu Fishing Port [53].	Anggawangsa R.F., Hargiyatno I.T., Suryanto, Widodo A.A.	2023

In summary, recent studies in CF methodology are based on international norms, localized with the characteristics of a region, port, or terminal, and focused on the strategies that can reduce CF in ports. Some evaluate those strategies according to their effort. Nonetheless, they need to concentrate on proposing new methods or improving previous ones in an application form for all the ports in the region. This is demonstrated by the study topics listed in Table 2.

2.2. System Boundaries and Data

This section discusses the collection of data for CF evaluation at seaports. These data can be split into three primary subcategories. These categories, in order of priority, are geographical boundaries, temporal boundaries, and emission statistics.

The port's geographic boundary is split into land and marine sections. The land section may be easily distinguished because all ports have gates and other instruments to delineate their land area. Furthermore, the commercial anchoring area and access channels are part of the port jurisdiction area and are governed by the port authority following the United Nations' delineation of maritime boundaries [54].

Additionally, due to the presence of a seaport, which causes the activities in the anchorage area and the access channel, CO_2 emissions in these areas must be considered in the port's emission inventory. At any rate, some vessels only stay in the anchorage area for different purposes and then leave it, making it difficult to determine their emissions. On the other hand, if assessment borders include anchorage regions, the estimation of the total emission inside the anchorage can't be done accurately because all ships can't be tracked in the anchorage, and accordingly, anchoring zones aren't considered in the evaluation boundaries for calculating CF in ports. In these cases, the entrance of the port access channel serves as the marine-based boundary for the methodology of this study.

Regarding the temporal boundary, the main objectives of carbon footprinting in an area like a seaport are to have statistics available for making new policies, standards, and measurements to reduce CF and, secondly, to evaluate the effectiveness of these issued measurements and standards. Additionally, it can be helpful to compare the performance, measurements, and policies of similar regions, such as some ports in another region, with different approaches to find better initiatives and efficiencies in the broader aspect. Therefore, in this study, the period used to calculate CF in seaports is per year. Due to the availability and accuracy of the necessary statistics for verification, 2016 is also considered the primary time of evaluation in this research's CF calculation for seaports.

Concerning emission statistics, the improved methodology, which will be demonstrated in the following chapter, divides all emissions in a port into two main categories, namely direct and indirect emissions, with three main scopes. Direct emissions, which include only the first scope, are caused directly and are controlled by the port authority. All these emissions can be obtained from the port's statistics inventory.

Indirect emissions include the second and third scopes, the second and third being those caused indirectly. The second scope pertains to the electricity the port authority consumes and may include all data from port authority statistics inventories. In contrast, the third scope pertains to all other indirect GHG emissions of the port, corresponding to emissions derived from the consumption of electricity and fuel by concessionary companies working inside the port, or the effect of work that comes to the port but is not directly controlled by the port authority. This information was disclosed by port authorities and included in their published statistics or those of registered companies involved with the port activities.

3. New Methodology for CF Calculation

As expected, there are many standards for CF calculation. Some common ones include the "GHG protocol" of the World Resource Institute (WRI)/World Business Council on Sustainable Development (WBCSD), ISO 14064, IPCC Guidelines for National GHG inventories, BSI Clean Cargo Working Group Carbon Emissions Accounting Methodology, etc. Most of these have the same theme [8,15,55], but this work introduces a new methodology in the new life cycle approach method for calculating CF in ports retrieved from PAS 2050 [56].

The procedures include five steps, as shown in Figure 4. PAS 2050 is "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services", a publicly available specification developed by the British Standards Institution (BSI) that provides a methodology for measuring the carbon footprint of products and services. The authors created the diagram based on their research findings.

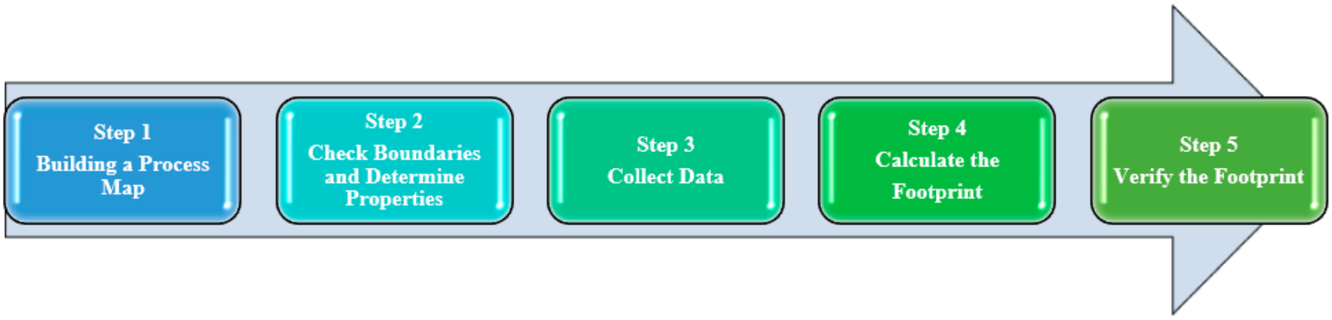

Figure 4. The Process for a CF Using the PAS 2050 Standard (authors' work).

This process has five main steps: (1) process mapping, which includes designating geographical boundaries and is an essential and sensitive section; (2) boundaries and properties, which means time boundaries and the activities included in the estimation process; (3) data collection; (4) CF calculation using formulas and methods; and (5) calculation validation. In later sections, an extended discussion of this method takes place.

The port mapping outlines emission calculations and generalises how environmental protection is implemented at specific ports. Only confined waters (starting from the main harbor's entrance and internal basins) are considered when estimating ports' CF in many previous methods. A new approach to international law is retrieved from the "UN delimitation of maritime boundaries". Being logical, using the port access channel counts as one of the port activities; therefore, the air pollution of these activities should be considered.

Time boundary and CF features are crucial for estimating inventories, and reporting usually advocates a yearly time boundary as a common boundary to allow authorities to compare policies and initiatives with their own and other ports. However, estimating success depends on aims and materials. On the other hand, estimating and assessing success refers to the important tasks and resources that must be considered throughout the evaluation.

Three separate data may be used in the calculation, including "source data", "activity data", and "emission factors". GHG data can be collected on the ground in real-time or evaluated using emission variables, methods, and models. The proper technique should be adopted based on the purpose (mandatory, voluntary, or internal management), dependability, practicality, cost, and capacity. The most popular and widely used approach for measuring emissions for things, entities, and events are emission factor models, which use data on fuel, energy, and other inputs to focus on CO_2 emissions. This new method uses emission factor data due to its accuracy. In the next chapter, emission factors and concerns will be discussed.

An Emission Factor (EF) shows how much raw material is processed or burned and how much pollution is created. EF from recognized inventories must be used in emission factor calculations.

Many countries have developed country-specific emission factors, such as "The Emission Factors of Carbon Footprint Registry, Offsetting and Carbon Dioxide Absorption Projects," issued by the Ministry for Ecological Transition and the Demographic Challenge through the Spanish Office for Climate Change (Oficina Espanola de Cambio Climatico (OECC)) in Spain and covering all the EF for all scopes and stages of CF calculation that are used for the case study [57].

The CF must be determined using the methods introduced in the final sections. The standard carbon CF footprint for ports is calculated using the Equation (2) as the ratio of Co_{2eq} to the amount of cargo:

$$CF = \text{Total Emission} \div \text{Total Amount of Transported Cargo} \quad (2)$$

where total emission can be expressed as "Kg of Co_{2eq}" or "Tones of Co_{2eq}", and total cargo is always reported in tones.

Finally, in the verification section, self-verification will be used in this work-study. However, alternative verification techniques, such as verification by another party or independent third-party verification, are also feasible.

This study's new method considers the scopes based on GHG protocols, IPCC Guidelines and ISO 14,064 [14,58]. The classification of scopes is shown in Figure 5 and is created by the authors based on their research findings.

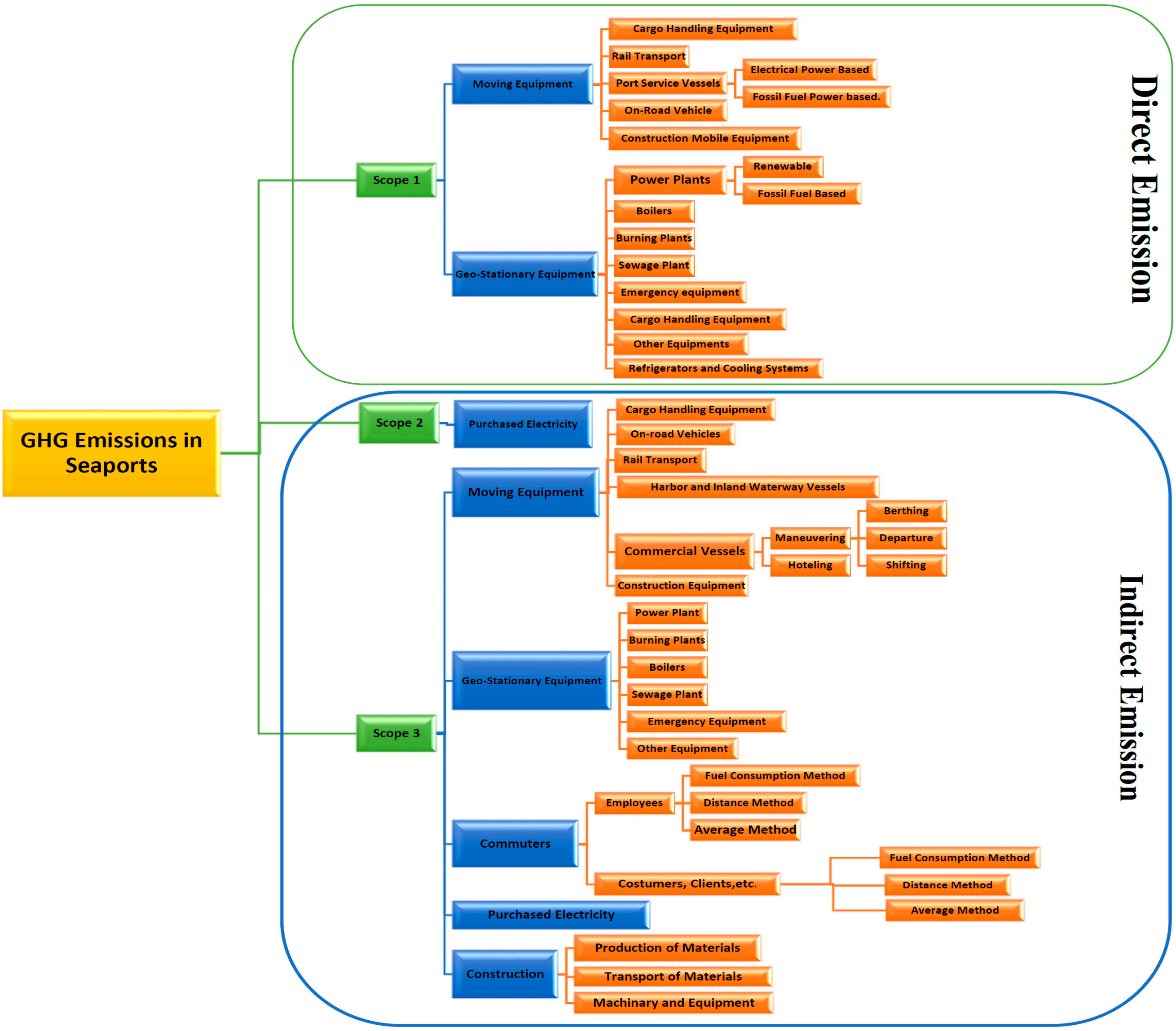

Figure 5. Overview of Emission Categories and Scopes in Ports (authors' work).

3.1. Emission Scopes

A system's GHG emissions can be split into direct and indirect emissions and three "scopes" based on its activities. (See Table 3).

$$\text{Emission} = \sum_{i=1}^{3} E_{\text{scope i}} \tag{3}$$

where Co_{2eq} is total emission caused directly or indirectly by port activities. Direct emissions are those caused by activities that the port authority directly controls, while indirect emissions are those brought on by electricity consumption and port operations that the port authority does not directly control.

Table 3. Ports Emission Classifications and Scopes.

Emission Type	Scopes	Definitions	Port
Direct Emissions	Scope 1	Emissions from operations that are owned or controlled by the port authorities.	Port-Owned Fleet Vehicles (vessels and vehicles), Buildings, and Stationary Sources.
Indirect Emissions	Scope 2	Emissions from the generation of purchased or acquired electricity, steam, heating, or cooling consumed by the port authority or companies working inside the port boundary.	Purchased Electricity for Port- Owned Buildings and Operations, District Heating by Owned Operations.
	Scope 3	All indirect emissions (not included in scope 2) occur in the value chain of the reporting port authority or companies inside the port boundary, including up- and downstream emissions.	Ships, Trucks, Cargo Handling Equipment, Rail, Harbour Craft, Construction and Maintenance, Port Employee Vehicles, Buildings, Purchased Electricity, Business Travels, Loading fuels, Suppliers, Outsourced activities (IT, Security), etc.

3.1.1. Scope 1

Scope 1 covers the port authorities' direct emissions, such as those from machinery or industry within the port's boundaries. After this, it considers all seaport activities, infrastructure ownership, and machinery. Scope 1, which is created by the authors based on their research findings, discusses, and which categorizes with further sections, as shown in Figure 6, is as follows:

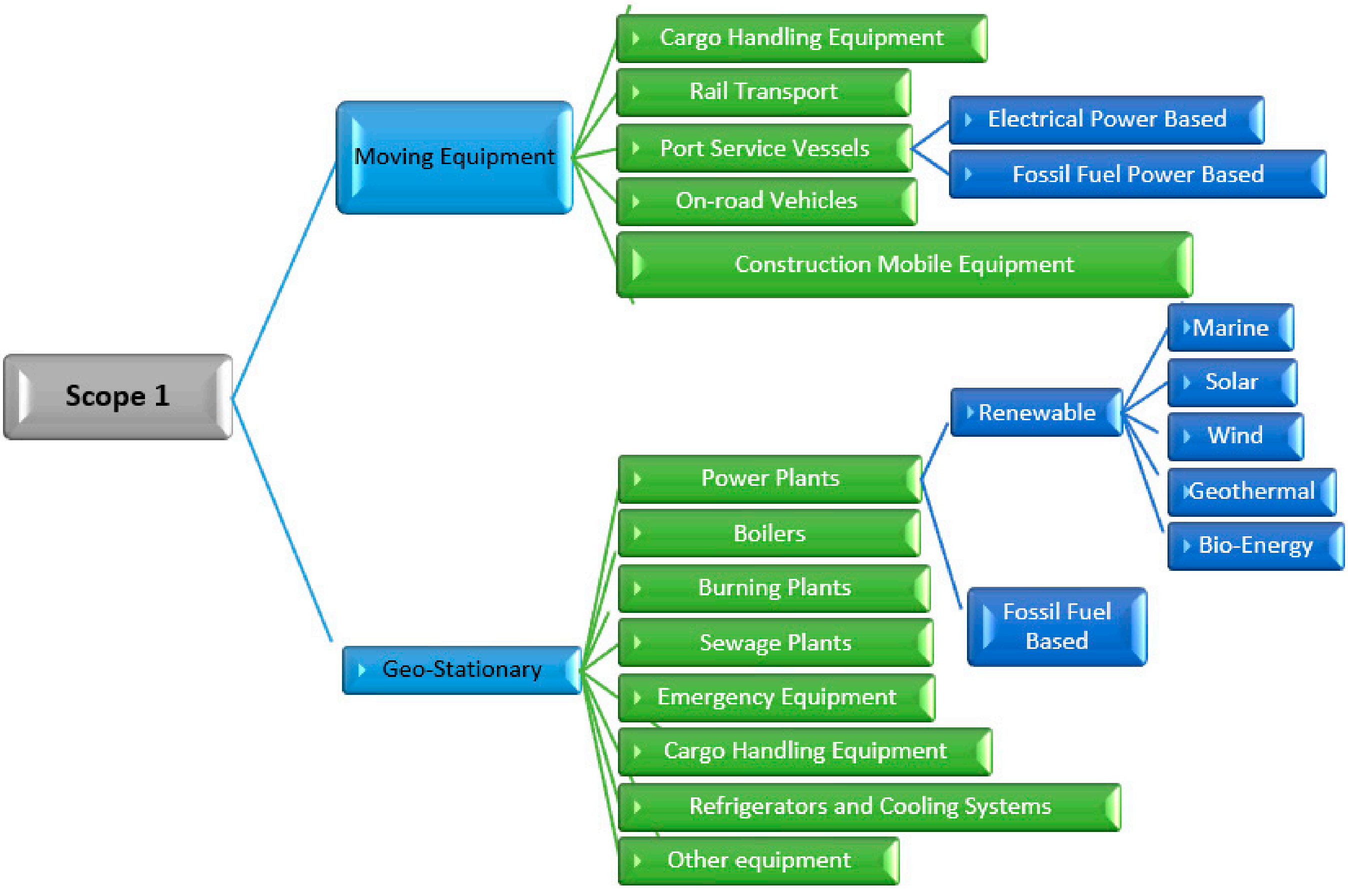

Figure 6. Overview of Subsections of Scope 1 in a Seaport (own authorship).

The emissions' equation in Scope 1 can be formulated as follows:

$$\text{Emission}_{\text{scope 1}} = \sum_{i=1}^{n} \text{Emission}_{n} \quad (4)$$

where $\text{Emission}_{\text{scope 1}}$ is the total mass of Co_{2eq} emissions of the scope (tones), Emission_{n} is each source's total emissions (tones).

This scope is divided into two main categories (Moving Equipment and Geo-Stationary) and various subcategories. Performance, power, model, and energy consumption can be used to classify each subcategory; however, energy consumption is critical when computing carbon emissions.

- *Moving Equipment Category*

  1. *Cargo Handling Equipment*

Rich stackers, lift tracts, shore mobile cranes, and other moving cargo handling equipment can be categorized into two classes based on their energy source: fossil fuel-powered or electricity. The electrical equipment emission can be included in scope two and will be described later.

There are two primary methods for emission calculation of fossil fuel-based equipment; time-based (5) and fuel-based approaches (6) as follows:

$$\text{Emission}_{i} = \sum_{i=1}^{n} \text{Fuel Consumption}_{i} \times \text{EF(Standard Formula)} \quad (5)$$

or

$$\text{Emission}_{i} = \sum_{i=1}^{n} \text{T} \times \text{A.C}_{i} \times \text{EF(Formula A)} \quad (6)$$

where $Emission_i$ is the emission of each subcategory (Co_{2eq}), and EF is the emission factor of consumed fuel (kg Co_{2eq}/litter). T is the time of equipment operation in an hour, $A.C_i$ is the average consumption of equipment as per the instruction manual and manufacture specification sheet, and EF is the emission factor of consumed fuel (kg Co_{2eq}/litter).

Moreover, the formula below, which combines Formulas (5) and (6), can calculate emissions for mobile construction and cargo handling equipment.

$$Emission_i = \sum_{i=1}^{n} D \,.\, C_1 \,.EF + \sum_{i=1}^{n} T \,.\, C_2 \,.EF \quad (7)$$

where $Emission_i$ is the emission of each subcategory (Co_{2eq}), D is the total distance travelled (km) inside the port boundary, C_1 is the average fuel consumption (L/km), T is the average running time of equipment or machinery, C_2 is the average fuel consumption per hour (L/h), and EF is emission factor of consumed fuel (kg Co_{2eq}/litter).

2. *Rail Transport Equipment*

The following formula should be used to compute rail transit emissions within ports. However, distances inside port limits must be considered.

$$Emission_i = M \times D \times C \times EF \quad (8)$$

where $Emission_i$ is the emission of each subcategory (Co_{2eq}), M is the total volume of cargo handled inside the port border by rail transport (tone), D is the total distance of rail transport inside the port (kilometre), C is the average locomotive fuel consumption (tones/kilometre), and EF is fuel emission factor (kg Co_{2eq}/lit).

3. *Port Service Vessel*

For the emissions of port service vessels and ships owned by ports, such as tugboats, pilot boats, search and rescue boats, fresh water, fuel supplies, etc., two main categories can be considered: electrical power-based and fossil fuel-based.

The port authority's total electricity purchase, which includes Scope 2 and will be discussed later, can be used to estimate electrical power-based emissions due to vessel ownership. The "Standard Formula" can calculate fossil fuel power-based emissions since distance-based estimation is unreliable due to the nature of the activity.

4. *On Road Vehicles*

A few modern seaports use electric on-road vehicles, although most use fossil fuel vehicles. There are two basic methods for estimating the emissions of these vehicles; the first one uses the "Standard Formula", and the second uses "Formula A" for these vehicles.

5. *Mobile Construction Equipment*

For mobile construction equipment, the formula below can be used to get a more precise result of their emission:

$$Emission_i = \sum_{i=1}^{n} D \,.\, C_1 \,.EF + \sum_{i=1}^{n} T \,.\, C_2 \,.EF \quad (9)$$

where $Emission_i$ is the emission of each subcategory (Co_{2eq}), D is the total distance travelled (km) inside the port boundary, C_1 is the average fuel consumption per kilometre (L/km), T is the average running time of equipment or machinery, C_2 is the average fuel consumption per hour (L/h), and EF is emission factor of consumed fuel (kg Co_{2eq}/litter).

- *Geo-Stationary Equipment Category*

1. *Power Plants, Boilers, Burning Plants, Sewage Plants and Emergency and Cargo Handling Equipment*

The emission of geo-stationary equipment, including power plants, boilers, burning plants, sewage plants, emergency equipment, renewable power plant and fossil fuel-based energy generators, all of which are stationary, could be calculated into two different methods: by using (A) "Standard Formula" or (B) working hours-based formula "Formula A".

Furthermore, there are two main types of cargo handling equipment: those that run on electricity and whose emissions can be estimated by the amount of electricity used or the average running time per hour, and those that run on fossil fuels and whose emissions can be estimated by the "Standard Formula" or "Formula A."

2. *CF of Refrigerators and Cooling Systems*

Due to the considerable number of emission factors for fluorinated gases, which are most often used in fixed refrigeration and air conditioning installations, the total emissions of ports must include an estimate of the fluorinated gas emissions from refrigeration and air conditioning systems, and the GWP of these gases are considered as their emission.

GWP is "the relative potency, molecule for molecule, of any gas, taking account of how long it remains active in the atmosphere of each gas" [59] and is equal to emissions due to the following formula:

$$E_n^i\ (CO_2\ eq) = E_n^i.GWP^i \tag{10}$$

where: $E_n^i\ (CO_2\ eq)$ = Total mass of Co_{2eq} (tones Co_{2eq}). E_n^i = total mass of emissions of each gas. GWP^i = global warming potential of each gas (tones Co_{2eq}/tones gas).

Then GWP of each fluorinated gas is considered equal to its emission and can be applied to the total emissions of related scope/scopes. There are national or international inventories for the GWP of all fluorinated gases, and by taking this research's case study into account, the relevant inventory may be found in "Factores de Emision Registro de Huella de Carbono, Compensacion y Proyectos de Ab-sorcion de Dioxido de Carbono." [57].

3. *Other Equipment*

This category can describe all other fixed equipment used for maintenance, use, or special short-term missions under the command and control of port authorities. You can figure out the emissions by using the "Standard Formula" which is based on fuel consumption, the "Formula A" method, or the "hybrid method" as follows:

$$\text{Emission}_i = \sum_{i=1}^{n} D\ .\ A.C_1\ .EF + \sum_{i=1}^{n} T\ .\ A.C_2\ .EF \tag{11}$$

where Emission_i is the emission of each subcategory (Co_{2eq}), D is the total distance travelled (km) inside the port boundary, $A.C_1$ is the average fuel consumption per working load (L/ton), T is the average running time of equipment or machinery, $A.C_2$ is the average fuel consumption per hour (L/h), and EF is emission factor of consumed fuel (kg Co_{2eq}/litter).

3.1.2. Scope 2

Scope 2 only covers port electricity use; however, the amount of CF can be calculated using supplier inventories. On the other hand, Scope 2 is needed in GHG inventories and covers the port authority's initial indirect emissions from electricity use. It can be said this way:

$$\text{Emission}_{\text{scope 2}} = \sum_{i=1}^{n} \text{Purchased Electricity}_i \times EF \tag{12}$$

where: $\text{Emission}_{\text{scope 2}}$ is the total CO_2 emissions, Co_{2eq} (tones). $\sum$ Electricity Consumption is the total amount of Electricity Consumption in the port authority. (kwh).

EF is the CO_2 Emission Factor (kgCO_2/kWh) for each factory which generates electricity that in each country can be obtained from official inventories published annually or periodically by approved organizations. In Spain, the National Markets and Competition Commission (Comisión Nacional de los Mercados y la Competencia, CNMC) issued a document titled "Mix Comercial y Factores de Impacto Medio Ambiental (Commercial Mix and Environmental Impact Factors)". Furthermore, the OECC published a report titled "Factores de Emision Registro de Huella de Carbono, Compensacion y Proyectos de

Absorcion de Dioxido de Carbono" based on the aforementioned reference and it has tables of Emission Factors for the Purchased Electricity, updated annually [57].

3.1.3. Scope 3

Scope 3 covers indirect emissions, mainly from port operations and other sources. The "GHG Protocol" does not require Scope 3 to be included in a GHG inventory, but due to the variety of activities inside ports that cause pollution, Scope 3 is essential in CF accounting.

It's important to note that Scope 3 includes several emission sources, including manufacturing, transportation, and purchased goods. Upstream and downstream emissions also exist. Additionally, Scope 3 has several categories and is classified in Figure 7, which the authors create based on their research findings:

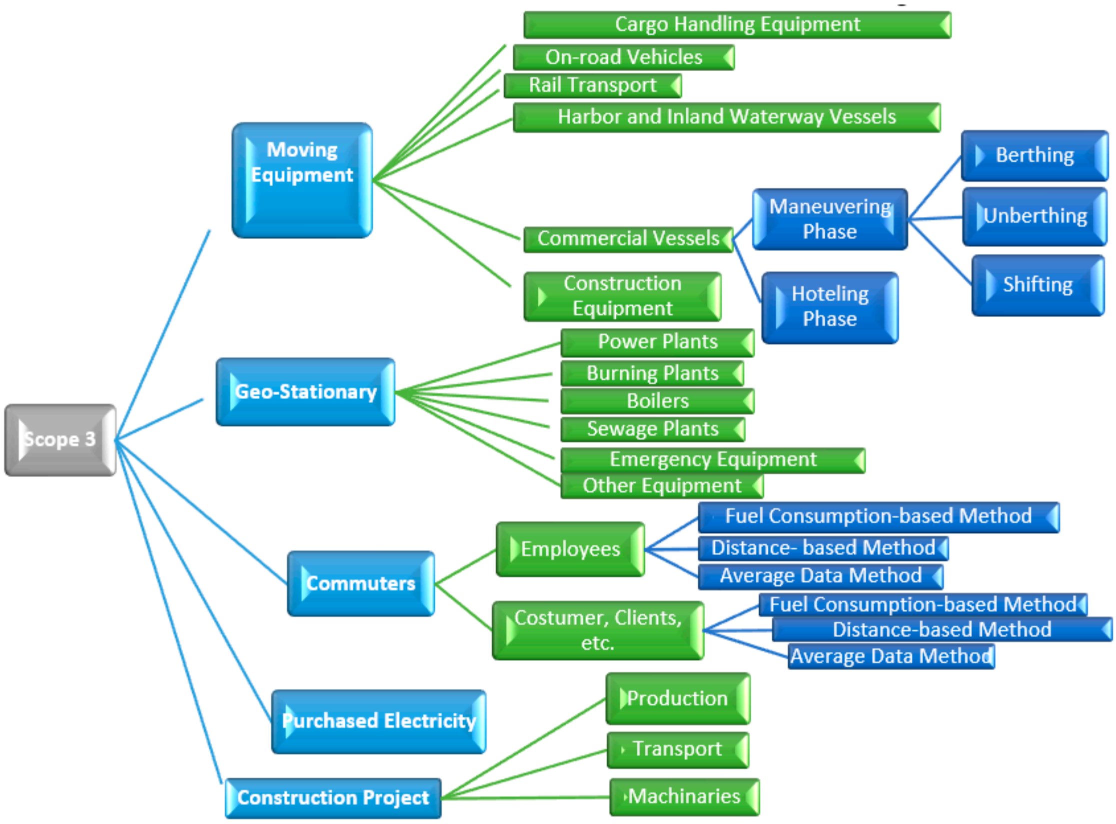

Figure 7. Overview of Subsections of Scope 3 in a Seaport (own authorship).

- *Moving Equipment*
  - i. *Cargo Handling Equipment*

In the first part of Scope 3, cargo handling and construction equipment emissions can be calculated using fuel consumption-based (Standard Formula) or working hours-based (Formula A).

However, considering the type of machinery and applying the following formula can simplify the calculation of emissions from machinery, cranes, and auxiliary equipment for loading, unloading, and ground transportation.

$$\text{Emission}_i = P_i \times L.F_i \times T_i \times C_i \tag{13}$$

where Emission_i is the emission of each subcategory (Co_{2eq}), P_i is the total power of the motors of the mobile equipment in kW, $L.F_i$ is the load factor of each machinery that can be retrieved from approved inventories and published by CARB (The California Air Resources Board) [60], and also, for the case study of this research, is mentioned in the Guía metodológica para el cálculo de la huella de carbono en puertos, delineated by type of auxiliary port machinery and by type of auxiliary vessel such as tug boats, etc. T_i is the total running time in an hour, and the C_i is the fuel consumption per unit of power consumed (g/kWh) [61].

ii. On Road Vehicles

This amount, which stands for the total emission of trucks, lorries, and other on-road vehicles used to transport cargo inside ports, can be calculated using the following formula:

$$\text{Emisssion}_i = \sum_{i=1}^{n} D_i \times \text{ Ave. } C_D \times EF + \sum_{i=1}^{n} T_i \times \text{ Ave .} C_T \times EF \quad (14)$$

where Emission_i is the emission of each subcategory (Co_{2eq}), I is the number of trucks, and D is the total distance travelled in KM inside the port boundary as defined for this study, Ave. The C_D is the average fuel consumption in litres/kilometre, T is the average running time of a truck in hours, Ave. C_T is the average fuel consumption in litres/hour, and EF is the emission factor of the consumed fuel.

iii. Rail Transport Equipment

The following formula must be used to calculate rail transport within a port; however, distances within the *port boundaries* must be considered.

$$\text{Emission}_i = M \times D \times C \times EF \quad (15)$$

where Emission_i is the emission of each subcategory (Co_{2eq}), M is the total amount of cargo handled inside the port boundary by rail transport(tone), D is the total distance of rail transport inside the port (by kilometre), C is the average fuel consumption of locomotive (tones/kilometre), and EF is emission factor (kg Co_{2eq}/litre).

iv. Harbour and Inland Waterway Vessels

For the emissions of the harbour and inland waterway vessels such as leisure craft, scientific research vessels, etc., there are two major categories: electrical power-based and fossil fuel-based.

An entity that utilizes electricity for its boats and crafts, can consider its energy use as "purchased electricity," which is part of Scope 3 and will be explored later. Furthermore, due to the nature of harbor and inland waterway vessel activities, fossil fuel power users cannot utilize distance-based estimates as an emission calculation method, and the "Standard Formula" calculates total emission, whereas their emission can be estimated as follows too:

$$\text{Emission}_i = P_i \times L.F_i \times T_i \times C_i \quad (16)$$

where Emission_i is the emission of each subcategory (Co_{2eq}), P_i is the total power of the motors of the vessel in kW, and $L.F_i$ is the load factor published by national and international communities such as CARB (The California Air Resources Board), which are listed by type of machinery and by type of vessel such as tug boats, etc. In the case of this research, they can be retrieved from the Guía metodológica para el cálculo de la huella de carbono en puertos [61]. T_i is the total running time in an hour, and the C_i is the fuel consumption per unit of power consumed (g/kWh).

v. Commercial Vessels

According to international regulations and following the nature of the commercial vessels' operations, the geographical limit for the port area in the new method is defined from the entrance of the access channel and the entirety of the seaport basins.

In this section, two independent phases—the "Maneuvering Phase" and the "loading/discharging (hoteling) Phase"—are used to calculate the emissions from commercial vessels that enter or leave ports.

The following formula can be used to calculate emissions during manoeuvring, which is broken down into (A) berthing, (B) unberthing (departure), and (C) in port shifting, and is based on the engine power, fuel type, and duration of the vessel's manoeuvring.

$$\text{Emission}_i = \sum_{i=1}^{n} (\text{M.E.P} \times \text{LF} \times \text{T})_i \times \text{EF} \tag{17}$$

where Emission_i is the amount of emission for the vessel (i), n is the number of vessels, M.E.P is the maximum engine power of the vessel in kw, LF is the load factor of the vessels that the following formula can obtain:

$$\text{LF} = (\text{manuevering speed}/\text{max speed})^3 \tag{18}$$

The maximum speed can be obtained in the vessel's specification sheet that the vessel manufacturer prepares, where both measurements are in knots, T is the duration of operation in hours, and EF is the emission factor of fuel consumed by vessels in knots in Kg Co_{2eq}/litter or tone Co_{2eq}/m^3. Finally, the local port regulations or the customary practices of ships maneuvering inside the port's boundaries might be used to determine the speed restriction when manoeuvring.

- N.B: Most vessels use their auxiliary engines and machinery for various tasks during all phases of maneuvering, including berthing, unberthing, and shifting, etc.; these machines consume fossil fuel as well, but their consumption is much smaller than that of the main engine and can be disregarded in thorough calculations

However, for a more exact calculation and to obtain the quantity of Hoteling emissions, which is the second phase of this segment, the "Standard Formula" fuel (heavy fuel oil or diesel oil), with the help of emission factor may be used.

vi. Construction Equipment

Due to fuel consumption, any equipment in this category can employ the "Standard Formula" or "Formula A", or the following formula from the Guía metodológica para el cálculo de la huella de carbono en puertos [61] can be used:

$$\text{Emission}_i = P_i \times \text{L.F}_i \times T_i \times C_i \tag{19}$$

where Emission_i is the emission of each subcategory (Co_{2eq}), and P_i is the total power of the motors of the mobile equipment in kW, L.F_i is the load factor published by CARB (The California Air Resources Board) or, in the case of study of the research can be retrieved fromGuía metodológica para el cálculo de la huella de carbono en puertos that is included by type of auxiliary port machinery and by type of auxiliary vessel such as tug boats, etc. T_i is the total running time in an hour, and the C_i is the fuel consumption per unit of power consumed (g/kWh) [61].

- *Geo-Stationary*

The "Standard Formula" and "Formula A" can be used for all equipment in this category, including power plants, burning plants, boilers, sewage plants, emergency equipment, etc. The introduced inventory in the last section can also be used.

- *Commuters*

Employees and non-employees (customers, tourists, passengers) are port commuters. Since port authority workers commuting are not directly supervised by the port, all seaport commuters fall under Scope 3. In this scenario, it is necessary to count the number of commuters for the port authori-ty as well as other employees, clients, and visitors who drive privately and utilize pub-lic transportation. The data must then be sorted in order to calculate commuter carbon emissions. Finally, the "Standard Formula", distance travel method, and hybrid or average data methods calculates interior port commuter emissions as follows:

$$\text{Emission}_i = \sum_{i=1}^{n} D_i \times A.C_i \times EF \quad (20)$$

or

$$\text{Emission}_i = \sum_{i=1}^{n} A.D \times W.D \times P.N \times EF \quad (21)$$

where Emission_i is the amount of emission in kilograms or tones, n is the number of commuters, D is the travelled distance of cars by kilometres, $A.C_i$ is the average consumption of the car (Litter/Kilometre), which can be obtained from manufacturers particular, A.D is the average travelled distance of commuters in a standard pattern inside ports boundary in kilometres, W.D is the working days of the period under study, P.N is the personnel number that commuting to the ports and EF is the emission factor of consumed fuel of cars in (kg Co_{2eq}/litter).

In some countries, there is a standardized inventory of average fuel consumption by vehicle type as the official reference. For the case study of this work study, the "Guía metodológica para el cálculo de la huella de carbono en puertos" in Spain has a table that standardizes fuel consumption by vehicle type [61], and most of these standards are the result of scientific research and approaches concerning fossil fuels, gasoline, and fuel oil, which are used in various automobiles [62–64].

- *Purchased Electricity*

The following calculation can determine the amount of purchased electricity in Scope 3 emitted by entities located within ports but not directly under the control of the port authorities.

$$\text{Emission}_i = \sum_{i=1}^{n} \text{Purchased Electricity}_i \times EF \quad (22)$$

where Emission_i is the total emission of electricity consumed by the other than port authority entities inside the port in (Co_{2eq}), i is the number of the entity, and EF is the CO_2 Emission Factor (kg Co_{2eq}/litter) for each factory which generates electricity and can be obtained from the inventories and sources mentioned in Scope 2.

- *Calculation of Other Indirect GHG Emission Including Construction, Production and Transport of Materials*

This section, which is a part of Scope 3, can be divided into three subcategories because of the nature of the activities:

1. *Production of Construction Used Materials*

The amount of each material anticipated to be used will be divided by the "cradle-to-gate" emissions factor for each material unit to calculate the emissions for the component's work.

Port projects typically employ borrowed material for filling, aggregate types in larger amounts, concrete and steel for reinforcing, and materials for paving dykes, esplanades, and roadways.

The project's measurements and standard sections will figure out how much of each material will be used in each phase, and national organizations usually publish the inventory of emissions of significant materials used in seaport projects. It must be applied in scope three emissions.

The "Guía metodológica para el cálculo de la huella de carbono en puertos" lists the emissions of cradle-to-gate data of aggregate and soils, concrete, steel, and paving that can be used for this research's case study [61].

2. *Transport of Construction Materials*

There are four options for calculating the emission of transporting construction materials used in port construction projects: "Standard Formula" for each vehicle, distance trip form, hybrid data method, and average data method as follows:

$$\text{Emission}_\text{i} = \sum_{i=1}^{n} D_i \times A.C_i \times EF \tag{23}$$

or

$$\text{Emission}_\text{i} = \sum_{i=1}^{n} A.D \times W.D \times V.N \times EF \tag{24}$$

where "Emission_i" is the amount of Co_{2eq} emission in kilograms or tones, n is the number of trucks, "D" is the travelled distance of trucks by kilometres, "$A.C_i$" is the average consumption of the trucks (litres/kilometre) which can be obtained from the manufacturer's particulars, "A.D" is the average travelled distance of the vehicle from the gate of the port to discharging, "W.D" is the working days of the period under study, "V.N" is the number of the truck that commuting to the ports and "EF" is the emission factor of consumed fuel of trucks in (kg Co_{2eq}/litter). Finally, in the case study, there is a table which lists "Average well-to-wheel emissions per unit of material transported per kilometre travelled" for all materials, and emissions can directly be derived from this table in the same resource [61].

3. *Emissions of Machinery and Other Equipment Used in Construction*

For the machinery used in the construction project inside the ports, the "Standard Formula" can be used.

4. Case Study

The verification for the proposed method in Section 3, the Valencia port authority, named Autoridad Portuaria de Valencia (APV), is where the case study takes place.

There are many well-known ports that could serve as a good case study for this research, and some of them, such as the port of Vigo in Spain and the port of Busan in South Korea, have had their carbon footprints calculated recently in other studies [65,66]. However, because the Valencia port has access to accurate information and is included in EcoPorts, it was chosen for this study.

The Valencia port is a member of EcoPorts, the major environment program for the European port industry. Since 2011, it has been completely integrated into the European Sea Ports Organisation (ESPO), founded in 1997 by several proactive ports [65]. One of the most significant ports in Spain, located in the south of the country, it handled 7295 vessels and 255,630,994 tones of cargo in 2021, according to the most recent information from the port authorities [66].

Valencia is in eastern Spain at 39.4457° N 0.3199° W. The APV oversees three ports: Valencia, Sagunto, and Gandia. These are located on Spain's east Mediterranean Sea coast, along an 80-km stretch. Within a 350-km radius, the APV is the center of commercial activity. The port has a 12-km quay length and 300 acres of storage capacity [67]. In addition, APV plans to construct a new container port in Valencia's northern ex-pansion until 2030 [68].

- *Data Collection, Geographical, Time and Gas Boundary*

Due to the apparent availability of information and statistics for the Valencia port in 2016, the verification of the new methodology is applied to 2016 to have exact figures calculated by the port authority and the availability of comparing this figure with the figure produced by the new methods. All the data for the verification is taken from APV official websites [67], he APV 2016 statistical Yearbook [69], the Valencia port environmental statement 2016 [70], the port of Valencia GHG report [71], and the CF registry, offsetting, and carbon dioxide absorption project [57].

- *Geographical, Time and Gas Boundary*

The APV's geographical boundary consists of the entirety of the ports of Valencia, Sagunto, and Gandia, and is divided into two parts: the first is the land section, which includes the entire area of these three ports; and the whole port layouts, which include 77 different major components, as presented in Figure 8 and illustrated in Table 4, taken from the port authority's official website and are as follows:

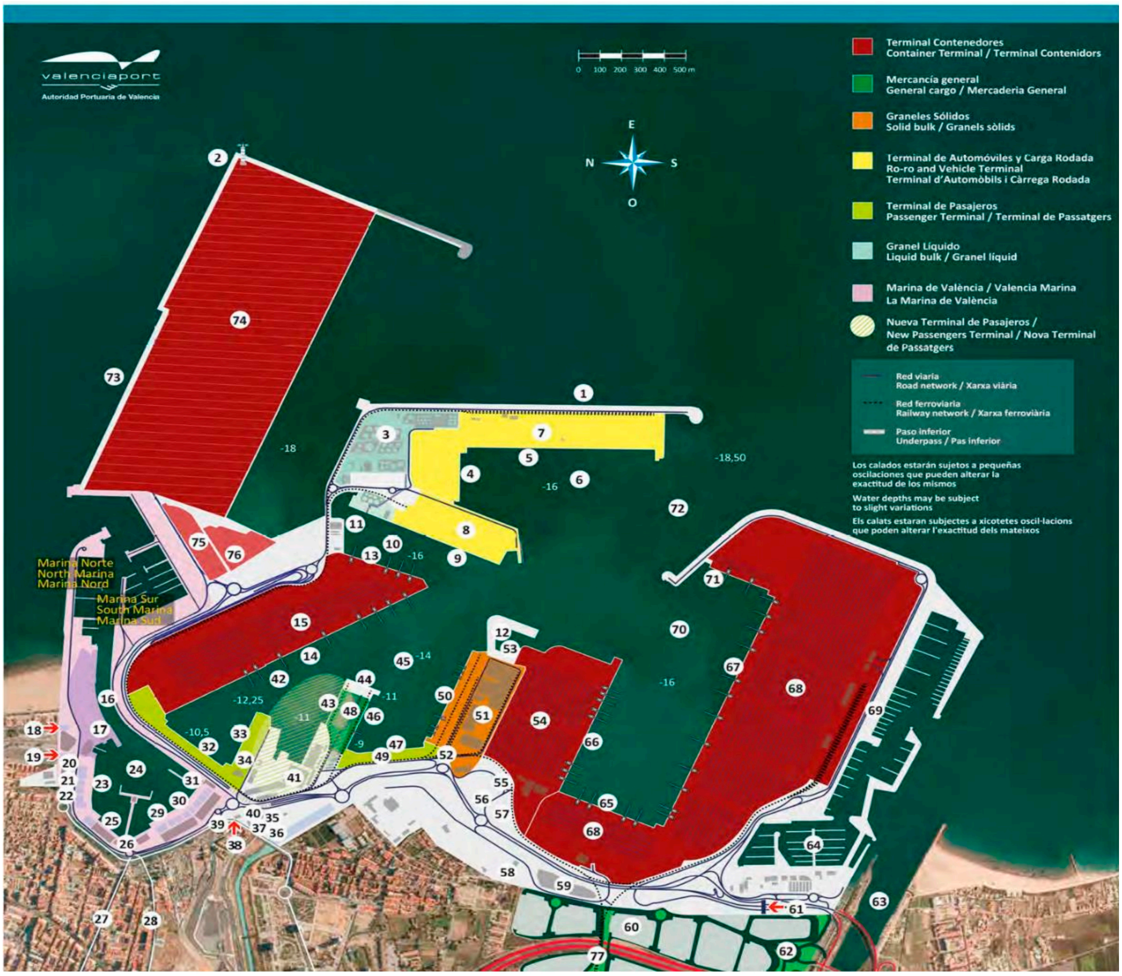

Figure 8. Overview of Valencia Ports, including Valencia, Gandia and Segundo, retrieved from [67].

Table 4. Valencia Port layout.

Valencia Port Major Parts					
1	East Breakwater.	27	Avda. del Puerto.	53	Technical and Nautical services Dock.
2	Lighthouse.	28	Avda. Baleares.	54	Container Terminal 2 (MSC).
3	Chemical and Oil Terminal	29	Former Terminal Quay.	55	Puesto De Inspección Fronteriza (PIF).
4	Transversal East.	30	Nazaret Quay.	56	Harbormaster's Office.
5	East Breakwater Quay	31	Fish Market.	57	Cold sage warehouses.
6	East Dock.	32	Transversal Quay.	58	CPE Valencia.
7	Ro-Ro & Vehicle Terminal 1	33	Poniente Quay.	59	Logistics warehouse.
8	Ro-Ro & Vehicle Terminal 2.	34	Ferry, Passenger and Cruise Terminal.	60	Logistics Activities Area (ZAL).
9	North Quay (Xitá).	35	Port Police.	61	South Access.
10	Xitá Dock.	36	Valencia port Foundation.	62	ZAL Access.
11	Scrapyard Quay.	37	Port Authority of Valencia.	63	New Turia riverbed.
12	Port services (pilots, tugboats, and mooring).	38	Nazaret gate.	64	Royal Valencia Yacht Club.

Table 4. *Cont.*

Valencia Port Major Parts					
13	Llavera Quay	39	Naval Command.	65	Costa Quay.
14	Levante Quay.	40	Plant Health Service.	66	Transversal Costa Quay.
15	Container Terminal 3.	41	Foreign Trade Inspection dep.	67	Principe Felipe Quay.
16	Moveable bridge.	42	Levante Dock.	68	Public Container Terminal 1.
17	"Veles e Vents" building.	43	North Turia Jetty Quay.	69	Marine Civil Guard Building.
18	J. Carlos I Marina access.	44	End Turia Jetty.	70	South Dock.
19	Customs gate.	45	Turia Dock.	71	East Wuay.
20	Customs Administration.	46	South Turia Jetty Quay.	72	Entrance channel.
21	Foreign Health Dep.	47	Turia Quay.	73	North Extension Breakwater.
22	Valencia 2007 Consortium	48	General and bulk cargo,	74	New Container Terminal.
23	Customs Quay.	49	Passenger Terminal,	75	Container depot one.
24	Inner Dock.	50	South Quay.	76	Container depot two.
25	Grao Quay.	51	Solid Bulk Terminal.	77	Connection to the national railway
26	Clocktower building	52	Spanish Customs Control Authority.		

The colour green in Figure 9 represents the marine delimitation of the case study that presents ports' maritime portions, including their access channels and the entire marine basins.

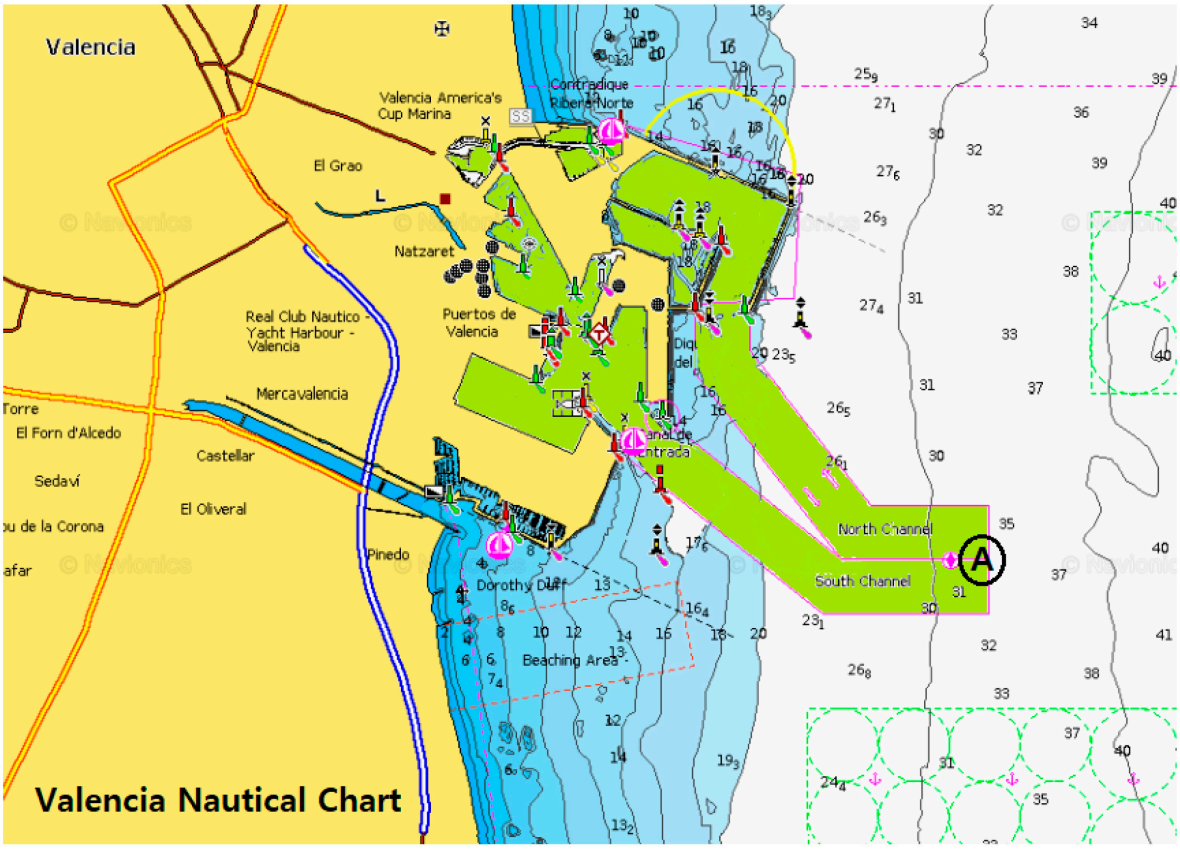

Figure 9. Case study maritime delimitation, retrieved from [67,72].

4.1. Statistics of Maritime Traffic and Cargo

According to official data presented in Table 5, the APV experienced the following maritime and cargo traffic volumes in 2016:

Table 5. Vessel Traffic at the Different Ports of PAV.

Port Name	Amount of Traffic and GT in 2016	Overall Ratio
Valencia–Number	6232	80%
G.T. (thousand tones)	230,807	90%
Gandia–Number	150	2%
G.T. (thousand tones)	876	1.5%
Sagunto - Number	1320	18%
G.T. (thousand tones)	24,205	8.5%
Total Number of Ships	7702 Ships	100%
Total Number of GT	255,888,000 Tones	100%

In another hand, the percentage of maritime traffic by the sort of vessels is listed in Table 6, as follows:

Table 6. Valencia Port Maritime Traffic in 2016.

Type of Vessel	Amount of Traffic in 2016	Overall Ratio
Container carrier	3264	42.5%
General Cargo carrier	1014	13%
Ro-Ro ships	1180	16%
Ropax and cruise ships	1605	21%
Tanker ships	276	3%
Bulk carrier ships	330	4%
Other	33	0.04%
Total	7702	100%

Furthermore, the cargo traffic of Valencia port is broken down into a few categories in Table 7, as follows:

Table 7. Cargo Traffic of Valencia Port in 2016.

Valencia Port	Amount of Cargo	Overall Ratio
Liquid Bulk	1,250,863	2%
Solid Bulk	1,344,987	2.2%
Non-Containerized Merchandise	8,091,786	12.8%
Containerized Merchandise	53,229,414	82%
Fishing	406	0.06%
Refuelling	443,589	0.06%
Total	64,361,045	100%

- *Gas Boundaries*

The GHG inventory has included the quantification of emissions due to the following gases:

- CO_2: Carbon Dioxide: Global Warming Factor of one.
- (Methane): Global Warming Factor of twenty-five.
- N2O: Nitrous Oxide: Global Warming Factor of 298.

The results have been expressed in tones of Co_{2eq}.

4.2. Scopes

The APV (Port of Valencia) includes the following gases CO_2, CH4, and N2O in its GHG emissions, expressed in Tones of Co_{2eq}, in its scope:

(a) Direct emissions, (b) indirect emissions from energy, and (c) other indirect emissions connected to concession company activities, emissions from ships and cargo transit produced in the Port of Valencia, all under normal operating conditions.

4.2.1. Scope 1

APV Direct GHG emissions; Scope 1 includes emissions from the fuel consumption of the APV–Port of Valencia's vehicle fleet.

The formula is as follows:

$$\text{Emission}_i = \sum_{i=1}^{n} \text{Fuel Consumption}_i \times \text{EF} \quad (25)$$

And Fuel consumption for gasoline and diesel in 2016 was 33,177 liters and 25,404 liters, respectively. However, before 2019, inventories did not classify diesel according to categories B and C, so the emission factors for that year were calculated by averaging B and C retrieve retrieved from the "Factores de Emision Registro de Huella de Carbono, Compensacion y Proyectos de Absorcion de Dioxido de Carbono", mentioned in Table 8, as follows:

Table 8. Fossil Fuel Emission Factors [57].

Type of Fuel	Year 2014	Year 2015	Year 2016	Coefficient
Propane Gas	2.938 kg CO_2/kg	2.938 kg CO_2/kg	2.938 kg CO_2/kg	1gr CO_2 = 1.007 Co_{2eq}
Natural Gas	0.202 kg CO_2/kWh	0.202 kg CO_2/kWh	0.202 kg CO_2/kWh	1gr CO_2 = 1.003 Co_{2eq}
Diesel C	2.868 kg CO_2/L	2.868 kg CO_2/L	2.868 kg CO_2/L	1gr CO_2 = 1.016 Co_{2eq}
Diesel A/B	2.544 Kg CO_2/L	2.544 Kg CO_2/L	2.539 Kg CO_2/L	1gr CO_2 = 1.012 Co_{2eq}
Gasoline	2.205 kg CO_2/L	2.205 kg CO_2/L	2.196 kg CO_2/L	1gr CO_2 = 1.008 Co_{2eq}

Then Co_{2eq} of Scope 1 can be described in Table 9, as follows:

Table 9. Total GHG Emissions of Scope 1 of Co_{2eq} at the Port of Valencia.

Emission	Fuel Consumption Litters	Fuel Consumption KWH	Emission Factor for 2016	Co_{2eq} EmissionsIn Kg	Co_{2eq} Emissions in Tones	Overall Ratio
Emissions Associated with Diesel Fuel	33,177	336,702.42	2.703 Kg CO_2/L	89,677.431	89.67	54%
Emissions Associated with Gasoline	25,404	239,985.75	2.196 Kg CO_2/L	61,418.05	61.41	37%
Emissions Associated with Gas Consumption (Natural Gas)	-	74,925.00	0.202 kg CO_2/KWh	15,133.77	15.13	9%
Total Emissions Scope 1	58,581.00	651,613.17	-	166,229.251	166.229	100%

Note below:

- In 2016 the port authority of Valencia just used natural gas in its operations.
- In 2016 the APV did not have fixed refrigeration and air conditioning installations in its buildings that involve the consumption of fluorinated gases.

4.2.2. Scope 2

Indirect GHG emissions of the APV–Port of Valencia due to electricity consumption of port authority; it considers the indirect emissions derived from the electricity consumption of the activities of the APV–Port of Valencia.

In terms of emissions resulting from the organization's electricity use, the following distinctions have existed and are listed with statistics in Table 10:

- Emissions connected with electricity use for lighting and all necessary power in APV–Port of Valencia buildings.
- Emissions from electricity consumption at APV–Port of Valencia buildings for air cooling.
- Emissions related to the APV–Port of Valencia's electricity use concerning port road lights.

Table 10. Scope 2 Emissions of the Port of Valencia in 2016.

Description	Electricity Consumption KWh	Emission Factor Kg CO_2/KWh	Co_{2eq} Emissions in Kg	Co_{2eq} Emissions in Tones	Overall Ratio
APV Buildings: Lighting + Power	3,309,969.53	0.2829	936,480.85	963.48	38%
APV Roadway Lighting	2,493,451.62	0.2829	705,465.62	705.46	28%
APV Buildings: Air conditioning.	1,750,656.82	0.2829	495,308.66	495.30	19%
Other consumption	1,320,876	0.2829	373,711.93	373.71	15%
Total Emissions Scope 2	8,874,954.00	-	2,510,967.06	2510.96	100%

It must be noted that there was not any cold ironing in 2016 in the Port of Valencia.

Due to secrecy, only the emission factor, 0.2829 Kg CO_2/KWh, is published in the official data from Valencia that served as the basis for our work study. The names of the electricity providers are not revealed in these reports [71].

4.2.3. Scope 3

Scope 3 includes indirect GHG emissions from concessionary companies' energy and fuel use, goods transport within the APV, and vessel calls, computed using this work study's improved methodology.

The following distinction has been made about the disaggregation of Scope 3 which includes indirect emissions from the electricity consumption of concessionary companies of the APV's emissions associated with commercial activities, presented in Table 11:

- Emissions from service-oriented activities.
- Emissions associated with activities related to the others.

There is no information on other activities, which can contain a variety of activities and information, but standard emission-estimating methodologies must be mentioned.

Table 11. Emission Due to Electricity Consumption of Scope 3 in Valencia Port in 2016 listed by activity classifications.

Description	Fuel Oil Consumption KWh	Emission Factor Kg CO_2/KWh	Co_{2eq} Emissions in Kg	Co_{2eq} Emissions in Tones	Overall Ratio
Commercial	52.895.613	0.282	14,965,614.68	14,965.61	94,24
Service-Oriented	1.420.833	0.282	401,992.49	401.99	2.53
Others	1.814.322	0.282	513,321.28	513.32	3.23
Total	56,130.768	-	15,880,928.46	15,880.92	100%

- *Indirect emissions from fuel consumption of group A*, including cargo transport and handling equipment, rail transport, harbour and inland waterway vessels, construction equipment, power plant, burning plant, port boilers, sewage treatment plants, and emergency equipment by APV Concession Companies are mentioned in Table 12, as follows:

Table 12. Indirect Emission Due to Group A Equipment and Facilities in Valencia Port in 2016 (Group A).

Description	Fuel Consumption KWh	Emission Factor CO_2/KWh	Co_{2eq} Emissions in Kg	Co_{2eq} Emissions in Tones	Overall Ratio
Group A	76,978,166	0.270 Kg	20,875,731.12	20,875.73	100%
Total	76,978,166	-	20,875,731.12	20,875.73	100%

Another set of emissions (Group B) comes from concessionary firms' fuel use in APV ports for commercial and service activities. The APV GHG inventory of the port in 2016 supplies the emission factor and the emission for these activities [71], which are tabulated in Table 13, as follows:

Table 13. Indirect Emissions Due to Concessionaires' Fuel Consumption Year 2016 (Group B).

Discerption	Fuel Oil Consumption KWh	Emission Factor CO_2/KWh	Co_{2eq} Emissions in Kg	Co_{2eq} Emissions in Tones	Overall Ratio
Commercial	121,392,432.05	0.270 Kg	32,811,783.33	32,811.787	95.5%
Service-Oriented	5,523,956.79	0.270 Kg	1,519,054.80	1519.05	4.5%
Total	126,916,388.84	-	34,330,838.13	34,330.83	100%

- *Indirect Emissions Due to Fuel Consumption Associated with Vessel Calls.*

  Emissions Associated with the Container Ships.

1. Emissions Associated with the Cruise Ships.
2. Emissions Associated with the RoRo-Ferrys Ships.
3. Emissions Associated with Other Vessel Category
4. Emissions associated with the Auxiliary Tug Category (not owned by APV).

The new methodology offers two ways to evaluate ship emissions at APV. The first approach calculates emissions from commercial vessels trading in port using two phases: manoeuvring and hoteling.

The following formula can be used to calculate emissions during the manoeuvring phase, which is divided into (A) berthing, (B) unberthing (departure), and (C) shifting (if it exists), depending on the vessel's engine power, fuel type, and duration of operation.

$$\text{Emission}_i = \sum_{i=1}^{n} (\text{ M.E.P } \times \text{LF } \times \text{T})_i \times \text{EF} \tag{26}$$

where Emission_i is the amount of emissions for the vessel (i) in tones, n is the number of vessels, M.E.P is the maximum engine power of the vessel in kw, LF is the load factor of the vessel that the following formula can obtain:

$$\text{LF} = (\text{manuevering speed}/\text{max speed})^{\ 3} \tag{27}$$

The maximum speed can be found in the vessel manufacturer's specification sheet. The manoeuvring speed can be thought of as the average speed of the vessel while it is manoeuvring. Both speeds are measured in knots, and T is the duration of operation in hours, which depends on the distance from the port's entrance to the nominated jetty for incoming vessels or vice versa. EF is the emission factor of fuel consumed by vessels in knots (Kg Co_{2eq}/litter) or (tone Co_{2eq}/m^3).

The second method uses vessel type and fuel consumption, and the Port of Valencia's 2016 GHG report, and the amount of emissions in this estimation are listed in Table 14 as follows:

Table 14. Indirect Emission Due to Maritime Traffic of The Valencia ports (Valencia, Segundo and Gandia) in 2016.

Description	Fuel Consumption KWh	Emission Factor Kg CO_2/kWh	Co_{2eq} Emissions in Kg	Co_{2eq} Emissions in Tones	Overall Ratio
Container carrier ships	88,305,890.39	0.673	59,429,864.20	59,429.864	65%
Cruise ships	3,077,724.56	0.750	2,308,293.42	2308.293	2.9%
Ro-Ro & Ferries Ships	6,769,347.93	0.721	4,880,699.86	4880.699	5.4%
Other Ships (Tanker, Bulk and General cargo carrier)	21,071,066.67	0.686	14,454,751.7	14,454.751	15.9%
Auxiliary Tugs	36,305,933.25	0.271	9,845,816.49	9845.816	10.8%
Total Emissions	155,529,962.80	-	90,919,425.79	90,919.425	100%

- All the emission factors are retrieved from the "Factores de Emision Registro de Huella de Carbono, Compensacion y Proyectos de Absorcion de Dioxido de Carbono" [57].
- The amount of emission factor for row fourth, which includes tankers, bulk, and general cargo carriers, is the average of each factor retrieved from the mentioned inventory and computed to be 0.686 Kg CO_2/kWh.
- For the auxiliary tugs, the emission factor was retrieved from the GHG inventory of Valencia port, which was calculated as 0.271 0.686 Kg CO_2/kWh [71].
- The following issues have been considered when estimating emissions linked to vessel calls:

The number of vessels by type, the engine's principal power, the auxiliary engine's power, the way the ship's engines are used while berthing, the length of the port visit and the berthing process, the distances travelled inside the port's boundaries, vessel's speed.

These factors have been utilized to calculate the total energy spent, and the emission factor is then applied based on the fuel used [71].

- *Commuters Emission*

The final step for estimating scope 3 of APV is to calculate the emission of commuters attending the port. (Group D)

According to the official statistics of the Valencia port authority, the number of employees of the port was 428 in 2016 [70]; importantly, APV is working continuously on all days, which meant 365 days in 2016.

Additionally, according to Google Maps, the closest distance between the port's four main entrances, including the "costume gate, ZAL entrance, south entrance, and Nazaret entrance", and the nearest building and lodging, including the "port authority office, the Spanish costume control authority office, various warehouses, various terminal buildings, the foreign health department, the costume administration, etc.", is less than one kilome-ter.

Then according to calculations made with statistical software, the average dis-tance travelled by each car to attend to different portions of the port can be calculated at 12 km, with the furthest distance being 18 km (see Figure 8), Finally, using the above-mentioned overview map of the port's layout with its numerous offices and presuming that each of the two workers only owns one car and performs round jour-neys to and from their homes every morning and every evening, the following emission computation can be used:

$$\text{Emission}_i = \sum_{i=1}^{n}\left(2\times \text{W.d} \times \text{D}\times \frac{\text{p}}{2}\times \text{Ave.C}\right)_i \times \text{EF} \quad (28)$$

where W.d is the number of working days in a period of measured. D is the distance travelled by car, P is the number of personnel or employees that represent the number of cars, and Ave.C is average consumption simplified by the "Inventario Nacional de emisiones de Gases de Efecto Invernadero" and retrieved from the "Guía metodológica para el cálculo de la huella de carbono en puertos" into Table 15, shown below [61,73].

Table 15. Car Average Consumption.

Type of Vehicle	Average Consumption
Gasoline Private Car	0.091 L/km
Diesel A Private Car	0.066 L/km
Van (diesel A)	0.094 L/km
Coach (diesel A)	0.377 L/km

EF is retrieved from Table 8 of this chapter for the gasoline, which is 2.196 (Kg Co_{2eq}/L).

Thus, the total emission from commuting of employees inside the port area for 2016 is as follows:

$$\text{Emission}_i = \sum_{i=1}^{n}\left(2 \times 365 \times 12\text{km} \times \frac{428}{2} \times 0.091\right)_i \times 2.196 \quad (29)$$

And the amount of emission is equal to (374,620.000 Kg of Co_{2eq}) or (374.620 Tones of Co_{2eq}) for commuters visiting the port.

$$Emission_{scope\ 3} = \sum_{i=A}^{D} Emission_{group\ i} \quad (30)$$

Total emission of Scope 3 = 15,880.29 + 20,875.73 + 34,330.83 + 90,919.42 + 374.62 = 162,380.89 tones of Co_{2eq}, is presented in Table 16.

Table 16. Scope 3 Emissions of Valencia in 2016.

Description	Energy Consumption (KWh)	Co_{2eq} Emissions (Kg)	CO_2 Emissions (T)	Overall Ratio
Total Emissions from Electricity Use	56,130.768	15,880,298.46	15,880.29	9.8%
Emissions from Transportation (Group A)	76,978,166	20,875,731.12	20,875.73	12.8%
Emissions from Fuel Consumption (Group B)	126,916,388.84	34,330,838.13	34,330.83	21.2%
Total Emissions from Vessel Calls	155,529,962.80	90,919,425.75	90,919.42	56.1%
Emissions from Port Commuters	121,517.76	374,620	374.62	0.2%
Total	415,676,804	162,380,890	162,380.89	100%

Figure 10 displays the proportion of each category of activities that contributed to Scope 3 emissions in the Valencia port in 2016:

Finally, for the calculation of the total emissions of the Port of Valencia in the scale of Co_{2eq} and in the year 2016, the following procedures are to be followed and later tabled in Table 17 with each scope's emissions:

$$\text{Emission} = \sum_{i=1}^{3} E_{\text{scope i}} \quad (31)$$

Emission of Scope 1: 166.21 tones of Co_{2eq}.
Emission of Scope 2: 2510.96 tones of Co_{2eq}.
Emission of Scope 3: 162,380.89 tones of Co_{2eq}.

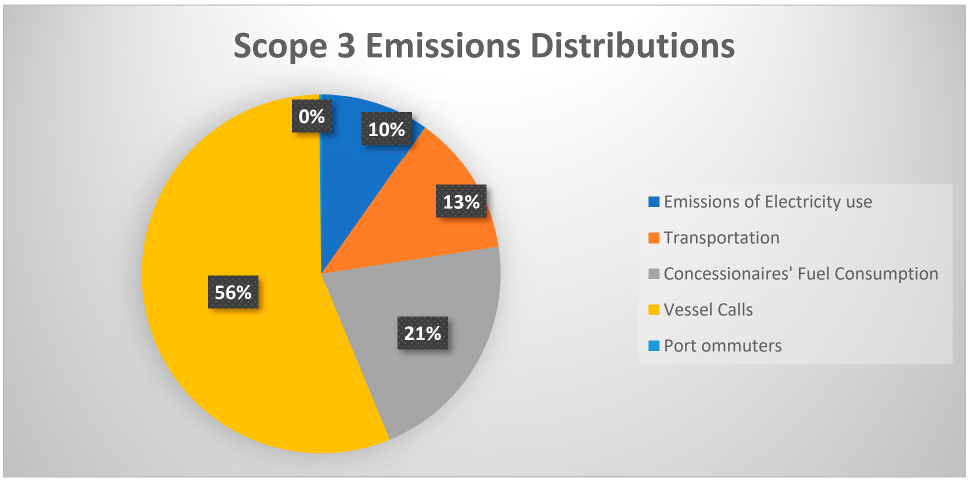

Figure 10. Scope 3 factors proportion emissions (own authorship).

Table 17. Total Emissions of the Port of Valencia in 2016.

Description	Energy Consumption in KWh	Co_{2eq} Emissions in Kg	Co_{2eq} Emissions in Tone	Overall Ratio
Scope 1	651,613.17	166,229.251	166.229	0.1%
Scope 2	8,874,954.00	2,510,967.06	2510.96	1.4%
Scope 3	415,676,804	162,380,890	162,380.890	98.5%
Total	424,718,371	165,058,080	165,058.08	100%

$$\textbf{Emission} = \sum_{i=1}^{3} \mathbf{E}_{\mathbf{scope\ i}} \mathbf{=166.21+2510.69+162{,}380.89=165{,}058\ tones\ of\ Co_{2eq}}$$

The total emissions of Valencia port in 2016 were equal to 164,950 tones of Co_{2eq}.

Then, finally, the CF of the Port of Valencia in 2016 will be calculated from the following formula and later shown in Table 18 as follows:

$$\text{CF} = \text{Total Emission/Total Amount of Transported Cargo}$$

Table 18. Carbon Footprint of the Port of Valencia in 2016.

Description	Value
Total GHG Emissions in Kg of Co_{2eq}	165,058,080
Total Volume of Goods Traffic of the Port of Valencia in Tones	64,361,045
CF (Kg of Co_{2eq}/tones of transported Goods)	2.56

5. Discussion

Numerous local, national, and international institutes and organizations have developed several methodologies for measuring the amount of CF in different industri-al sectors. All these methods are based on a general standard or framework, such as ISO 14064, IPCC, and WPCI guidelines [15,56,74].

However, with the development of technology and the expansion of industrial activities in different commercial sectors, modification to the current methods of measurement should be made in terms of enhancing them in line with the development of the various types of commercial and industrial activities, as well as all the various cases that the development of the sector has produced, as well as considering new technologies and activities.

According to the frameworks used in the estimating models, Scope 3 is where the most relevant studies and revisions on the CF are done. This area needs constant revision due to the apparent sector's expansion and the variety of its dimensions.

In the revised new model presented by this research, the maritime logistics field and its area has been studied and re-organized. Previous models for estimating the CF in ports paid less attention to the sea area, or they attempted to make an average estimate for this section by standardizing the measurement of the marine sector.

This model may entail more maritime operations due to the port's existence in the area, and as seen in the calculation of the case study, the maritime traffic was responsible for approximately 56 per cent of Valencia port's total GHG emissions in 2016; the need to monitor these operations and uphold its established land boundaries, therefore, seems to be increasing, and so a more thorough study in this sector is needed for future policymaking on CF reduction metrics.

This issue will be more significant in ports with long access channels, such as: the Port of Rotterdam, Netherlands, with a 25 Nautical Mile (NM) access channel; the Port of Singapore with a 14 NM access channel; the Port of Los Angeles, United States with a 25 NM access channel; the Port of Busan, South Korea with a 17 NM access channel; the Port of New York and New Jersey, United States with an access channel of approximately

19 NM; and the Port of Shanghai, China with 29 NM access channel. The innovative method described in this article can further demonstrate its efficacy in CF estimate in the numerous other ports across the world with long access channels and substantial maritime traffic.

On the other hand, regarding commuters and people transportation in ports, there has always been the theory that their emission rate is very low compared to the overall emission rate in ports, and this amount can be ignored; in the case of our study's calculation, the approximate volume of this category was 0.2% of the entire set of emissions; however, from the authors' perspective, this small amount must also be monitored, so that it can be reduced and optimized in line with the overall emission rate. Furthermore, larger bodies can be formed by combining all the small parts.

Additionally, there are several ports in the world with long coastlines and expansive land areas, such as the Port of Shanghai in China, which is 3619 square km in size and which has a coastline that stretches over 100 km along the Yangtze River; the Port of Rotterdam in the Netherlands, which has a land area of about 12,500 hectares and a coastline that stretches for about 42 km along the North Sea; the Port of Houston, in the United States, which has a coastline of about 25 km along the Gulf of Mexico; and the Port of Dubai, in the United Arab Emirates, has a coastline of about 72 km along the Persian Gulf. where commuter vehicles can cause large emissions, and adopting the novel methodology described in this paper can help to estimate ports' CF with greater accuracy. On the other hand, some ports around the world have a significant number of registered employees, such as the Port of Shanghai in China, which has over 30,000, the Port of Singapore, which has 17,000, the Port of Rotterdam in the Netherlands, which has 18,000, and others. These ports are thought to have a high potential for emissions from commuters, who can contribute to port emissions, so policymakers need to give attention to them. The newly proposed methodology may estimate their emissions, resulting in a more precise calculation of the port's total emissions for the purpose of implementing mitigation measures.

This study measured the total amount of GHG emissions in the port of Valencia in 2016. The overall amount of estimation was estimated to be 165,058,080 kg, and the total amount of goods transported in the port was 64,361,045 tones; consequently, the CF of the port for the mentioned year was equal to 2.56 (Kg of Co_{2eq}/tones of transported Goods), and this amount is two-tenths of a per cent different from the amount measured by the APV in 2016, which was equal to 2.58 [75].

The difference between the current calculation and the calculation of the port authorities is due to the progress and updating of the emission factor for various fuels. The amount of emissions caused by sea traffic, calculated using the new method, shows a more accurate calculation by the newly presented estimate than the previous estimate.

Transport personnel and employees have also been determined to result in 374,620 kg of emissions. In the port's assessment, this issue must be addressed, and its estimation can aid in developing efficient strategies to lessen the management of this component.

Finally, based on the preceding explanations and the analysis of the new method presented and its enhancement in the two previously mentioned sections, it can be concluded that the new method is more practical and has a more accurate calculation of the emission rate than the previous estimates, particularly for ports with long access channels or those located along rivers. Furthermore, it has a wider application for ports with larger hinterlands and wider roadways with more traffic because it allows for more precise CF quantification.

6. Conclusions

In calculating the CF, following the "GHG Protocol" and other standard guidelines, which serve as the primary criteria for developing new methodologies, the majority of the focus has been on Scope 3 and its continued expansion, because by moving ports toward deploying renewable energies and energies supplied from their own power plants, Scope 2 is becoming a lesser emission scope day-by-day, while on the other hand, geo-stationary power plants in Scope 1 and purchased power in Scope 3 move toward fewer and even zero emissions.

Following that, the focus of changes in the new methodology given in this study was likewise on the elements assigned in Scope 3. As stated in the previous chapters, activities have been divided into land and sea bases. In both categories, revisions have been made, and in the case of land activities, an aspect of calculations that had been ignored has been investigated.

In the case of marine activities, attention has been paid to the proper development of the studied marine boundary to estimate the precise results. The authors believe the calculation of the entire amount of CF obtained is optimized by combining the calculation formulas with their appropriate delimitations. The significance of this limitation has been examined from legal, scientific, feasibility, and all other applicable standpoints. Due to the modified formulas, this study appears more useful for future research and exploration.

On the other hand, it is anticipated that further changes will be made to the three current domains for estimating CFs, particularly in sea and land logistics, because of technological advancement and the growth of various activities.

In conclusion, this new methodology highlights the critical role that scientific research and innovation can play in addressing global environmental challenges. This research study's new carbon footprint method is a game-changer. It offers a comprehensive and accurate procedure to measure the environmental impact of port activities, enabling port authorities and other stakeholders to identify areas for improvement and to implement targeted measures to reduce emissions.

Considering a range of variables and factors, this approach provides a detailed and nuanced view of carbon emissions inside seaports, making it a crucial tool in the fight against climate change. The challenges of climate change require a collective effort, and this technique represents an essential step towards a sustainable port for future research.

Adopting and implementing this proposal can pave the way for more sustainable seaports, ensuring a better world for the next generations, and allowing for professionals, entities, societies, and practitioners to take responsibility for their actions and work towards a cleaner and greener environment.

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