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# Development of a standardized tool to calculate Carbon Footprint in Ports

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## Abstract

An important goal to tackle environmental problems and foster sustainable development in the near future is to reduce the generation of greenhouse gas emissions (GHG) from different industrial sectors including ports. According to the last environmental review of the European Sea Port Organization (ESPO), Climate Change occupies the second position in the ranking of top 10 environmental priorities in ports. This reflects the importance of this issue in the whole set of port environmental priorities. In addition, it has been predicted by diverse institutions (e.g. The International Council on Clean Transportation (ICCT)) that GHG emissions from shipping activities will increase in the forthcoming years.

The first concerns about Climate Change were expressed in 1979 when the first World Climate Conference was held in Geneva. Since then, many initiatives have been taking place (i.e. Paris Agreement 2015) and several international guidelines to calculate the Carbon Footprint have been developed. In particular, in the Maritime sector, several ports, port terminals and ships have started to calculate their emissions.

However, after the deep research conducted in this thesis on Climate Change and Carbon Footprint in ports, it has been seen that there does not exist a single and unified method for ports to calculate their GHG emissions. Therefore, nowadays it is not possible to compare the Carbon Footprint results among different ports. As a consequence, there is a need to develop a standard methodology to calculate this indicator in ports. This calculation tool has been demanded by the port sector in several conferences and workshops (e.g. Greenport conference, 2018).

Therefore, this thesis focuses on this aspect and develops a practicable, user-friendly and easy to use tool with a standardized method for the calculation of Carbon Footprint in ports. The development of the tool has been done in Excel and Visual Basic software based on the most updated international guidelines (i.e. World Port Climate Initiative, IPCC guidelines and GHG Protocol). In this tool, all the scopes and all the sources that are recommended by these guidelines are taken into account.

The tool has been tested by 20 experts through personal visits, telephone calls or via email. Their opinion has been taken into account to improve it. In addition, the tool has been validated with the existing results of the Port of Oslo (Norway) and Ports de la Generalitat (Catalonia, Spain). The results obtained are in line with the ones used by these ports. Finally, a case study model has been created to test all the functionalities of the tool that have been not proved with the previous case studies. The emission values obtained for this case study have been compared with those obtained with the Catalan Office for Climate Change (OCCC) tool and Ecological Transition Ministry (MITECO) tool. The outcomes are very similar with minor changes due to different emission factors.

As a consequence, the main objective of the thesis has been achieved and a standard tool for the calculation of GHG in ports is now freely available for the whole port sector. The completion of this tool is expected to be around 20 minutes (if data are available). The tool provides options to select the scopes and boundaries that are more suitable and applicable to each port. In addition, the tool allows normalizing (standardize to a common ground) the total annual emissions in terms of total tonnes of cargo handled or annual TEUs. The tool, the guidelines and the video can be downloaded from http://eports.cat/carboonfootprint

**Keywords**: Global Concern, Climate Change, Carbon Footprint, Greenhouse Gases, port, Standardized tool

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## Glossary

**B**

BPO: Ballistic Port Organization

**C**

CCF: Corporate Carbon Footprint

CCWG: Clean Cargo Working Group

CDM: Clean Development Mechanism

CLUM: Consumption Land Use Matrix

COP: Conferences of the Parties

**E**

EPA: U.S. Environmental Protection Agency

EuDA: European Dredging Association

ESPO: European Sea Port Organization

**G**

GHG: Greenhouse Gases

GRI: Global Reporting Initiative

GWP: Global Warming Potential

**I**

IAPH: International Association of Ports and Harbors

ICCT: International Council on Clean Transportation

ICTA: International Center for Technology Assessment

IHMA: International Harbor Masters' Association

IMarEST: Institute of Marine Engineering, Science & Technology

IMO: International Maritime Organization

IMPA: International Maritime Pilots' Association

IPCC: Intergovernmental Panel on Climate Change

ISO: International Organization for Standard

IWI: Inland Waterways International

**L**

LPG: Liquefied Petroleum Gas

**M**

MARPOL: International Convention for the Prevention of Pollution from Ships

MC3: Compound Method based on Financial Accounts

MEPC: Marine Environment Protection Committee

MITECO: Ecological Transition Ministry

**O**

OPS: Onshore Power Supply

OCCC: Catalan Office for Climate Change

**P**

PIANC: World Association for Waterborne Transport Infrastructure

POST: Parliamentary Office of Science and Technology

**S**

SFC: Smart Freight Centre

**U**

UN: United Nations

UNEP: United Nations Environmental Program

UNFCCC: United Nations Framework Convention on Climate Change

**W**

WBCSD: World Business Council for Sustainable Development

WMO: World Meteorological Organization

WPCI: World Ports Climate Initiative

WPSP: World Ports Sustainability Program

WRI: World Resources Institute

WWF: World Wide Fund for Nature

# Chapter 1: Introduction

Ports are important infrastructures that serve as a catalyst for economic growth and development. They have strategic importance to a nation, acting as gateways to trade. They also constitute a key node in the global supply chain (Wright, 2013). At the same time, they are very complex systems, regulated by diverse levels of legislation: Global, European, National and Local one.

According to the International Association of Ports and Harbors (IAPH, 2010) the increase of Green House Gas (GHG) emissions in port operations is the main cause of the impact that these areas have in global Climate Change. According to the last environmental review of the European Sea Port Organization (ESPO), Climate Change occupied the 2nd position in the ranking of top 10 environmental priorities in ports in 2020 (ESPO, 2020a). This reflects the importance of this issue in the whole port environmental priorities and the fact that the topic of Climate Change in the maritime industry is getting more importance every day. It is predicted that seaport and inland waterway infrastructures will be affected by the consequences of Climate Change, in ways such as sea level rise and changes in weather or in the storm frequency (Becker et al., 2011).

Therefore, Ports require a special treatment as far as controlling the effects on Climate Change on them, due to their economic importance, their role as essential links in supply chains, their location in the heart of sensitive estuarine environments, their reliance on waterfront locations and the significant existing infrastructure that links them to inland transportation networks (Becker et al., 2011).

On the other hand, shipping generates over one thousand million tonnes of GHG emissions annually (IMO, 2014). In the recent years, this means 2.5% of global GHG emissions (Bass, 2020). Due to the foreseeable raise of the maritime trade and the fact that that most of the ships are powered by fossil fuels, it is expected that GHG emissions will increase in the future (Wright, 2013). The International Council on Clean Transportation (ICCT) predicted that greenhouse gas emissions from shipping activities will triple by 2050 (Olmer et al., 2017). Based on the result of a research from Winnes et al. (2015) on GHG emissions from ships in ports, the emissions of $CO_2$ are projected to increase by 40% to 2030 in a business as usual (BAU). For this reason, the problem of Climate Change is gaining more importance every day in this sector and particularly in port areas, which contribute with their daily activities to GHG emissions. The global community has recognized the need to reduce global emissions and the fact that shipping is expected to become one of the fastest growing sectors in terms of greenhouse emissions, along with the aviation sector (Gilbert et al., 2010).

To describe better the concept of Climate Change, the next section is devoted to it.

## 1.1. Climate Change

Climate Change is an inherent global issue which has become a major focus of attention because of its potential hazards and impacts on the environment, particularly invulnerable systems (Sánchez-Arcilla, et al., 2011). Climate is the most important part of the nature, the basis for human survival and development, a crucial resource, and the basic condition for sustainable economic and social development. Since the industrialization of human society coupled with the marked increase in human activities, the already variable climate of the Earth has been influenced significantly by such human actions (Chao & Feng, 2018).

Generally, Climate Change refers to the gradual change in the Earth's climate and physical geography that accompanies an increase in the Earth's temperature. It is one of the greatest challenges facing life on Earth. Climate-related changes have already been observed globally and these include increases in air and water temperatures, reduced frost days, increased frequency and intensity of heavy downpours, a rise in sea level, and reduced snow cover, glaciers, permafrost, and sea ice. Longer ice-free periods on lakes and rivers, lengthening of the growing season, and increased water vapor in the atmosphere have also been observed. In addition, over the past 30 years, temperatures have risen faster in winter than in any other seasons (Karl et al., 2009).

The on-going global Climate Change has been related to GHG emissions because of the atmospheric warming effect of these emissions (IPCC, 2015a). The GHGs which have been mainly implicated in trapping heat in the atmosphere are methane ($CH_4$), carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$). In addition, Climate Change due to carbon dioxide emissions from transportation is considered to be a significant environmental threat (Akerman & Hojer, 2006; Koroneos & Nanaki, 2007)

Concerns about Climate Change were expressed in 1979 when the first World Climate Conference was held in Geneva and sponsored by World Meteorological Organization (WMO). It was one of the first major international meetings on Climate Change (Sprinz& Luterbacher, 1996).

After that, in 1988, the United Nations Environmental Program (UNEP) and the WMO created the Intergovernmental Panel on Climate Change (IPCC) to provide policymakers with regular scientific assessments on the current state of knowledge about Climate Change (IPCC, 2015b). In addition, IPCC published a set of guidelines for the National Greenhouse Gas Inventories in 1995. The revised versions of these guidelines were issued in 2006 and updated in 2019 (IPCC, 2006 and 2019). Moreover, since 1988 the IPCC has produced five comprehensive Assessment Reports and several Special Reports on specific topics related to Climate Change. At the moment, IPCC is working on the Sixth Assessment Report that started in April 2021 and it is assumed it will release in May 2022 (IPCC, 2020).

Another important attempt to control Climate Change is the United Nations Framework Convention on Climate Change (UNFCCC) which was developed in Rio de Janeiro in 1992. The aim of this convention was to stabilize GHG concentrations in the atmosphere. The parties of this convention have met annually since 1995 in the Conferences of the Parties (COP) to assess progress regarding Climate Change (UNFCCC, 1992).

Besides in 1997 the Kyoto Protocol[1] developed an action to limit Greenhouse Gas emissions by at least 5% below 1990 levels in the commitment period from 2008 to 2012. The six key greenhouse gases listed in the Kyoto Protocol were: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and three groups of

[1]The Kyoto Protocol which was adopted in Kyoto (Japan) in 11 December 1997 and entered into force in 16 February 2005. The Kyoto Protocol was an international agreement linked to the United Nations Framework Convention on Climate Change (COP3), which committed its Parties by setting internationally binding emission reduction targets.

fluorinated gases (sulphur hexafluoride (SF6), Hydrofluro Carbons (HFCs), and Perfluoro Carbons (PFCs) (UNFCCC, 1998).

In addition, in 1998 the GHG Protocol was created by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (WRI and WBSCD, 2004). The GHG Protocol developed standards, guidance documents, tools and online training that helped countries and cities track progress towards their climate goals.

Moreover, in April 1998 EPA (U.S. Environmental Protection Agency) General Counsel prepared a legal opinion concluding that $CO_2$ emissions were within the scope of EPA's authority to regulate. The path to EPA regulation of GHG emissions begins in 1999, when the International Center for Technology Assessment (ICTA) and 18 other organizations filled a petition for rulemaking with EPA, requesting that EPA regulated GHG emissions from new motor vehicles and new motor vehicle engines under section 202 of the Clean Air Act (NACAA, 2013).

Gold Standard emission allowance is another initiative that was established in 2003 by the World Wide Fund for Nature (WWF) and other international Non-Governmental Organizations (NGOs) to ensure that the projects reduced carbon emissions under the UN's Clean Development Mechanism (CDM) and also contributed to sustainable development. Its next-generation standard, launched in 2017, called Gold Standard for the Global Goals, allowed climate and development initiatives to quantify, certify, and maximize their impacts towards climate security and sustainable development. Gold Standard now has more than 80 NGO supporters and more than 1400 certified projects in over 80 countries, creating billions of dollars of shared value from climate and development action worldwide (ECOFYS, 2006).

In 2006 International Organization for Standard (ISO) developed ISO 14064 which contains detailed principles and requirements for designing, developing, managing and reporting organization or company level GHG inventories (ISO, 2006). In addition, ISO 14064-2 focuses on GHG projects or project based activities specially designed to reduce GHG emissions or increase GHG removals. ISO 1464-3 developed to validate and verify GHG inventories. The revised version of this standard, ISO 14060 family was developed in 2018 in order to clarify and provide consistency to quantify, monitor, report and validate or verify GHG emissions and removal to support sustainable development (ISO, 2006 and 2018).

In 2009, an initiative from the United Nations (UN) was launched, called the Partnership for Learning on Climate Change (UN CC: Learn). This was a collaborative initiative involving more than 30 multilateral organizations, whose main function was to provide support to countries that wanted to develop and implement training plans in sustainability. These plans were intended to address Climate Change (United Nations Institute for Training and Research, 2015).

GRI (Global Reporting Initiative) is an international independent organization that has pioneered corporate sustainability reporting since 1997. GRI helps businesses, governments and other organizations understand and communicate the impact of business on critical sustainability issues such as Climate Change, human rights, corruption and many others (GRI, 2019). The GRI Sustainability Reporting Guidelines offer Reporting Principles, Standard Disclosures and an Implementation Manual for the preparation of sustainability reports by organizations, regardless of their size, sector or location (GRI, 2013). Emissions reporting, as one of the most mature areas of sustainability disclosure, is consistently considered essential information. GRI has included climate related metrics in its Standards since 1997 to allow companies to communicate their climate related impacts (GRI , 2019). The GRI launched its fourth generation Sustainability Reporting Guidelines

(G4) in May 2013. The G4 Guidelines are the product of an intensive, two years, multi-stakeholder process (KPMG, 2013).

More recently, in 2015 the Paris Agreement within the framework of the United Nations Framework Convention on Climate Change (21st COPs of the UNFCCC) recognized Climate Change as an urgent threat and set the mitigation goal of limiting the global temperature increase up to 2 °C and ideally up to 1.5°C (United Nations, 2015). However, the greenhouse gas emissions continued to rise (Quéré et al., 2016). The concentration of $CO_2$ in the atmosphere increased from approximately 277 parts per million (ppm) in 1750 (Joos & Spahni, 2007) at the beginning of the industrial era, to 403 ppm in 2016 (NOAA & ESRL, 2019).

Following the Paris Agreement, the Conference of Parties (COP 25) gathered in Madrid in December 2019. The main achievements of this COP were increasing the countries ambitions to Paris Agreement, recognizing the importance of the oceans in the climate system, promoting women's participation in international climate negotiation, allocating more funds to vulnerable countries to fights against Climate Change, recognizing the importance of non-governmental actors in climate action and invite them to increase their role. In addition, this COP recognized that climate policies must be constantly updated based on the advances in Science (El National, 2019). The next one is the COP 26 that was originally scheduled for November 2020, in Glasgow, UK, but finally it will be in November 2021 due to the COVID-19 pandemic situation (UNFCCC, 2021). During COVID 19 pandemic, there was a decrease of the GHG emissions caused by mobility restrictions which meant a reduction of global warming. However, this was mostly temporary. If this decrease could go together with investments in low-carbon solutions carried out by the governments, a reduction of global warming by 0.3°C by 2050 could be achieved and put the world on track to meet the Paris Agreement goals (Forster et al., 2020). Unfortunately, based on the stimulus plans, most governments are still on crisis mode and so far appear to be missing this unique and critically important opportunity for green investments (Climate Action Tracker, 2020). The period following the containment of the pandemic, when additional recovery packages will be designed and released, will be crucial for the global climate (Erik et al., 2021).

In order to measure the potential contribution of human activities, to Climate Change, an environmental indicator can be used: The Carbon Footprint. In next section this concept is described.

## 1.2. Carbon Footprint

An environmental indicator, the Carbon Footprint, has been developed over the last decade (Peters, 2010, Wiedmann & Minx, 2008). Carbon Footprint is an active research topic on which a large number of initiatives are currently underway in several countries (Peters, 2010). Carbon Footprint has become a widely used term and concept in the public debate on responsibility and abatement action against the threat of global Climate Change. The term itself is rooted in the language of Ecological Foot printing (Bazan, 1997) and, it is usually quantified in units of area (Wiedmann & Minx, 2008).

The Global Footprint Network, an organization that compiles 'National Footprint Accounts' on an annual basis (Wackernagel et al., 2005) sees the Carbon Footprint as a part of the Ecological Footprint. Carbon Footprint is interpreted as a synonym for the 'fossil fuel footprint' or the demand on '$CO_2$ area' or '$CO_2$ land'.

The Parliamentary Office of Science and Technology (POST, 2006) defines Carbon Footprint as the total amount of $CO_2$ and other GHG emitted over the full life cycle of a process or product. The other GHGs are expressed as $CO_2$ equivalent ($CO_2$eq). The carbon dioxide equivalent of a quantity of gas is calculated by multiplying the mass of the gas (in tonnes), by the gas global warming potential (GWP). GWP value for $CO_2$ is equal to 1 for 100-year time horizon, for $CH_4$ is equal to 28 and for $N_2O$ is equal to 265 (IPCC, 2015a).

Wiedmann & Minx (2008) proposed the following definition of the term Carbon Footprint: "The Carbon Footprint is a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product."

In the UK, the Carbon Trust[2] aimed at developing a more common understanding about what a Carbon Footprint of a product is and circulated a draft methodology for consultation. This method emphasize that only input, output and unit processes which are directly associated with the product should be included, whilst some of the indirect emissions (e.g. from the commuting of workers to the factory) are not factored in (Carbon Trust, 2017).

In addition, according to Dube Trade Port Corporation[3], the Carbon Footprint can be described as the total amount of carbon dioxide and other Greenhouse Gas (GHG) emissions (expressed as carbon dioxide equivalents or $CO_2$eq) for which an organization or site is responsible, or over which it has control (Dube TradePort, 2016).

Among the different initiatives related to Climate Change and Carbon Footprint, some of them have developed guidelines to calculate Carbon Footprint. The next section presents these guidelines together with other focused on reducing $CO_2$ emissions.

## 1.3. International guidelines to calculate Carbon Footprint

Several organizations are working actively to provide guidelines and instructions to calculate $CO_2$ emissions and Carbon Footprint. They are introduced in the next subsections.

### 1.3.1. IPCC Guidelines

The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to Climate Change. As it was mentioned in section 1.1, the IPCC was set up in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to provide policymakers with regular assessments of the scientific basis of Climate Change, its impacts and future risks, and options for adaptation and mitigation.

IPCC assessments provide a scientific basis for governments at all levels to develop climate related policies, and they underlie negotiations at the UN Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC). Participation in the IPCC is open to all member countries of the WMO and United Nations. It currently has 195 members (IPCC, 2019b).

The IPCC Guidelines for National Greenhouse Gas Inventories were accepted in 1994 and published in 1995. UNFCCC COP3 held in 1997 in Kyoto reaffirmed that the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" (IPCC, 2003). The revised version of the IPCC Guidelines for National Greenhouse Gas Inventories were issued in 2006 and updated in 2019 (IPCC, 2006 and 2019).

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[2]The Carbon Trust is a private company set up by the UK government to accelerate the transition to a low carbon economy. The Carbon Trust methodology estimates the total emission of greenhouse gases (GHG) in carbon equivalents from a product across its life cycle from the production of raw material used in its manufacture, to disposal of the finished product (excluding in-use emissions)

[3]The Dube Trade Port Corporation, is a business entity of the KwaZulu-Natal Provincial Government in South Africa that manages a 3,000 ha infrastructure project called the Dube Trade Port Special Economic Zone set up to promote local and international trade.

The gases covered in the Guidelines are the direct greenhouse gases, carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$), the indirect greenhouse gases carbon monoxide (CO), oxides of nitrogen ($NO_x$) non-methane volatile organic compounds (NMVOCs), halocarbons (HFCs, PFCs) sulphur hexafluoride ($SF_6$) and sulphur dioxide ($SO_2$). The stages of calculation GHG emissions based on these guidelines are (IPCC, 2006 and 2003):

- Step 1: Planning the inventory which includes listing the GHG emission sources.
- Step 2: Using the IPCC default methods/data. The IPCC Workbook contains default methods for the estimation of each of the main source categories.
- Step 3: Using the workbook which is designed to be a working document. It can be used as an integral part of making an inventory of greenhouse gas emissions and removals. It is divided into five modules, each with its own icon:
    - Energy
    - Industrial Processes and product use
    - Agriculture, Forestry and Other Land Use
    - Waste
    - Other (e.g., indirect emissions from nitrogen deposition from non-agriculture source)

Within each module a series of emission sources are identified. Each emission source contains one or more Worksheets. These are blank forms to create the inventory that needs to be filled in and returned to IPCC.

To help to use the Worksheets, each emission source section contains the below mentioned aspects. More information about a particular emission source is also provided at IPCC Greenhouse Gas Inventory Reference Manual.

- A brief introduction
- A survey of data sources
- An overview of the methodology recommended for the source
- Instructions for completing the Worksheet

- Step 4: Providing documentation. Written documentation should be provided along with inventory results.
- Step 5: Reporting finer levels of detail in the worksheets. For simplicity and clarity, the Workbook deals with calculation of emissions at a national level, with source categories broken down into relatively few subcategories. The level of detail in the subcategories is designed to match the available sources of default input data, carbon contents and other assumptions.

### 1.3.2. Greenhouse Gas (GHG) protocol

The GHG Protocol is a multi-stakeholder partnership of businesses, non-governmental organizations (NGOs), governments, and others convened by the World Resources Institute (WRI), (a U.S.-based environmental NGO), the World Business Council for Sustainable Development (WBCSD) and a Geneva-based coalition of 170 international companies. The Greenhouse Gas Protocol was launched in 1998 and its mission is to develop internationally accepted greenhouse gas accounting and reporting standards for business and to promote their broad adoption. The GHG Protocol Initiative comprises two separate but linked standards (WRI and WBSCD, 2004):

- GHG Protocol Corporate Accounting and Reporting Standard: this document provides a step-by-step guide for companies to use in quantifying and reporting their GHG emissions.

- GHG Protocol Project Quantification Standard: a guide for quantifying reductions from GHG mitigation projects.

GHG Protocol covers the accounting and reporting of the six greenhouse gases covered by the Kyoto Protocol: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and Sulphur hexafluoride ($SF_6$). The standard and guidance were designed with the following objectives:

- To help companies to prepare a GHG inventory that represents a true and fair account of their emissions, through the use of standardized approaches and principles
- To simplify and reduce the costs of compiling a GHG inventory
- To provide business with information that can be used to build an effective strategy to manage and reduce GHG emissions
- To provide information that facilitates participation in voluntary and mandatory GHG programs
- To increase consistency and transparency in GHG accounting and reporting among various companies and GHG programs

To complement the provided standard and guidance, a number of cross-sector and sector-specific calculation tools are available on the GHG Protocol Initiative website (www.ghgprotocol.org), including a guide for small office-based organizations. These tools provide step by-step guidance and electronic worksheets to help users calculate GHG emissions from specific sources or industries. The tools are consistent with those proposed by the Intergovernmental Panel on Climate Change (IPCC) for the compilation of emissions at the national level (IPCC, 2003). They have been refined to be user-friendly for non-technical company staff and to increase the accuracy of emissions data at a company level (WRI and WBSCD, 2004).

Therefore, GHG Protocol is an accounting tool used by organizations and governments to understand quantify and manage their greenhouse gas emissions. It provides the world’s most widely used greenhouse gas accounting standards. Since 1998, it has been used by more than 1,000 businesses and organizations worldwide (Carbon Trust, 2017).

### 1.3.3. International Standard Organization (ISO) 14064

ISO 14064 provides guidelines for the calculation of GHG emissions. Besides, it has guidelines for reduction and verification purposes. The first version of this standard was published in 2006 and the revised one was published in 2018. ISO 14064 is divided in different sections. Figure1.1 displays the relationship between the different parts of ISO 14064, which are described below (ISO, 2018).

ISO 14064-1 details principles and requirements for designing, developing, managing and reporting organization or company-level GHG inventories. It includes requirements for determining GHG emission boundaries, quantifying an organization's GHG emissions and removals, and identifying specific company actions or activities aimed at improving GHG management. It also includes requirements and guidance on inventory quality management, reporting, internal auditing and the organization's responsibilities for verification activities (ISO, 2006).

ISO 14064-2 details principles and requirements for determining baselines for monitoring, quantifying and reporting of project emissions. It focuses on GHG projects or project-based activities specifically designed to reduce GHG emissions and/or enhance GHG removals. It provides the basis for GHG projects to be verified and validated.

ISO 14064-3 details requirements for verifying GHG statements related to GHG inventories, GHG projects, and Carbon Footprints of products. It describes the process for verification or validation, including verification or validation planning, assessment procedures, and the evaluation of organizational, project and product GHG statements.

ISO 14065 defines requirements for bodies that validate and verify GHG statements. Its requirements cover impartiality, competence, communication, validation and verification processes, appeals, complaints and the management system of validation and verification bodies. It can be used as a basis for accreditation and other forms of recognition in relation to the impartiality, competence and consistency of validation and verification bodies.

ISO 14066 specifies competence requirements for validation and verification teams. It includes principles and specifies competence requirements based on the tasks that validation or verification teams have to be able to perform.

ISO 14067 defines the principles, requirements and guidelines for the quantification of the Carbon Footprint of products. The aim of ISO 14067 is to quantify GHG emissions associated with the life cycle stages of a product, beginning with resource extraction and raw material sourcing and extending through the production, use and end-of-life phases of the product.

ISO/TR 14069 assists users, providing guidelines and examples for improving transparency in the quantification of emissions and their reporting (ISO, 2018).

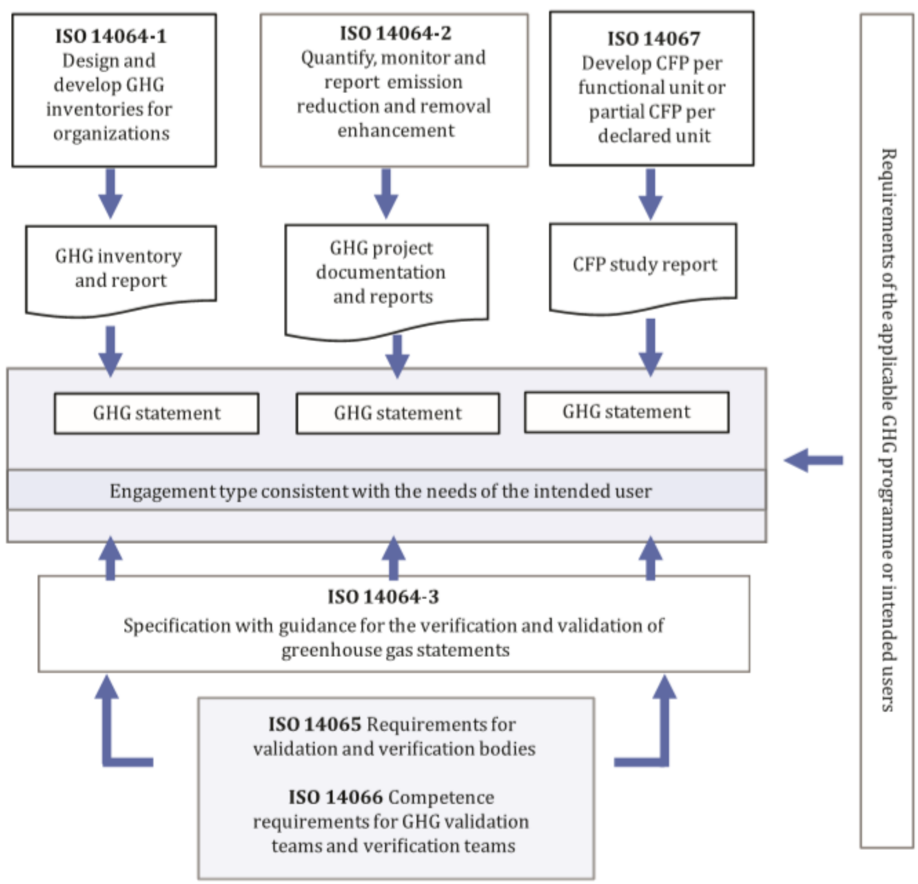


**Figure 1.1: Developing GHG inventories base on ISO 14064 (ISO, 2018)**

### 1.3.4. Carbon Footprint Calculation guidelines by the Ecological Transition Ministry of the Spanish government

Since 2007, the Ecological Transition Ministry (MITECO) of the Spanish government developed a tool and guidelines to calculate the Carbon Footprint. The last version of these guidelines was published in 2019 and they aim to calculate emissions by scope. Emissions are categorized based on scopes: Scope 1 emissions are direct emissions from sources that are owned or controlled by the agency or organization; Scope 2 emissions are indirect emissions from electricity consumption and Scope 3 emissions are other indirect emissions that emits from assets not owned or controlled by the reporting organization. In particular the MITECO tool calculates emissions from scope 1 and scope 2, in 3 groups (MITECO, 2019):

- Organizations
- Municipalities
- Agriculture

This Excel based tool allows to calculate direct and indirect (from the electricity consumption) GHG emissions. It also offers the possibility of quantifying the emission reduction and comparing the results of emissions between different years. The scopes of this tool are:

- Scope 1: Emissions from Fossil fuels consumption and Emissions from fluorinated gases (air conditioning equipment and cooling)
- Scope 2: Emissions from Electricity consumption

Emission factors[4] are obtained from the different editions of the National Emissions Inventory of Spain (from the 1990-2006 edition to the 1990-2017 edition) and in the IPCC guidelines for national inventories of greenhouse gases of 2006 (MITECO, 2019).

### 1.3.5. Practical guideline to calculate GHG emissions from the Catalan Office for Climate Change (OCCC)

In 2008, the Catalan Office for Climate Change developed an excel based tool to calculate $CO_2$ emissions. The latest version of this tool with its guideline was published in 2019. The purpose of this guideline is to facilitate the estimation of GHG emissions. The Guideline will help organizations and citizens to estimate the emissions associated with their activities, or to reduce the expected emissions by implementing a mitigation action. This Guide also includes the inventory framework and Carbon Footprints of organizations, as well as an explanation of the different categories of emissions (OCCC, 2019).

The main purpose of this guideline is to calculate emissions associated with energy consumption in stationary facilities and transport, fugitive emissions from fluorinated gases, emissions from municipal waste management and emissions produced by water consumption from urban networks.

The calculation tools of the OCCC have been developed based on the GHG Protocol and the latest version of ISO 14064. In this tool, emissions are categorized into 3 main groups (OCCC, 2019):

- Direct emissions (Scope 1): Emissions from fuel consumption, transportation and fugitive emissions.
- Energy indirect emissions (Scope 2): Emissions from electricity consumption, heat, steam or cooling.

[4]An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per mega gram of coal burned) (EPA, 2021)

- Other indirect emissions (Scope 3): Emissions from fossil fuel, electricity consumption, fugitive emissions, waste management and water consumption.

This guideline includes guidance to calculate emissions from different events (such as a workshop) and public entities (such as local councils or any other Public Administration) (OCCC, 2019).

### 1.3.6. European EN 16258 standard

In 2012, The European standard EN 16258 "Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services "was published by the German Institute for Standardization (Deutsches Institut für Normung, DIN) as DIN EN 16258 and by the British Standards Institution (BSI) as BS EN 16258 (Schmied and Knörr, 2012).

This guideline shows the total quantity of emissions in the form of what is known as $CO_2$ equivalents. The standard distinguishes between direct and indirect emissions. Direct emissions arise from the combustion of fuels from the company's own vehicles or from gas or heating oil in the company or are due to the release by the company itself of substances which impact on the environment (Scope 1). Indirect emissions are produced through the supply of electricity, district heating and process heat (Scope 2) and also from the services of subcontractors, from the buying and disposal of products, from the production of fuels or from business trips or journeys to work by staff (Scope 3) (Schmied and Knörr, 2012).

The calculation of energy consumption and emissions for a transport service must be carried out with standard EN 16258 in three steps (Schmied and Knörr, 2012):

- Step 1: Splitting the transport service into individual sections without changing mode of transport (legs) [5]
- Step 2: Calculating energy consumption and emissions per leg:
  - Specifying the Vehicle Operation System (VOS) for this leg (actual vehicle round-trip, routes or vehicle type or for total network; including empty trips)
  - Quantitative determination of total energy consumption for this Vehicle Operation System (e.g. diesel consumption in liters)
  - Conversion of the measured energy consumption into standardized energy consumption (MJ) and greenhouse gas emissions (kg $CO_2$ equivalents) for this Vehicle Operation System
  - Allocation of standardized energy consumption and greenhouse gas emissions to the transport service
- Step 3: Addition of the results of all legs of the transport service

### 1.3.7. Carbon Trust Guidelines

The Carbon Trust, a private company set up by the UK government, is an independent company with a mission to accelerate the move to a sustainable, low-carbon economy. Carbon Trust guidelines introduce two types of Carbon Footprinting that affect businesses: one that measures an organization's overall activities, and one that looks at the life cycle of a particular product or service. This guidelines helps organizations to calculate their carbon emissions, and work with them to develop a full carbon management strategy for their organization(Carbon Trust, 2017).

[5]Leg refers to the journey between two scheduled stops.

The Carbon Trust takes into account all six Kyoto GHG emissions and looks at different types of Carbon Footprint (Carbon Trust, 2017):

- Organizational footprint (scopes 1 and 2): An organizational Carbon Footprint measures the GHG emissions from all the activities across the organization, including energy used in buildings, industrial processes and company vehicles
- Supply chain footprint (scope 3): A supply chain Carbon Footprint measures the carbon impacts of the raw materials and services that are purchased by an organization in order to deliver its service (s) and/or product (s)
- Product Carbon Footprint: A product Carbon Footprint measures the GHG emissions over the whole life of a product (goods or services), from the extraction of raw materials and manufacturing right through to its use and final re-use, recycling or disposal

To enable organizations to calculate their Carbon Footprints, Carbon Trust developed two tools (Carbon Trust, 2017):

- Organizational footprinting/reporting software - Footprint Manager: A cloud-based reporting tool, enabling organizations to measure, manage and reduce its Carbon Footprint (Scope 1, 2 and business travel in Scope 3)
- Product footprinting software- Footprint Expert: A desktop-based software tool enabling organizations to produce fast and consistent Carbon Footprint measurements for products and services

### 1.3.8. U.S. EPA Guidelines

The U.S. EPA's (United State Environmental Protection Agency) Climate Protection Partnerships Division is committed to reducing GHGs through cost-effective partnerships to advance clean energy and energy efficiency across the U.S. economy. As part of this commitment, The EPA's Center for Corporate Climate Leadership was launched in 2012 (EPA, 2018).

The Center serves as a comprehensive resource to help organizations of all sizes measure and manage GHG emissions, providing technical tools, ground-tested guidance, educational resources, and opportunities for information sharing and peer exchange among organizations interested in reducing the environmental impacts associated with Climate Change. The U.S. EPA Center for Corporate Climate Leadership’s Greenhouse Gas guidance is based on The Greenhouse Gas Protocol.

The Center has developed specific GHG guidance meant to extend upon the GHG Protocol, to align more closely with EPA-specific GHG calculation methodologies and emission factors, and to support the Center’s GHG management tools and its Climate Leadership Awards initiative.

The following guidance documents which are published by EPA, describe methods that organizations may use to calculate and report GHG emissions from these sources (EPA, 2018):

- Direct Emissions from Stationary Combustion: This document is used to identify and estimate direct GHG emissions from stationary (non-transport) combustion of fossil fuels at a facility (e.g., boilers, turbines, process heat)
- Direct Emissions from Mobile Combustion Sources: This document is used to identify and estimate direct GHG emissions associated with fuel combustion in owned or operated mobile sources

- Indirect Emissions from Purchased Electricity: This document is used to identify and estimate indirect GHG emissions resulting from the purchase of electricity, steam, heat, or cooling.

As presented, there exist several initiatives related to Climate Change and Carbon Footprint and some of them published guidelines to assist organizations to calculate their $CO_2$ emissions.

As mentioned, ports are also contributing to Climate Change. Therefore, in the next section, the international organizations which are working on Climate Change and Carbon Footprint in the Maritime sector are introduced. In addition, three existing guidelines to calculate Carbon Footprint in the maritime sector are presented.

## 1.4. Climate Change and Carbon Footprint in the Maritime sector

While some GHGs occur naturally, there is agreement among climate scientists internationally that human activity has significantly increased the GHGs in the Earth's atmosphere, leading to accelerated global warming (IAPH, 2010). As mentioned previously, one of the human activities which has impact on Climate Change and could be affected by it, is shipping and activities in ports. Activities causing this warming include those that occur in and around a port, such as burning fossil fuels for operations, transportation, heating, and electricity consumption (IAPH, 2010). These emissions contribute to Climate Change and can have consequences in the marine sector, such as increases in air and water temperatures, reduction of the frost days, increases in the frequency and the intensity of heavy downpours, sea level rise and increases in water vapor content in the atmosphere (Karl et al., 2009). Therefore, besides general initiatives, several attempts have also been made in the maritime sector to control the effects of Clime Change.

In April 2008, the International Association of Ports and Harbors requested its Port Environment Committee, in consultation with regional Port Organizations, to provide a mechanism for assisting the ports in mitigating Climate Change. Through this request, a group of 55 ports from all over the world adopted the C40 World Ports Climate Declaration to work together to reduce the threat of global Climate Change. This group is now known as the World Ports Climate Initiative (WPCI). It was established to raise awareness in the port and maritime community concerning the need for action regarding GHG emissions.

As a part of the WPCI's mission to provide a platform for the exchange of information, its guidance document is intended to serve as an introduction to "Carbon Footprinting" and as a resource guide for ports wanting to develop or improve their GHG emissions inventories (WPCI, 2010). This guideline is presented in more detail in section 1.4.1. According to the World Ports Climate Initiative (WPCI, 2010), establishing a Carbon Footprint for ports will guide them to strategies that have the greatest reduction potential at their facilities in order to have a better understanding of the contribution of the existing port-related sources to Climate Change. A port should develop a comprehensive inventory of GHG emissions or a 'Carbon Footprint 'for both the port's directly controlled sources as well as sources controlled by port tenants. This guideline has also been used in developing our tool.

In 2008, IMO (International Maritime Organization) added a revised annex to the International Convention for the Prevention of Pollution from Ships (MARPOL)[6] of 1997. The regulations for the Prevention of Air Pollution from Ships (Annex VI) seek to minimize airborne emissions from ships ($SO_x$, $NO_x$, ODS (Ozone-depleting substances), VOC shipboard incineration) and their contribution to local and global air pollution

[6]The International Convention for the Prevention of Pollution from Ships (1973) was developed by the International Maritime Organization. The objective of this convention is to preserve the marine environment in an attempt to completely eliminate pollution by oil and other harmful substances and to minimize accidental spillage of such substances.

and environmental problems. Annex VI entered into force on 19 May 2005 and a revised Annex VI with significantly tightened emissions limits was adopted in October 2008 which entered into force on 1 July 2010 (IMO, 2019).

IMO's package for reducing shipping's $CO_2$ is another interesting initiative (IMO, 2014). In 2011, IMO adopted a suite of technical and operational measures which together provide an energy efficiency framework for ships. These mandatory measures entered into force as a 'package' on 1 January 2013, under Annex VI of the International Convention for the Prevention of Pollution from Ships (the MARPOL Convention).

PIANC[7] in 2014 published a guideline for Port Authorities. The purpose of this guideline was to create awareness about the advantages of implementing a green port philosophy and about what this philosophy means for ports around the world. This was done by supplying tools and guidance that show how proactive environmental measures can contribute to obtaining consent for future operations and developments, how opportunities can be created through own initiatives and how green growth can be realized. This guideline included seven key issues to deal with and one of them was Climate Change mitigation and adaptation. This guideline is not freely available (PIAN, 2014).

The Clean Cargo Working Group (CCWG) developed tools and methods to calculate the $CO_2$ footprint for a single shipment or a total transportation company. Transportation procurement managers use these tools as a factor in the supplier selection, and to quantify and drive improvements for this important category incorporate GHG reduction targets (CCWG, 2015).

Another initiative was the 72nd session of the Marine Environment Protection Committee (MEPC 72), held in April 2018 at IMO's headquarters in London. The outcome of this session was the adoption of the initial IMO strategy on reduction of GHG emissions from ships which includes: the objective to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008, whilst pursuing efforts towards decarbonizing the sector as soon as possible in this century. It was accompanied by a comprehensive list of possible emission reduction measures, including short-term measures (IMO, 2018). These IMO's decisions, created a need for finding ways to comply with this goal. In this direction, the European maritime community, gathered during the Green Ship Technology Conference in Copenhagen (March, 2019), proposed some solutions to reach this goal, such as the implementation of regulation, compliant fuels and expand or upgrade existing port infrastructure (BPO, 2019).

The World Ports Sustainability Program[8] (WPSP) aims to demonstrate global leadership of ports in contributing to the Sustainable Development Goals of the United Nations. It will initially implement the UN SDGs (The Sustainable Development Goals) along five themes. The second of them is related to Climate Change and energy: "Ports subscribe to the Paris Climate Goal which aims to keep global warming well below 2°C". Building on the output of the World Ports Climate Initiative, port community actors can collaborate in refining and developing tools to facilitate reduction of $CO_2$ emissions from shipping, port and landside operations. In addition, they can take initiatives to enable energy transition, improve air quality and

[7]The World Association for Waterborne Transport Infrastructure established in 1885. PIANC's mission is to provide expert guidance and technical advice by bringing together the best international experts, both public and private, on technical, economic and environmental issues pertaining to waterborne transport infrastructure.

[8]On 12 May 2017 the International Association of Ports and Harbors (IAPH) decided to set up a World Ports Sustainability Program, guided by the 17 UN SDGs (The Sustainable Development Goals). The program wants to enhance and coordinate future sustainability efforts of port community actors worldwide and foster international cooperation with partners in the supply chain, governments and societal stakeholders. The World Ports Sustainability Program builds on the World Ports Climate Initiative that IAPH started in 2008 and extends it to other areas of sustainable development.

stimulate circular economy (WPSP, 2018). Based on WPSP (2020),more than one third of the port projects in the WPSP Portfolio address the Climate and Energy areas of interest. GHG emission reduction from ships is the highest priority in this category. Initiatives include providing onshore power supply, incentivizing best-performing vessels, investing in infrastructure to supply low carbon fuels and port call optimization. This is in line with the international policy developments at the level of the International Maritime Organization and its Initial Strategy on GHG emission reduction, which aims at least halving emissions from international shipping by 2050, compared to 2008 levels. The second priority is improving energy efficiency of operations in the port area. This is being achieved through innovative processes and technologies addressing the production, demonstration and implementation of clean and renewable energy in ports. So far, few of the submitted projects address the issues around circular economy and the management of ecosystems for carbon capture and adaptation to climate change.

More recently, in 2019, PIANC's Working Group 188 on Carbon Management for Port and Navigation Infrastructure investigated the Carbon Footprint of activities related to development, maintenance and operation of navigation channels and port infrastructure including the management of dredged material. Life-cycle analysis (LCA) and other assessment methods supported this investigation and provided insights into opportunities for improved carbon management. This guideline is not freely available (PIANC, 2019 a).

The world's biggest ports, including the European ports of Rotterdam, Antwerp, Barcelona and Hamburg, launched the World Ports Climate Action Program (WPCAP). This program is a joint pledge to facilitate emissions reductions from the ports' supply chains and their larger geographical area. Under the WPCAP, ports have set up five working groups targeting specific action to accelerate the reduction of $CO_2$ emissions. These include: low-carbon maritime fuels, decarbonizing cargo handling facilities, power-to-ship solutions, increasing efficiency of supply chains using digital tools, and advancing common and ambitious policy approaches to reduce emissions within larger geographical areas (Greenport, 2019).

Another recent initiative is the Navigating a Changing Climate Partnership, whichis led by PIANC. This is a multi-stakeholder coalition of nine associations with interests in waterborne transport infrastructure. The Partners comprise of: The World Association for Waterborne Transport Infrastructure (PIANC), International Association of Ports and Harbors (IAPH), International Harbor Masters' Association (IHMA), International Maritime Pilots' Association (IMPA), Smart Freight Centre (SFC), European Dredging Association (EuDA), European Sea Ports Organisation (ESPO), Institute of Marine Engineering, Science & Technology (IMarEST) and Inland Waterways International (IWI).The partners have committed to work together to support the inland and maritime navigation infrastructure sector as they respond to Climate Change. By furthering understanding, providing targeted technical support, and building capacity, the partnership will encourage the owners, operators and users of waterborne transport infrastructure to reduce greenhouse gas emissions and shift to low carbon maritime and inland navigation infrastructure and act urgently to strengthen resilience and improve preparedness to adapt to the changing climate (PIANC, 2019 b).

Moreover, PIANC Working Group 178 prepared a technical guidance document to help the owners, operators and users of waterborne transport infrastructure to adapt to Climate Change (PIANC, 2020).

In February 2020, ESPO published its position paper on the European Green Deal (ESPO, 2020a). According to ESPO, European ports are trying to be the world's first net zero emission area by 2050.The greening of the shipping sector is a priority for European ports, a gradual approach should be developed to reduce emissions at berths with an initial focus on berths close to urban areas and a focus on particular segments such as cruise ships and ferries. By 2030, $CO_2$ emissions from ships at berth and in ports should be reduced by 50% on average and across all segments of shipping. In addition, onshore Power Supply (OPS) should be encouraged as an important part of the solution.

In october 2020, the IMO's seventh meeting of the Working Group on Reduction of GHG Emissions from Ships took place remotely. The working group agreed on new mandatory measures to cut the carbon intensity of ships, building on current mandatory energy efficiency requirements to further reduce greenhouse gas emissions from shipping (IMO, 2021).

Among these initiatives, the Marine Environment Protection Committee of IMO, WPCI and CCWG have published guidelinesto calculate $CO_2$ emissions in the maritime sector. In the next section these guidelines are introduced.

### 1.4.1. World Ports Climate Initiative (WPCI) Guidance Document

The World Ports Climate Initiative (WPCI) was established to raise awareness in the port and maritime community of the need for action regarding greenhouse gas emissions, to initiate studies, strategies and actions to reduce greenhouse gas emissions, to provide a platform for the maritime port sector for the exchange of information, and to make available information on the effects of Climate Change on the maritime port environment and measures for its mitigation (WPCI, 2010).

As a part of the WPCI's mission to provide a platform for the exchange of information, its guidance document is intended to serve as an introduction to “Carbon Footprinting” and as a resource guide for ports wanting to develop or improve their GHG emissions inventories. It has been developed in a collaborative process undertaken by several North American and European ports with a common interest in sharing knowledge and methods related to the planning and developing of Carbon Footprint inventories.

For the purpose of creating a plan, the port should select an appropriate base year to develop its current inventory. The GHG inventory should be categorized into three emission scopes, which are shown in Figure1.2 (WPCI, 2010):

**Scope 1:** Port Direct Sources. These sources are directly under the control and operation of the port administration entity and include port-owned fleet vehicles, port administration owned or leased vehicles, buildings (e.g., boilers, furnaces, etc.), port-owned and operated cargo handling equipment (to the extent the port is an operating one)[9], and any other emissions sources that are owned and operated by the port administrative authority.

**Scope 2**: Port Indirect Sources. These sources include port purchased electricity for port administration owned buildings and operations. Tenant power and energy purchases are not included in this Scope.

**Scope 3**: Other Indirect Sources. These sources are typically associated with tenant operations and include ships, trucks, cargo handling equipment, rail locomotives, harbor craft, tenant buildings, tenant purchased electricity, and the commuting of port and tenant employees (train, personal car, public transportation, etc.).

[9]A port which does not own the land or is given responsibility for managing the land on which the port is located

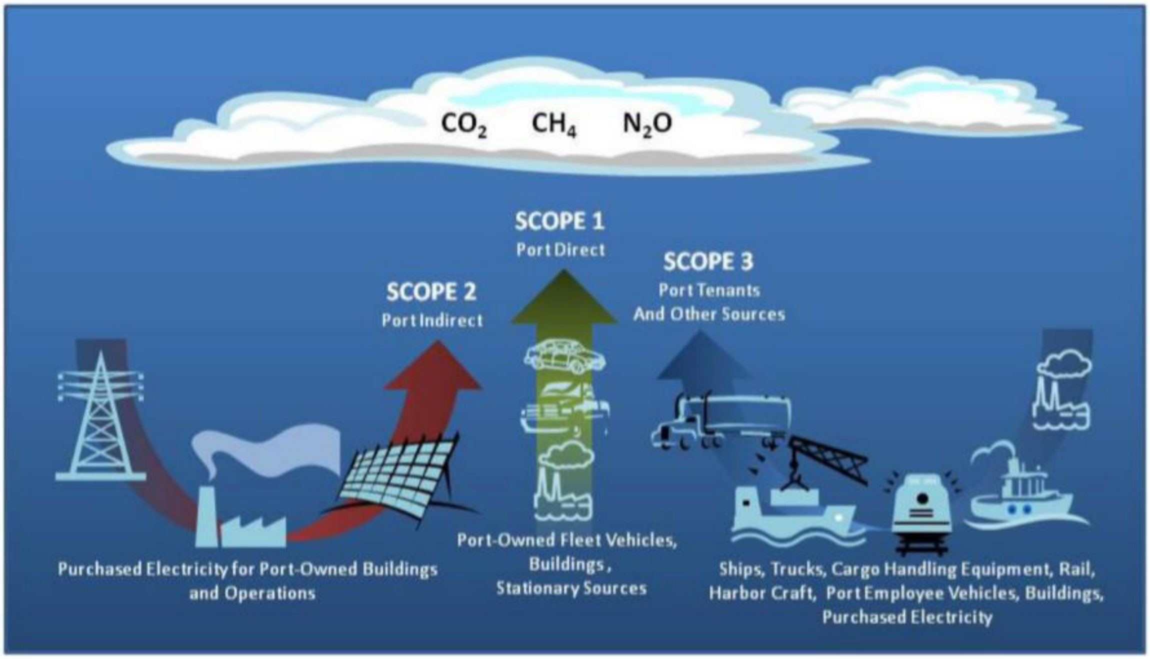


**Figure 1.2: Emission sources in ports (WPCI, 2010)**

### 1.4.2. Guidelines for voluntary use of the ship Energy Efficiency Operational Indicator

In July 2009, the Marine Environment Protection Committee of IMO, at its fifty-ninth session agreed to circulate the Guidelines for voluntary use of the Ship Energy Efficiency Operational Indicator (EEOI) (IMO, 2009).

These Guidelines can be used to establish a consistent approach for voluntary use of an EEOI, which will assist ship owners, ship operators and parties concerned in the evaluation of the performance of their fleet with regard to $CO_2$ emissions. As the amount of $CO_2$ emitted from a ship is directly related to the consumption of bunker fuel oil, the EEOI can also provide useful information on a ship's performance with regard to fuel efficiency. In order to establish the EEOI, the following main steps will generally be needed (IMO, 2009):

1. Define the period for which the EEOI is calculated
2. Define data sources for data collection
3. Collect data
4. Convert data to appropriate format
5. Calculate EEOI

### 1.4.3. Clean Cargo Working Group

Clean Cargo Working Group presents one common standard to collect and calculate $CO_2$ emission from ocean container transportation. This methodology is developed based on GHG Protocol supply chain guidelines, the European EN 16258 standard, and IMOs EEOI (Energy Efficiency Operational Indicator) guidelines (CCWG, 2015).

The current CCWG $CO_2$ methodology covers container transportation on oceangoing container ships. It is not applicable to non-containerized cargo transported in bulk, tank, Ro-Ro, and ferry vessels. This methodology only includes $CO_2$ emissions and no other GHG emissions (CCWG, 2015).

In this methodology, Emission Factors are calculated based on the IMO Carbon Conversion Factor (IMO, 2009) and fuel consumption.

When a shipper wants to calculate its company $CO_2$ footprint, it could use the $CO_2$ trade lane average emission factors. The method is straightforward (CCWG, 2015):

1) Map trade lanes
2) Identify the number of containers on each trade lane (conversion into TEU's)
3) Identify the distance travelled on each port pair per trade lane
4) Multiply the relevant trade lane average emission factors with the number of containers and the identified distance
5) Sum up the trade lane $CO_2$ emissions

After this theoretical research on maritime initiatives and guidelines related to Carbon Footprint, in the next section, the results of practical research are presented. This will help to have a better understanding of the situation of Carbon Footprint in ports.

## 1.5. Practical Research

The main incentive for developing a tool to calculate Carbon Footprint in ports is the result of Greenport Congress which was held in Valencia, the 17th and 18th October 2018. The data was obtained from the responses of different port actors that replied to 55 questionnaires during the Valencia Greenport Congress. Once the questionnaires were completed, the data were analyzed and conclusions were drawn by interpreting this information. A sample of the questionnaire can be found in Appendix 1.

### 1.5.1 Survey structure and participants

This survey is divided in four parts:

- First part: identification of the top environmental priorities in the participant ports
- Second part: questions on the relationship of the ports with climate issues
- Third part: questions on Carbon Footprint Management
- Fourth part: analysis of the scheme of Carbon Footprint

As it can be seen in Figure1.3, these questionnaires were distributed among participants from all over the world. Among European countries, most of the questionnaires were replied by Spanish participants (35%), which is normal since conference was held in Spain. After that, British, German and Finish participants were the ones with higher participation (9% each one). America was the second area with more representation (with countries from South America, North America and Canada). The African participants were Morocco, Ghana and Liberia. Just one participant from Asia (Malaysia) and Australia, respectively.

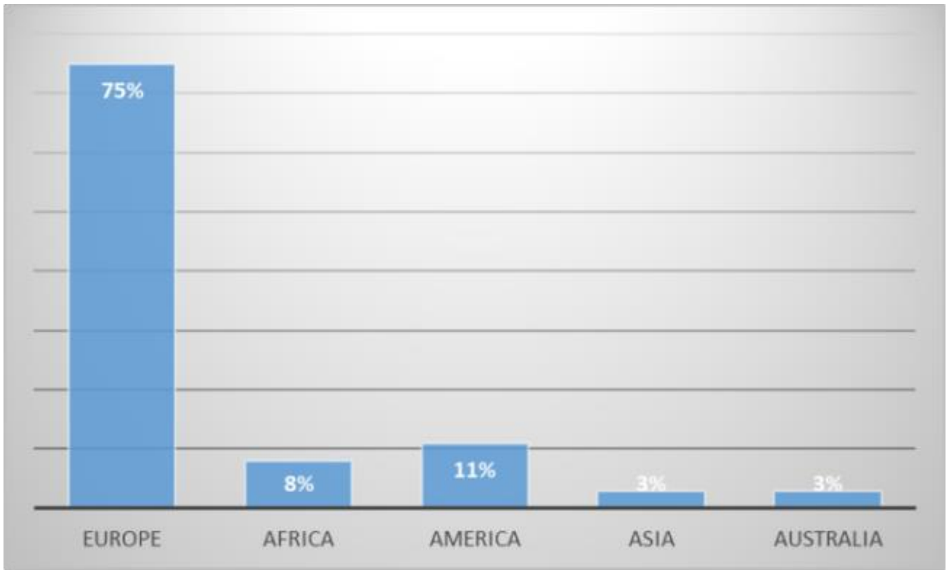


**Figure1.3: Participant Continents**

Figure1.4 illustrates that most of the participants were environmental managers (40%) followed by project managers (17.5%), port top managers and environmental experts (10%).

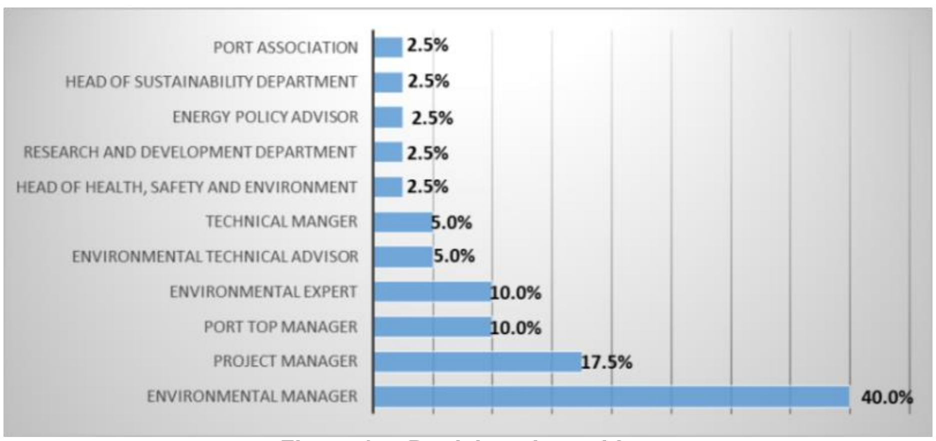


**Figure 1.4: Participant's position**

## 1.5.2. Results

As mentioned before the results of this survey are divided in four parts. In the next sections all these parts are analyzed and explained in detail.

- **Environmental aspects**

In this section the top Environmental priorities are presented, together with monitoring issues and the used of performance indicators. Table1.1 shows the Top 10 Environmental priorities identified in Valencia Greenport Congress 2018. As it can be seen, based on the responses, 'Energy consumption' is the most important environmental aspect which is directly associated with the cost of electricity and fossil fuels.

'Air quality' has been defined as the second environmental priority by Greenport Congress participants. This reflects the significance of this aspect due to its direct relation with the health of people working or living around ports (Puig, 2016). The third position belongs to 'Waste' followed by 'Noise'. Generally, engines of ships and machineries are the main source of unwanted noise in ports. 'Water quality' based on the result of Greenport Congress occupies the fifth position followed by 'Climate Change' which is in a relevant sixth position. The seventh position is for 'Dredging Operations'.

It is interesting to note that the 8th position belongs to 'Carbon Footprint' that is totally related with Climate Change. Therefore, the fact that these two aspects are present in the 10 top environmental issues shows the increasing attention that ports are paying to Climate Change. Also, equal to Carbon Footprint, 'Land planning' is in 8th position which is followed by 'Relationship with Local community' and 'Transport'.

**Table 1.1: Top 10Environmental priorities in Greenport Congress in Valencia in 2018**

| | Environmental priorities | Percentage (%) |
|---|---|---|
| 1 | Energy consumption | 80 |
| 2 | Air quality | 73 |
| 3 | Waste | 60 |
| 4 | Noise | 52 |
| 5 | Water quality | 42 |
| 6 | Climate Change | 23 |
| 7 | Dredging operations | 21 |
| 8 | Land planning | 13 |
| 8 | Carbon Footprint | 13 |
| 9 | Relationship with Local community | 11 |
| 10 | Transport | 11 |

The comparison of these results with ESPO survey 2018[10] (ESPO, 2018) shows that there are some similarities among the results of two surveys (Table1.2). Those priorities that are coloured are present in both surveys. Based on the results of Greenport Congress, 'Energy consumption' is the first whereas in ESPO survey it occupies the second position. However, 'Air quality' is the second issue for Greenport Congress and first for ESPO. Therefore,the two main priorities are the same but in different position.
'Noise' occupies a forth position in Greenport and a third position in ESPO. 'Water quality' is in fifth position in Greenport and in eight in ESPO. 'Climate Change' occupies a very similar position in both ranking 6th and 7th, respectively. The 'Relation with local community' occupies 9th position in Greenport whereas in ESPO is located in 4th position. In a whole, the top 10 issues for both surveys are quite coincident.

**Table 1.2: Top 10 Environmental priorities in Greenport Congress in Valencia and ESPO survey in 2018**

| | Greenport Congress survey | ESPO survey |
|---|---|---|
| 1 | Energy consumption | Air quality |
| 2 | Air quality | Energy consumption |
| 3 | Waste | Noise |
| 4 | Noise | Relationship with Local community |
| 5 | Water quality | Ship Waste |
| 6 | Climate Change | Land planning |
| 7 | Dredging operation | Climate Change |
| 8 | Land planning | Water quality |
| 8 | Carbon Footprint | |
| 9 | Relationship with Local community | Dredging operation |
| 10 | Transport | Garbage/port waste |

[10]The results of the conference are compared with the ESPO review 2018 and not with the ones of 2020, since it was found to be more realistic to compare the results for the same year of the conference.

Table 1.3 showsthe percentages of ports that monitordifferent  Environmental Aspects. Based on results of Greenport survey half of the ports monitor their ‘Energy consumption’, ‘Air quality’ and ‘Waste’. In the case of ‘Climate Change’, which is the main topic of this reseach, only 13% of ports monitor it.

**Table 1.3: The percentages of ports that monitor different Environmental Aspects**

| Issue | Percentage (%) |
|---|---|
| Energy consumption | 54 |
| Air quality | 52 |
| Waste | 49 |
| Noise | 38 |
| Water quality | 32 |
| Climate Change | 13 |
| Dredging operation | 14 |
| Land planning | 4 |
| Carbon Footprint | 7 |
| Relationship with Local community | 2 |

Table 1.4 shows the percentage of monitoring issues that have associated Environmental Performance Indicators.As it can be seen, half of the ports in the case of ‘Energy consumption’ are using Environmental Performance Indicators to monitor it. For the case of ‘Air quality’, ‘Waste’ and ‘Noise’ around 30% of the ports are also using performance indicators to control them. In the case of ‘Climate Change’ only 13% of ports have performance indicators to measure this aspect.

**Table 1.4: The percentage of monitoring issues that have associated Environmental Performance Indicators in ports**

| Issue | Percentage | Issue | Percentage |
|---|---|---|---|
| Energy consumption | 49 | Climate Change | 13 |
| Air quality | 38 | Dredging operation | 11 |
| Waste | 34 | Land planning | 4 |
| Noise | 27 | Carbon Footprint | 4 |
| Water quality | 20 | Local community | 0 |

### - Climate Change

This part investigates the awareness of port organizations about Climate Change and their efforts to control it. As it can be seen in Figure 1.5, 81% of ports organizations believe that Climate Change has impacts on their organizations such as the sea level rise. This shows that they are aware of the importance of this issue.

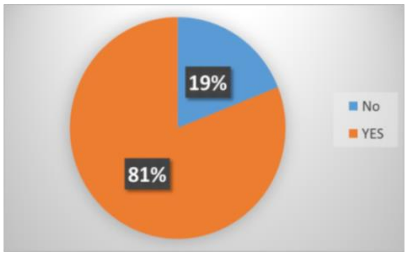


**Figure 1.5: Awareness of the impact of Climate Change on ports**

Concerning the existence of a Climate Change Risk Assessment plan, 57% of the participants have one plan to face this situation (Figure 1.6). A climate risk assessment should be part of a port broader risk management process. It identifies the risk of existing and future climate hazards with the aim of providing data that enable to make decisions about how and when to deal with these hazards (Scott et al., 2013)

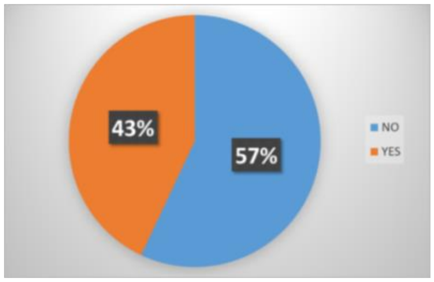


**Figure 1.6: Existence of a prepared Climate Change risk assessment plan**

The results in Figure 1.7 illustrate that 81%of organizations collaborate with other third-party organizations on the issue of Climate Change. This shows that ports are already taking in to account the port community and other stakeholders to face the Climate Change.

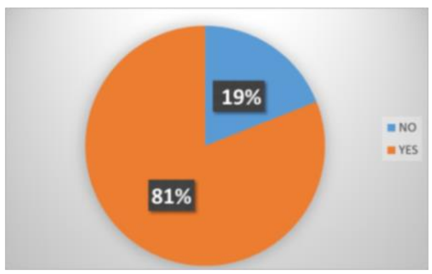


**Figure 1.7: Collaboration with other third-party organizations on the issue of Climate Change**

One of the main problems that ports encounter to deal with Climate Change is collecting data and having sufficient information. Based on results of this research, only 47% of organizations are collecting data on Climate Change (Figure 1.8).

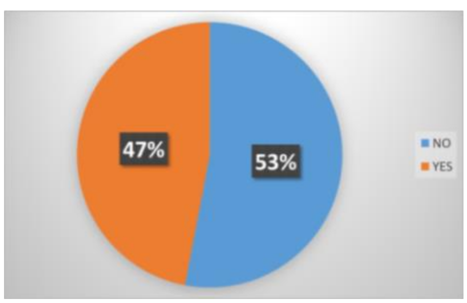


**Figure 1.8: Collection of data/information on Climate Change**

As it can be seen in Figure 1.9 only 24% of organizations are aware of the future released of PIANC working group 178 guidelines that will help port operators to face Climate Change.

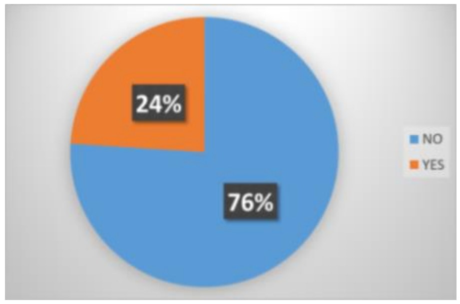


**Figure 1.9: Awareness of the future release of PIANC working group 178 guidelines/tool kit**

### - Carbon Footprint management

In this part, different aspects are commented such as the reporting on Carbon Footprint, main drivers to implement carbon management, key stakeholders for development of carbon management program and the major challenges and problems for developing and implementing a carbon management program.

The results in Figure 1.10 show that 62% of the organizations report their carbon emissions. However, the method used has not been specified.

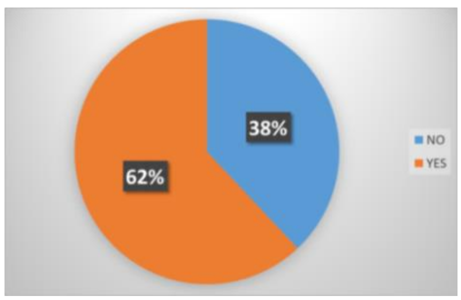


**Figure 1.10: Reporting on carbon emissions**

Table 1.5 presents five main drivers to implement carbon management which categorize in five priorities. The first driver is the 'Leadership role'; this means that the main reason for ports to manage carbon is being the leadership in these types of practices. After that 'Compliance with emerging regulations' is the driver with more impact which is quite reasonable since legislation is a must. The next driver is 'Potential to influence practice and regulation through innovation and investment'. Ports believe that being pioneers in this topic they can influence in future legal requirements. 'Opportunity to reduce and offset emissions from infrastructure development' together with 'Stakeholder pressure to reduce environmental impacts, are the last two drivers to implement carbon management.

**Table 1.5: The main drivers to implement Carbon Management**

| Drivers | Priority | Total points |
|---|---|---|
| **Leadership** role in Carbon management practices | 1 | 174 |
| **Compliance** with emerging regulations | 2 | 162 |
| Potential to **influence** practice and regulation through innovation and investment | 3 | 159 |
| Opportunity to reduce and **offset** emissions from infrastructure development | 4 | 135 |
| **Stakeholder** pressure to reduce environmental impacts | 5 | 134 |

Table 1.6 shows the key stakeholders for the development of a carbon management program in a port. Based on the results of the survey, 'Port operators' and 'ship owners' are those which have an important role for the

development of carbon management program. Outside the port the ‘Government’ is the main driver to implement carbon management plans. ‘Municipality’ and ‘Port authorities’ equally occupy the fifth position. Surprisingly, the ‘Environmental department’ which seems to have the most important role for development of carbon management program is in the sixth position and the last place belongs to ‘Customers’.

**Table 1.6: The key stakeholders for the development of carbon management program in a port**

| The key stakeholders | | Number | Percentage (%) |
|---|---|---|---|
| 1 | Port Operators | 18 | 25% |
| 2 | Ship Owners | 10 | 15% |
| 3 | Government | 7 | 9% |
| 4 | Senior manager | 6 | 8% |
| 5 | Municipality | 5 | 6% |
| 5 | Port Authorities | 5 | 6% |
| 6 | Environmental department | 4 | 4% |
| 7 | Customers | 3 | 3% |
| 8 | Other | 17 | 24% |

The major challenges and problems for developing and implementing a carbon management program are illustrated in Table1.7. The most important challenge is ‘Data collection’, gathering accurate data for calculating Carbon Footprint and GHG is a critical issue. This is linked directly with the second problem, ‘measuring and calculating data’. The third position belongs to two aspects: ‘Coordination among stakeholders’ and ‘Legislation’, with an equal percentage. These are two very important topics within a port. ‘External costs’, ‘Limited carbon management program to local footprint’ and ‘Setting boundaries for measuring shipping emission’, occupy the forth position with equal importance. Therefore, solving these problems could help port organizations to work on a climate issue in more suitable way.

**Table 1.7: The major challenges and problems of developing and implementing a carbon management program**

| | Major challenges and problems | Number | Percentage (%) |
|---|---|---|---|
| 1 | Data collection | 18 | 26% |
| 2 | Measuring and calculation Data | 14 | 20% |
| 3 | Coordination among stakeholders | 7 | 10% |
| 3 | Legislation | 7 | 10% |
| 4 | External costs | 6 | 9% |
| 4 | Limited to local footprint | 6 | 9% |
| 4 | Set boundaries for measuring shipping emission | 6 | 9% |
| 5 | Others | 5 | 7% |

### - Carbon Footprint Scheme

The European Union and its Member States have a strong preference for a global approach on the issue of Carbon Footprint. In addition, this is supported by the International Maritime Organization (IMO) in order to make it more effective. Considerable efforts to agree in such an approach have been made over recent years within both the IMO and the United Nations Framework Convention on Climate Change (UNFCCC).

In order to understand the number of ports that are aware about their role in greenhouse gas emission control and the importance of it, this survey has introduced a question on this. As it can be seen in Figure 1.11, almost 94% of organizations are aware about their role in reducing GHG. In addition, based on the results of this survey (Figure1.12), 86% of respondent ports consider that GHG emissions from shipping generated in port area should be included as third-party emission in the Carbon Footprint of the port.

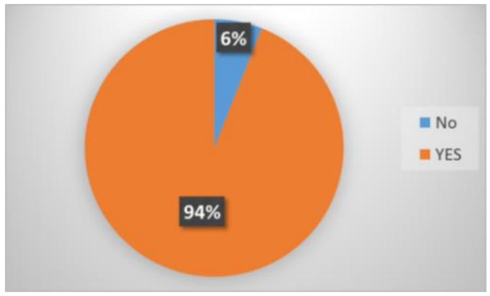


**Figure 1.11: Ports have a role in reducing Greenhouse Gas Emissions from shipping**

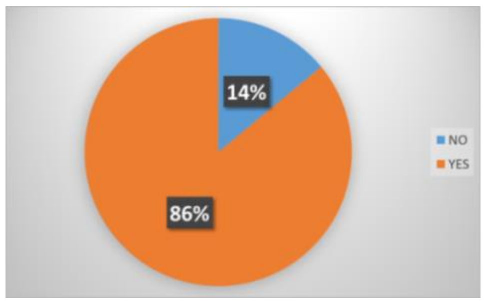


**Figure 1.12: Inclusion GHG emission from shipping generated in port as third-party emission in Carbon Footprint of the port**

Figure1.13 illustrates that 89% of the ports consider that a common port-sector Carbon Footprint scheme would benefit individual port authorities and the port-sector as a whole. Nowadays, there exist different systems and each port is using its own. Therefore, comparisons between the different values obtained are complicated.

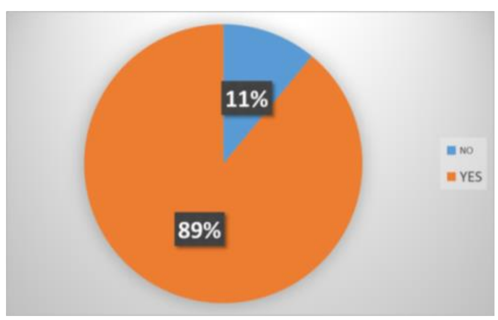


**Figure 1.13: Need of a common Port-sector Carbon Footprint scheme**

### 1.5.3. Conclusions

Climate Change has gained importance in maritime industry in recent years. Based on results of this practical research, this topic occupies the sixth position among top 10 environmental priorities in ports, and it is getting more importance day by day.

Based on the results of Greenport Congress, Energy Consumption is the first priority for participant ports whereas in ESPO survey 2018 occupies the second position. As one of the consequences of energy consumption is $CO_2$ and GHG gases emissions, this issue takes into consideration Climate Change, which occupies a very similar position in Greenport and ESPO survey ranking 6th and 7th, respectively. Therefore, controlling energy consumption indirectly could reduce $CO_2$ emission and GHG gases. Carbon Footprint is also in the top 10 priorities. This reflects the importance of these two issues in the whole environmental priorities.

The results of this survey show that most of the port organizations believe that Climate Change has an impact on their organizations. Also it proves that most of them are aware of the importance of this matter but few of them monitor Climate Change and have associated Environmental performance indicators to control it. Therefore, it is necessary that ports actively make more efforts in the field of monitoring of Climate Change issues.

Half of the organizations have prepared a Climate Risk Assessment plan and most of them have collaboration with other third-party organizations on the issue of Climate Change. However, half of the ports are collecting data on Climate Change, and also, more than a half of the participants report their carbon emissions. The problem is the way they do so and how each institution is using its own method.

Data collection, measuring and calculating data and Coordination among stakeholders are the most important challenges in implementing a carbon management program. Based on results of this research, only 47% of organizations are collecting data on Climate Change.

In the case of the role of ports in reducing Greenhouse Gas Emissions, results show that most of the participants are aware about their role in reducing GHG. Most of the respondents consider that GHG emissions from shipping generated in the port area should be included as third-party emission in the Carbon Footprint of the port. In addition, most of them consider that a common, port-sector Carbon Footprint scheme would benefit individual port authorities and the port-sector as a whole.

As a result of this practical research, a scientific paper has been published in Sustainability journal (Azarkamand et al., 2020a) and it can be found in appendix 7.1.

## 1.6. Research motivation

The results of Greenport Congress which were presented in the previous section prove the need for developing a standardized tool to calculate $CO_2$ emissions in ports. As recognized by ports, a common port-sector Carbon Footprint scheme would benefit individual port authorities and the port-sector as a whole. This same idea was highlighted by an article from Laboratorio de Ingeniería Sostenible (2004), which mentioned the need of a standardized single calculation methodology properly developed and which facilitates the calculation, comparison and coordinated planning of projects to reduce and mitigate emissions.

Therefore, although as it has been presented there are several international guidelines to calculate Carbon Footprint, there is no single, unified method to calculate it in ports. This is the main incentive for the development of this thesis.

As a consequence, a practicable, user-friendly and easy to use tool with a standardized method for the calculation of Carbon Footprint in ports will be developed

## 1.7. Objectives

An important goal to tackle environmental problems and foster sustainable development in the near future is to reduce the generation of GHG emissions from different industrial sectors. The International Council on Clean Transportation (ICCT) predicted that greenhouse gas emissions from shipping activities will triple by 2050 (Olmer et al., 2017). Therefore, calculating and controlling GHG emissions in ports is getting more importance every day. As mentioned before, in recent years many ports started to calculate their Carbon Footprint and report it. The problem is that there is not any common method to calculate it and allow comparing Carbon Footprint results among different ports.

Therefore, the main aim of this thesis is to develop a standardized tool specifically designed so that port authorities can calculate their Carbon Footprint and report it accordingly. This general objective can be divided into the following specific objectives:

- Research on Climate Change and Carbon Footprint in general and for the maritime sector
- Research on International guidelines to calculate Carbon Footprinting general and for the maritime sector
- Conduct a practical research on ports (Greenport Congress2018)
- Identify and compare Carbon Footprint calculation methodologies in different ports, port terminals and ships
- Develop a standardized tool to calculate $CO_2$ emissions in ports
- Develop a step by step user guidelines and video with instructions to use the tool
- Improve the tool through the feedback obtained from different reviewers
- Select pilot ports to validate the tool
- Create a case study model to test all the functionalities of the tool
- Validate the tool with the pilot ports and the case study model
- Improve the tool if necessary

## 1.8. Structure of the thesis

This thesis includes six chapters which are:

1. Introduction: This chapter includes the research on the concept of Climate Change and Carbon Footprint in general and in the maritime sector. The research on guidelines to calculate Carbon Footprinting general and for the maritime sector and the results of Practical Research are also presented. In addition, the research motivation and objectives are described in this chapter.
2. Research on existing methodologies: This part of the thesis includes the research on existing methodologies to calculate Carbon Footprint in ports, port terminals and ships. In addition, in this section, the weaknesses and strengths of these methodologies are identified, which will serve as a basis to develop the new tool.
3. Development of the tool: in this chapter, the scopes and boundaries are defined. The emission sources and pollutants are recognized and a suitable calculation method for each emission source is selected. The creation of a tool to calculate $CO_2$ emissions in ports is described. The guidelines are developed and are presented in this part.
4. Test and Improvement of the tool: in this chapter a revision of the tool is done through the feedback obtained via reviews from port professionals and environmental experts.

5. Case studies: in this chapter, the new tool is being validated with public data from the Port of Oslo (Norway) and Ports de la Generalitat (Catalonia, Spain). The results allow for comparing the published results of these ports with the results of the new tool. In addition, in order to test all scopes and sources of the tool, a case study model has been created. The emissions of this port are then calculated using the new tool, the OCCC tool and the MITECO tool.
6. Conclusions: this chapter includes the main findings and conclusions of the thesis.

# Chapter 2: Research on existing methodologies

This chapter constitutes the basis for the creation of a new tool to calculate $CO_2$ emissions in ports. In the next section, methodologies to calculate Carbon Footprint in ports, port terminals and ships are studied and analyzed. Ships are included since their emissions are contributing to the total port area Carbon Footprint. More than 20 different methodologies used by 15 ports, 3 port terminals and 4 ships were taken into account.

After having reviewed all these methodologies, a set of conclusions about their main strengths and opportunities for further enhancement are extracted.

## 2.1. Ports

As mentioned before, in recent years many ports have started to calculate their Carbon Footprint and report it. In this section the existing methodologies used in different ports are studied to have a better understanding of them.

### 2.1.1. The port of Gijón

Gijón Port Authority (Spain) has been the pioneer in the use of the Carbon Footprint indicator within the Spanish port system. This port detected all the direct and indirect emission sources and calculated its Carbon Footprint in 2002 (Laboratorio de Ingeniería sostenible, 2004). Details on this methodology were not provided in the mentioned reference. Later on, in the period from 2004 to 2008, in another study from Carballo-Penela, the Carbon Footprint was calculated again in this port (Carballo-Penela et al, 2012) and the results were then published.

Gijon´s port Corporate Carbon Footprint (CCF) was calculated by using the Compound Method based on a Financial Accounts (MC3) method. CCFis not limited to direct or on-site effects, as it takes into account the emissions along the whole chain of suppliers of the goods and services (Carballo-Penela et al., 2012).

- **Boundaries**

This method was applied to the port and all its services. The MC3 calculates the footprint for all goods and services included in the inventory. Additionally, waste derived from the acquisition of such goods and services, and the occupied spaces by the company are included in the inventory.

### - Scopes

The GHG Protocol Corporate Standard (WRI and WBSCD, 2004) was used for scoping CCF calculation in the port of Gijon. Based on this standard Gijón Port defined three scopes for its Carbon Footprint calculation (Carballo-Penela et al., 2012):

- Scope 1: Fuels consumption- Direct emission
- Scope 2: Electricity consumption- Indirect emission
- Scope 3: Other indirect emissions (Materials, Building Materials, Services and Contract services, Waste, Agricultural sources, Forest resources and Water)

### - Methodology

MC3 is one of the most practical methodologies to assess the amount of direct and indirect greenhouse gas emissions for the three scopes. A guideline for assessing the Carbon Footprint is included in this methodology. In addition, the MC3 was built under the premise of being fully consistent with ISO standards (Alvarez, 2014).

This method was published by the Spanish Association for Standardization and Certification (AENOR) and it was improved through the cooperation with five Spanish universities, and approved as a valid approach for assessing Carbon Footprint within the framework of the Spanish Voluntary GHG Reduction Agreement (Alvarez, 2014).

The necessary information to determine the CCF though the MC3 is mainly obtained from accounting documents such as the balance sheet and the profit and loss accounts, in this way all activities linked to each organization are perfectly defined.

Obtaining CCF using the MC3 methodology is done through the use of the calculation sheet. This works as a consumption land use matrix (CLUM), which applies the consumption of goods and services needed by companies. Figure 2.1 shows the sample of the CLUM matrix. The rows of the CLUM matrix show the footprints for each category of good/service consumed. Columns include several other elements such as annual consumption and relevant categories of productive space according to the Ecological Footprint analysis.

**Figure 2.1: Structure of the spreadsheet showing the CCF CLUM matrix (Carballo-Penela et al., 2012)**

| PRODUCT CATEGORY | ANNUAL CONSUMPTION | | | | | PRODUCTIVITY | | FOOTPRINT BY PRODUCTIVE SPACE (t $CO_2$ or Gha) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Consumption units [unit/year] | Euros,$... without VAT [Euro/year] | Tones [t/year] | Energy intensity [Gj/t] | Gj [Gj/year] | Natural [t/ha/year] | Energy [Gj/ha/year] Or Emission Factor [T/Gj $CO_2$] | $CO_2$ absorption land | Cropland land | Pastures | Forests | Built-up land | Fisheries ground | TOTAL CEF | COUNTER FOOTPRINT |
| 1. ENERGY | | | | | | | | | | | | | | | |
| 1.1 Electricity | | | | | | | | | | | | | | | |
| 1.2 Fuels | | | | | | | | | | | | | | | |
| 2. MATERIALS | | | | | | | | | | | | | | | |
| 2.1 Depreciable materials | | | | | | | | | | | | | | | |
| 2.2 Not depreciable materials | | | | | | | | | | | | | | | |
| 2.3 Construction materials | | | | | | | | | | | | | | | |
| 3. SERVICES | | | | | | | | | | | | | | | |
| 4. WASTES | | | | | | | | | | | | | | | |
| 5. LAND USES | | | | | | | | | | | | | | | |
| 6. AGRICULTURAL AND FISHING RESOURCES | | | | | | | | | | | | | | | |
| 7. FOREST RESOURCES | | | | | | | | | | | | | | | |
| 8. WATER | | | | | | | | | | | | | | | |

t: tonnes; VAT (value added tax)

Figure 2.2 presents the outline for the calculation of the CCF applying MC3. Consumptions units are multiplied by the energy intensity (the used amount of energy in GJ/t) to obtain the total energy used to produce each product category, considering a standard life cycle. Once the total energy is obtained, this is divided by the energy productivity[11] to get the ecological footprint of the company. Finally, Carbon Footprint is obtained after multiplying the ecological footprint by an absorption rate per hectare/year (5.21t $CO_2$/ha/year).

The calculation includes not only the $CO_2$ emissions generated by the company premises or by its means of production (e.g. those derived from solid-fuel consumption) but also emissions generated by the energy used in the production of goods and services acquired by the company, independently of whether or not they are used in the production process. The production of a certain good is transformed into $CO_2$ emissions by applying the emission factors (t $CO_2$/Gj) from the Intergovernmental Panel on Climate Change (Carballo-penela et al., 2012).

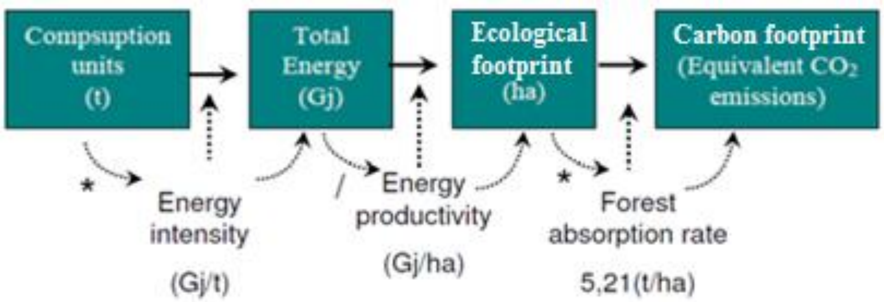


**Figure 2.2: Calculation of CCF applying MC3 (Carballo-penela et al., 2012)**

The data for calculating CCF in this port were obtained from accountability documents such as the trial balance[12], the tangible fixed assets[13] and the general ledger[14]. Other data such as electricity, fuel, water, and paper consumption were obtained from those responsible persons for these services (Carballo-penela et al., 2012).

- **Results**

The main results by good/service category and scope (in tonnes of $CO_2$ emitted) are presented in Table 2.1. According to this Table, two different patterns in the evolution of net CCF for Gijon's Port are identified. In the first place from 2005 to 2007 there is a decrease of around 7.5% by net CCF, whereas in 2008 this trend was disrupted presenting an increase of 8.6% compared to 2007.

Regarding Fuel consumption (Scope 1), the emissions from 2004 to 2006 increased, whereas from 2006 to 2008 they decreased. Concerning Electricity consumption (Scope2), from 2004 to 2008 the emissions decreased. In the case of other indirect emissions (Scope 3) almost all of them show a decreasing trend except Building materials and Services and Contract services.

[11]Energy productivity shows how many tonnes of each fuel were needed to generate the $CO_2$ volume. These can be absorbed per hectare on an annual basis by applying an absorption rate per hectare/year.
[12]A trial balance is a book keeping or accounting report that lists the balances in each of an organization's general ledger accounts.
[13]The tangible fixed assets generally refer to assets that have a physical value. Some of these assets such as computer equipment will incur depreciation, which needs to be factored into the accounts.
[14]A general ledger account is an account or record used to sort, store and summarize a company's transactions.

Focusing on 2008 results, the major contribution to CCF corresponds to the building materials (70.2% of the total) followed by electricity (scope 2), 11.7%. Scope 1 just present 1.7% of the total of emissions (Carballo-Penela et al., 2012).

For the case of Gijón's port, indirect emissions from scope 2 (electricity), and other indirect emissions of scope 3 (materials, building materials, services, wastes, agricultural resources and forest resources, and water), reached 31,910 $tCO_2$ in 2008 (98.3% of the Carbon Footprint; in particular, 86.3% of the emissions are due to scope 3). As it can be seen in Figure 2.3, Scopes 1 (1.7%) and Scope 2 (11.7%) represent only an average of 13.43% of the Carbon Footprint for 2008. Taking into consideration these results, efforts should be made to reduce indirect emissions (scope 3), which are the highest ones. In other words, carbon neutrality requires measures beyond scopes 1 and 2, so measurement of scope 3 is vital (Carballo-Penela et al., 2012).

**Table 2.1: CCF broken down by categories and scopes ($tCO_2$/year) (Carballo-Penela et al., 2012)**

| Scopes | 2004 | | 2005 | | 2006 | | 2007 | | 2008 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Amount | (%) | Amount | (%) | Amount | (%) | Amount | (%) | Amount | (%) |
| Fuel (Scope1) | 676 | 2.2 | 705 | 2.2 | 839 | 2.8 | 578 | 1.9 | 550 | 1.7 |
| Electricity (Scope 2) | 5,040 | 16.5 | 3,909 | 12.2 | 3,893 | 12.9 | 3,815 | 12.8 | 3,801 | 11.7 |
| Other indirect emissions (Scope3) | | | | | | | | | | |
| Materials | 4,036 | 13.2 | 3,916 | 12.2 | 3,795 | 12.5 | 3,728 | 12.5 | 3.756 | 11.6 |
| Building Materials | 16,281 | 53.4 | 19,000 | 59,1 | 19,113 | 63.2 | 19,411 | 64.9 | 22,772 | 70.2 |
| Services and Contract services | 786 | 2.6 | 1,447 | 4.5 | 1,197 | 4.0 | 1,247 | 4.2 | 863 | 2.7 |
| Waste | 1.143 | 3.7 | 1,250 | 3.9 | 10 | 0 | 59 | 0.2 | 27 | 0.1 |
| Agricultural sources | 410 | 1.3 | 521 | 1.6 | 449 | 1.5 | 490 | 1.6 | 159 | 0.5 |
| Forest resources and Water | 2,113 | 6.9 | 1,401 | 4.4 | 950 | 3.1 | 569 | 1.9 | 532 | 1.6 |
| **Gross CCF** | **30,485** | | **32,148** | | **30,245** | | **29,896** | | **32,460** | |
| **Counter Footprint**[15] | **59** | | **51** | | **51** | | **51** | | **52** | |
| **Net CCF** | **30,426** | | **32,097** | | **30,194** | | **29,845** | | **32,408** | |

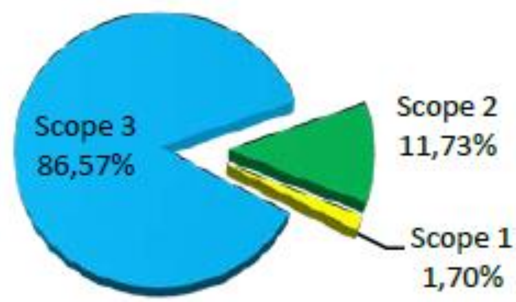


**Figure 2.3: Total $CO_2$ emissions in percentage by scope in 2008 (Carballo-penela et al., 2012)**

- **Strengths and weaknesses**

One of the strengths of this method is that it is a complete method, which collects the footprint from the consumption of all goods and services and wastes generated by a company, including direct and indirect emissions. Also, it is a flexible method. The calculation sheet allows the possibility of adding or modifying the factors used, by adapting to the characteristics of different types of companies. In addition, the method was built under the premise of being fully consistent with ISO standards.

[15]The concept of counter footprint is based on the fact that even though it is desirable for companies and organizations to reduce their footprint by becoming more efficient and reducing their consumption, it is also positive for companies to invest in natural capital. Thus, natural capital investments reduce their footprint. In such a way, the index encourages the private sector to preserve natural areas, which is positive in terms of sustainability.

Another strength is that the MC3 approach has been recognized by the Spanish Observatory for Sustainability as a valid methodology for assessing and reducing GHG emissions arising from companies under the frame of the Spanish GHG Voluntary Reduction Agreement (Carballo-Penela et al., 2012).

Regarding the weaknesses of this method, only $CO_2$ emissions are calculated and other GHGs are not taken into account. In addition, regarding fuel consumption (direct emissions), the types of sources are not specified such as different stationary sources and mobile sources. As an another weakness, the emissions from the employees' commuting and vessels (scope 3) are not taken into account.

### 2.1.2. Ports of Long Beach and Los Angeles

Since 2005, the ports of Long Beach and Los Angeles (San Pedro Bay Ports- SPBP, United States of America) have developed an annual Air Emissions Inventory (EI) report. In November 2006, the Ports took a joint action to improve air quality in the South Coast Air Basin by adopting the CAAP (Clean Air Action Plan), a plan aimed at significantly reducing the health risks posed by air pollution from port-related mobile sources, specifically ships, trains, trucks, terminal equipment and harbor craft, such as tugboats. In 2017, the San Pedro Bay Ports updated the CAAP targets for reductions in GHG emissions from port-related mobile sources (Ports of Long Beach and Los Angeles, 2016):

- Reducing GHGs to 1990 levels by 2020
- Reducing GHGs to 40% below 1990 levels by 2030
- Reducing GHGs to 80% below 1990 levels by 2050

- **Boundaries**

The geographical boundary of the emissions includes the harbor district. For commercial marine vessels and harbor crafts, the domain lies within the harbor and up to overwater area bounded in the north by the southern Ventura County line at the coast, and in the south with the southern Orange county line at the coast.

For rail locomotives and on-road trucks, the domain extends from the Port to the cargo's first point of rest[16] within the South Coast Air Basin (SoCAB) or up to the SoCAB boundary, whichever comes first. The geographical boundaries for cargo handling equipment are the terminals and facilities in which they operate (Starcrest Consulting Group, 2019b)

The baseline year of the inventories is 1990. The Ports GHG annual emissions inventories began in 2005 therefore, the Ports do not know their GHG emissions from 1990. Thus, the Ports developed a methodology to estimate their 1990 GHG baseline emissions levels (Starcrest Consulting Group, 2019a).

- **Scopes**

The scopes are not defined.

- **Methodology**

The California Air Resources Board (CARB) is the only agency within California that estimated GHG emissions in 1990 for all energy sectors. However, CARB developed their GHG estimates only at state level, and more detailed allocations of GHG emissions at regional, county, or air district levels are not available.

[16]First point of rest (FPR) is the first official stop after the Carrier unloads the goods and hands over the custody/responsibility of the goods to the consignee (Association of European Vehicle Logistics, 2011).

Therefore, the ports have developed a methodology for establishing the ports' baseline emission levels from available and credible sources of historical information.

The information sources include the ports own emissions inventories, developed annually for the calendar years 2005 and 2017, and state-wide mobile emission source GHG estimates developed and published by CARB (Starcrest Consulting Group, 2019a)

The methodology report contains five source categories:

- Ocean-going vessel (OGV)
- Harbor craft
- Cargo handling equipment (CHE)
- Locomotive
- Heavy-duty vehicle (HDV)

The reports also include estimates of carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) emitted from maritime industry-related tenant operational mobile sources. Only $CO_2$eq values are presented in the reports because they include all three GHGs in an equivalent measure to $CO_2$. The GHG emissions are presented in metric tonnes (Starcrest Consulting Group, 2019b)

In the next subsection the emissions from different sources which were mentioned above are described in more detail (Starcrest Consulting Group, 2019b):

❖ **Emission estimation for OGVs**

Emissions are estimated from the following sources on board OGVs (Starcrest counsulting group, 2019b):

- Propulsion systems or propulsion engines that move the ship through water.
- Auxiliary power systems or auxiliary engines (diesel generators) that provide electricity during ship operations.
- Auxiliary boilers that produce hot water and steam for use in the engine room and for crew amenities

Incinerators are not included in the emission estimates because incinerators are not used within the study area. Interviews with the vessel operators and marine industry indicate that vessels do not use their incinerators while at berth or near coastal waters.

Vessel activity data and the methods of estimating emissions are discussed below for propulsion engines, auxiliary engines and boilers. Equations 2.1 and 2.2 report the basic equations used in estimating emissions by mode (Starcrest counsulting group, 2019).

$$\boldsymbol{Ei} = \boldsymbol{Energyi} \times \boldsymbol{EF} \times \boldsymbol{FCF} \times \boldsymbol{CF} \qquad \text{(Equation 2.1)}$$

Where:

Ei= Emissions by mode

$Energy_i$ = Energy demand by mode calculated using Equation 2.2 below as the energy output of the engine(s) or boiler(s) over the period of time (kWh)

EF = Emission Factor depends on engine type and fuel used (g/kWh)

FCF = Fuel Correction Factors are used to adjust from a base fuel associated with the EF and the real fuel being used (dimensionless)

CF = Control factor(s) for emission reduction technologies (dimensionless)

To calculate the Energy demand by mode ($Energy_i$), the following equation is used:

$$Energy_i = Load_i \times Activity_i$$ (Equation 2.2)

Where:

$Energy_i$= Energy demand by mode (kWh)
$Load_i$ = It is the multiplication of Maximum Continuous Rated (MCR)* propulsion engine power (kilowatts) by the load factor (kW) calculated through Equation 2.3.This Load can be calculated for auxiliary engine(s) operational load by mode i(kW) or auxiliary boiler operational load by mode i (kW)
$Activity_i$ = Time of activity for mode i (hours) (calculated using Equation 2.4)
*MCR is defined as the manufacturer's tested maximum engine power and it is used to determine propulsion engine load by mode, and it is the highest power available from a ship engine during average cargo and sea conditions.

To calculate the Load Factor and the Activity, the following equations are used:

$$Loadi = (SpeedActual / SpeedMaximum)^3$$ (Equation 2.3)

Where:
Loadi= Load Factor (dimensionless)
Speed Actual = Actual speed (knots)
Speed Maximum = Maximum speed (knots)

$$Activity = D/Speed_{Actual}$$ (Equation 2.4)

Where:
Activity = Activity (hours)
D = Distance (nautical miles)
Speed Actual= Actual ship speed (knots)
The reference for the GHG emission factors (EF) comes from Cooper & Gustafsson (2004). Fuel Correction Factors (FCF) for Ocean Going Vessels were obtained from CARB (Air Resources Board of California, 2006).

### ❖ Emission estimation for Harbor Crafts

Harbor craft emissions are estimated for each engine individually, based on the engine's model year, power rating, and annual hours of operation. The San Pedro Bay Ports harbor craft emission calculation methodology is similar to the methodology used by the CARB to estimate emissions for commercial harbor craft emissions operating in California.

Emissions from the following sources are estimated for harbor craft (Starcrest counsulting group, 2019b):

- Propulsion engines that move the harbor craft through water
- Auxiliary Engines that provide power for electricity and other house loads

The basic equation used to estimate emissions from harbor craft engines is shown below in Equation 2.5.

$$\boldsymbol{E = Power \times Activity \times LF \times EF \times FCF \times CF} \quad \text{(Equation 2.5)}$$

Where:
E = Emissions (grams/year)
Power = Maximum rated power of the engine (hp or kW)
Activity = Engine activity (hours/year). Power and activity information are obtained during the data acquisition process
LF = Load Factor which is the ratio of average power used during normal operations as compared to maximum rated power (dimensionless). The engine load factors are obtained from CARB's emission estimation methodology report
EF = Emission Factor, grams of pollutant per unit of work (g/hph) or (g/kWh). Emission factors for $CO_2$, $CH_4$, and $N_2O$ are obtained from (Cooper & Gustafsson, 2004)
FCF = Fuel Correction Factors are used to adjust EF associated with a base fuel to the fuel being used to reflect changes in fuel properties that have occurred over time (dimensionless). They are obtained from CARB.
CF = Control factor to reflect changes in emissions due to the installation of emission reduction technologies not originally reflected in the emission factors (dimensionless)

- **Emission estimation for Cargo Handling Equipment (CHE)**

The emissions calculation methodology used to estimate CHE emissions is consistent with CARB's latest methodology for estimating emissions from CHE. The basic equation used to estimate CHE emissions is as follows (Starcrest counsulting group, 2019b):

$$\boldsymbol{E = Power \times Activity \times LF \times EF \times FCF \times CF} \quad \text{(Equation 2.6)}$$

Where:

E = Emissions (grams/year)
Power = Maximum Rated Power of the engine (hp or kW)
Activity = Equipment's engine activity (hr/year)
LF = Load Factor (ratio of average load used during normal operations as compared to full load at maximum rated horsepower) (dimensionless)
EF = Emission Factor, grams of pollutant per unit of work (g/hph) or (g/kWh)
FCF = Fuel Correction Factors which are used to adjust EF associated with a base fuel to the fuel being used to reflect changes in fuel properties that have occurred over time (dimensionless).They are obtained from CARB
CF = Control Factor that reflects changes in emissions due to the installation of emission reduction technologies not originally reflected in the emission factors (dimensionless)

- **Emission estimation for Locomotives**

Railroad operations are typically described in terms of two different types of operations, line haul and switching. Line haul refers to the movement of cargo by train over long distances. These operations occur at or near the Port as the initiation or termination of a line haul trip, as cargo is either picked up for transport to destinations across the country or is dropped off for shipment overseas (Starcrest counsulting group, 2019b).

Switching refers to short movements of rail cars, such as in the assembling and disassembling of trains at various locations in and around the Port, sorting of the cars of inbound cargo trains into contiguous "fragments" for subsequent delivery to terminals, and the short distance hauling of rail cargo within the Port.

Locomotives used for line haul operations are typically equipped with large, powerful engines of 4,400 hp or more, whereas switch engines are smaller, typically having one or more engines totaling 1,200 to 3,000 hp(Starcrest counsulting group, 2019b).

Emissions are estimated for locomotives operating in switching and line haul service, on-port and off-port. They are calculated using information provided by the railroads and the terminals, and from published information sources such as the "Emission Factors for Locomotives" and their Regulatory Support Document (RSD) from (EPA, 1997).

Emissions from on-port switching company are based on the horsepower-hours of work calculated from their reported annual locomotive fuel use, emission factors from the EPA documents, and information published by the locomotive manufacturers. The calculations estimate the horsepower-hours worked by each locomotive based on fuel consumption in gallons per year and combine the horsepower-hour estimates with emission factors in terms of grams of emissions per horsepower-hour (g/hph) (Equation 2.7). Fuel usage is converted to horsepower-hours using conversion factors(the Figures are presented in Equation 2.8) that equate horsepower-hours to gallon of fuel (hph/gal) (Starcrest counsulting group, 2019b).

$$\boldsymbol{Annualwork\ (hp\text{-}hr/year) = gallons/year \times hp\text{-}hr/gallon} \qquad \text{(Equation 2.7)}$$

The calculation of emissions from horsepower-hours uses the following equation.

$$\boldsymbol{E = \frac{Annual\ work \times EF}{(453.59\ g/lb \times 2{,}000\ lb/ton)}} \qquad \text{(Equation 2.8)}$$

Where:
E = Emissions (tonnes per year)
Annual work = Expressed inhph/yr
EF = Emission Factor (grams pollutant per horsepower-hour)
453.59 g/lb× 2,000 lb/ton= Conversion units

❖ **Emission estimation for Heavy Duty Vehicles (HDV)**

The two major geographical components of truck activities have been evaluated for this (Starcrest counsulting group, 2019b):

- On-terminal operations, which include waiting for entering in to the terminal, transiting the terminal to drop off and/or pick up cargo, and departing the terminal.
- On-road operations, consisting of travelling on public roads within the SoCAB. This also includes travel on public roads within the Ports' boundaries and those of the adjacent San Pedro Bay Ports.

Data for the HDV emission estimates came from three basic sources: port and terminal activity records, terminal contacts, and computer modeling of on-road HDV traffic volumes, distances, and speeds.

A simplified equation for estimating the emissions from a fleet can be expressed as (Starcrest counsulting group, 2019b)

$$\boldsymbol{E = Activity \times EF} \qquad \text{(Equation 2.9)}$$

Where:
E = Emissions (grams/year)

Activity = Average number of miles driven per truck, hours of idle operation[17]
EF = Emission Factor which is the amount of pollutant emitted per unit of activity (g/mile org/hour)
The emission factors were obtained from the latest version of EMFAC[18]. This is a computer model developed by CARB to estimate emissions from on-road vehicles operating in California. The used version in this methodology is EMFAC2017.

CARB makes available a web-based data base of model results that allows querying for emission factors stratified by speed and vehicle model year for individual air basins or for the state as a whole. The database query performed for the ports' emissions inventories utilizes the South Coast Air Basin factors. The activity (miles and hours) and emission factors (g/mile and g/hour) are combined to estimate fleet emissions.

It should be mentioned that in this method there are more formulae for different modes of transports and different speeds but as they are not related to the objectives of this thesis, they are not presented here.

- **Results**

Table 2.2 shows the results of GHG emissions from different sources in 2005, 2017 and its comparison to the baseline year (1990) established by the SPBP. As it can be seen, the total emissions estimated for the baseline year (1990) are 1.511.975t$CO_2$eq. The total amount of emissions in 2005 and 2017 increased compared to the baseline year but the amount of emissions in 2017 decreased compared to 2005.This decrease could be explained by the establishment of the GHG emission reduction goals by the State of California in 2006 (International Emissions Trading Association, 2014). The CAAP calls for reductions in GHG emissions from port-related mobile sources to 40% below 1990 levels by 2030, and 80% below 1990 levels by 2050. To meet these reductions, the ports will need to not overpass the value of 907,185 metric tonnes of $CO_2$eq by 2030 and 302,395 metric tonnes of $CO_2$eq by 2050 (Starcrest Consulting group, 2019a). This is an important challenge for these ports.

**Table 2.2: SPBP CO2eq in Metric Tonnes (Starcrest Consulting group, 2019a)**

| **Emission sources** | **$CO_2$eq, metric tonnes** | | |
|---|---|---|---|
| | 1990 | 2005 | 2017 |
| OGVs | 260.691 | 682.438 | 513.763 |
| Harbour Craft | 64.663 | 101.671 | 103.998 |
| CHE | 467.844 | 238.331 | 288.738 |
| Locomotives | 99.661 | 142.780 | 126.630 |
| HDV | 619.116 | 856.316 | 686.781 |
| Total | 1.511.975 | 2.021.536 | 1.719.910 |

- **Strengths and weaknesses**

The strength of this methodology lies in the well-developed calculation methods for each emission source.

The main weakness of this method is that the calculation is not classified in scopes. Furthermore, the scope 2 (emissions related to electricity consumption) is not taken into account. In addition, emissions from construction equipment, emissions from waste and emissions from stationary sources are not included in the calculation. Also, it is not clear if emissions from the employees' commuting (scope 3) are included or not.

[17]An idle operation consumes fuel to keep the engine and its accessories running while the ship is still. Therefore, no usable power is produced to move.

[18] The Emission Factors (EMFAC) model is developed by the California Environmental Protection Agency. This model is used to calculate emission rates from all motor vehicles, such as passenger cars to heavy-duty trucks, operating on highways, freeways and local roads in California.

### 2.1.3. The Port of Oslo

Port of Oslo (Norway) calculated the Carbon Footprint for the first time in 2007. The Carbon Footprint calculation in this port was developed based on the ISO14064-1 (ISO, 2006) standard that was previously explained in section 1.3 (Port of Oslo, 2008).

#### - Boundaries

The inventory of port of Oslo was developed for the calendar year 2008. In order to establish the organizational boundaries, the Port of Oslo chose the operational control approach (Port of Oslo, 2008), which collects and consolidates all data or information from assets which are operated by the company, whether for itself or by a joint venture[19] (IPIECA, 2011).

Under the operational control approach, the activities form the port of Oslo itself and its daughter company, HAV Eiendom AS[20] were taken into account. HAV Eiendom AS company office is located in one of the buildings owned by the Oslo Port Authority. The only emission sources from the company are indirect emissions from electricity use for heating and lightening. The electricity use was taken into account in the estimates for electricity usage for buildings owned by Port of Oslo (Port of Oslo, 2008).

#### - Scopes

The Port of Oslo has calculated all direct and energy indirect emissions and a selection of other indirect emissions. The emission scopes are described below (Port of Oslo, 2008):

- Scope 1 (Direct emissions): Activities resulting indirect emissions for the Port of Oslo are fuel usage for heating of buildings, by company owned cars, by operational vessels owned by Port of Oslo and by operational machines and cranes owned by Port of Oslo. The data provided for the analysis were from the Port of Oslo measuring system. Fuel consumption was based on accounting Figures related to the complete cost of fuel divided by the average cost of fuel in 2007. There was no oil consumption for heating, no combustion of biomass in operations controlled by the Port of Oslo and no export of energy from sites that were under the control of Port of Oslo in 2007.
- Scope 2 (Energy indirect emissions): Activities resulting in energy indirect emissions by the Port of Oslo are electricity usage by cranes owned by Port, electricity usage for the purpose of harbor lightning, electricity usage for buildings owned by Port of Oslo (e.g. heating, lightning), electricity usage by lighthouses owned by Port and electricity usage from other sources in Port of Oslo.

  The electricity consumption was based on measurements. The Port of Oslo was able to distinguish between power consumption for cranes, lighting of the harbor and lighthouse. Electricity used for heating and lighting of buildings was assumed by the Port of Oslo based on the renting contracts and invoicing to companies renting out space in buildings. The emissions in the category "other sources" were calculated by subtracting the emissions in the other four categories from the total measured consumption which could include intake of power by ships (both owned by the Port of Oslo and other companies) as well as other possible power use. No heat or steam was imported by the Port of Oslo.
- Scope 3 (Other indirect emissions): Activities resulting in other indirect emissions by the Port of Oslo are car diesel usage, car petrol usage and kilometers driven by train, public transport, motorcycle and by boat due to employees' commuting. In addition, this scope also includes domestic business travel by

[19] The joint venture is used as a generic term for any operations or activities involving more than one party.

[20] HAV Eiendom AS was founded in 2003. This company is responsible for the urban redevelopment of the Bjørvika area of Oslo, Norway.

plane (short-haul business travel and long-haul business travel), business travel by taxi and in non-company-owned vehicles. The commuting distances estimates are extrapolated based on a survey done by Port of Oslo among its employees. The survey included 55% of the employees.

### - Methodology

The Carbon Footprint of the Port of Oslo is developed based on the ISO14064-1 standard. This standard has been derived from GHG protocol. Both guidelines have been explained in section 1.3 of this thesis (WRI and WBSCD, 2004).

### - Results

The results show that the total estimated $CO_2$ emissions from the Port of Oslo activities are 1346 $tCO_2eq$, excluding the terminal operators' activities. The relatively low outcome, to a large extent, is due to the fact that Port of Oslo is being mainly driven by electricity based on hydropower, which is the major source of energy in Norway(Port of Oslo, 2008). Figure 2.4 shows $CO_2$ emissions for the port of Oslo by scope. As it can be seen, scope 1 is the largest emission source (44%). Scope 2 is in the second position with 34% of the total emissions. Business travel (scope 3) constitutes the smallest part of the Carbon Footprint (22%).

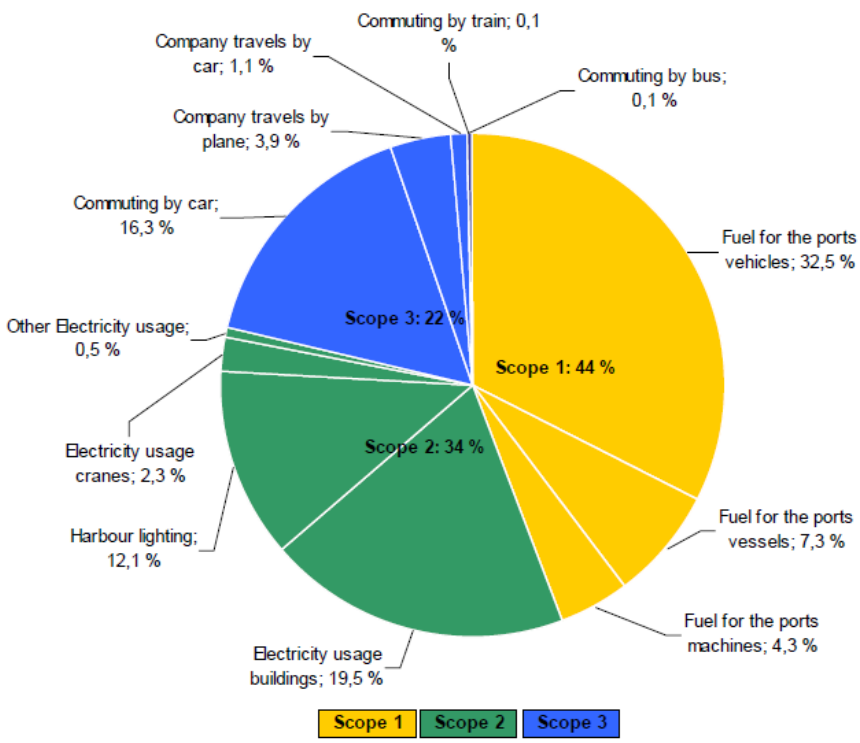


**Figure 2.4: $CO_2$ emissions for port of Oslo by scope excluding terminal operators (Port of Oslo, 2008)**

### - Strengths and weaknesses

The strengths of this method are that it follows ISO 14064 standard that derives from GHG protocol and that includes almost all emission sources required by this standard ("direct emissions" and "energy indirect emissions").

The weakness of this method is that the Port of Oslo rents out a lot of space to other companies but cannot control their energy consumption. Therefore, the emissions resulting from energy use in rented out buildings were excluded from the Carbon Footprint. Also, the emissions from the terminal operators activities were not calculated. In addition, emissions from waste operations such as incinerators were not taken into account.

Another weakness of this method is that activity data were partly based on measurement and partly based on estimates. If data were not available, expert estimates were made both by the Port of Oslo employees and external experts.

### 2.1.4. Climeport

CLIMEPORT (Mediterranean Ports' Contribution to Climate Change Mitigation) is a European project that involved six ports committed with Climate Change Mitigation (2007-2013). These ports are: The Port Authority of Valencia (Spain), acting as leader of the project, alongside other port authorities like Algeciras Bay (Spain), Marseille (France), Livorno (Italy), Kopper (Slovenia) and Piraeus (Greece).

The objective of this project was to provide a common methodology for port authorities and their collaborators in order to assess their initial situation related to GHG emissions. This methodology provided a way to collect and classify the available information, including questionnaires, invoice data to tenants, and other potential data sources in an ordered way (MED, 2012a).

- **Boundaries**

The boundaries include the six ports. As it can be seen in Figure 2.5, the GHG emissions from port activities and industries which are located in these ports are taken into account (Industries which are not highly related to marine transport are considered briefly). Concerning vessels, only the captive fleet is considered in detail and ocean-going vessels are taken into account when berthed in the harbor (MED, 2012a). List of aspects that are Included in this study are (MED, 2011):

- Passenger terminals
- Container and bulk terminals
- Perishable goods terminals
- Other port buildings
- Transport related internal traffic
- Berthed vessels
- Road vehicles and vessels (port services) Captive fleets
- Berthed and inner traffic of ships

Figure 2.5 shows the boundaries of this project.


**Figure 2.5: Boundaries of the Climeport project (MED, 2012a)**

Development of a standardized tool to calculate Carbon Footprint in ports

## - Scopes

In this project scopes are classified in three levels (MED, 2011):

- In-port emissions and sinks: Related to GHG emissions production or reduction due to equipment directly controlled inside the port community (vessels, vehicles, energy produced, etc.)
- Outside port emissions and sink: Related to energy produced outside the port, as electricity, and waste treatment outside the port premises
- Other emissions to be considered: Goods consumption and workers working travels

## - Methodology

In this project a web based tool (ECO ABACUS software tool) was developed to calculate the Carbon Footprint in ports. The development of this tool was done using of ISO 14064 standard which has been described in section 1.3.3 (MED, 2011).

In this study, emissions are estimated using the following equation (MED, 2011):

$$\text{Emissions} = \text{Energy Consumption} \times \text{EF} \qquad \text{(Equation 2.10)}$$

Where:
Emissions: Emissions of GHG ($CO_2eq/t$)
Energy Consumption: Consumption of fuel or electricity (kWh or Liter)
EF: Emission Factor obtained from WPCI (WPCI, 2010) and IPCC (IPCC, 2006)

The calculation of Carbon Footprint has been done by the equation 2.11(MED, 2012a):

$$\text{Carbon Footprint} = \frac{\text{Total amount of } CO_2 \text{ eq.emitted } (T_{CO_2})}{\text{Total amount of goods managed } (T_g)} = \frac{\text{tonnes CO2e}}{\text{tonnes}} \qquad \text{(Equation 2.11)}$$

## -Results

Figure 2.6 shows the total $CO_2$- eq (Tone) of the six ports from Climeport projects. As it can be seen, Algeciras Bay (Spain) with 27% of emissions is the main emitter, port of Livorno (Italy) with 26% comes after that. Port of Marseille (France) with 17% occupies the third position and Valencia port (Spain) with 16% is almost equal to the Port of Marseille and comes in the fourth position. The port of Piraeus (Greece) with 9% is in the fifth position and the port of Koper (Slovenia) is lower emitter with 5% (MED, 2012a)

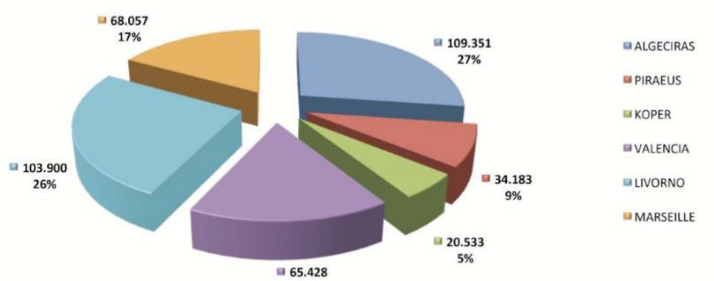


**Figure 2.6: Total $CO_2$- e (Tone) of the six ports from Climeport projects in 2008 (MED, 2012a)**

Figure 2.7 shows the Carbon Footprint of the six ports involved in the Climeport in 2008, which were calculated by the equation 2.11. As it can be seen, the highest Carbon Footprint value is for Livorno port, Marseille is in the second position and Kopert port occupies the third position. Valencia port, Algeciras Bay and Piraeus occupy fourth, fifth and sixth position respectively (MED, 2012a).

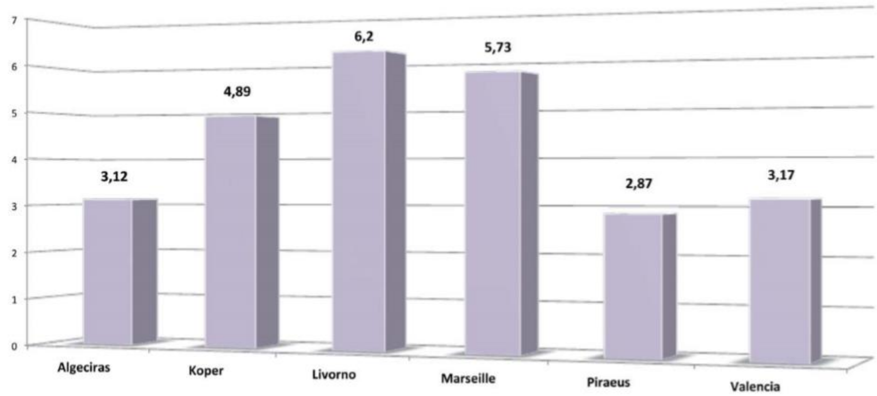

**Figure 2.7:The Carbon foot print of the six ports at the Climeport in 2008 (MED, 2012a)**

- **Strengths and weaknesses**

The strength of this method is that it is a web-based tool and it has been developed based on diverse methods (ISO 14064, WPCI and IPCC). However, the tool is not available. Another strength of this method is that there exist a user guideline that is freely available (MED, 2012b). In addition, the Climeport results have been quantified by means of dividing the total emissions by the total cargo (Goods managed by port), which is an accurate and useful indicator and easy to manage by any organization.

A weakness of this method is that the tool is not available. In addition, scopes are not defined and emission sources are not clear.

### 2.1.5. The port of San Diego

The Climate Action Plan (CAP) was developed by the San Diego Unified Port District (United States of America) to identify policies and measures to reduce GHG emissions in 2013. The goals of the CAP are (Port of San Diego, 2013):

- Reducing the 2006 GHG emissions level by 10% in 2020,
- Reducing the 2006 GHG emissions level by 25% in2035.

- **Boundaries**

Regarding the establishment of the organizational boundaries, emissions from all tenants and activities at the Port were calculated. The GHG inventory for the Port included three sectors: Port Operations, Maritime Tenants and Non-Maritime Tenants (Hooven et al., 2011).

The emissions inventory is limited to GHGs that are generated by activities in the port from a defined set of sources (e.g., transportation, electricity use, and waste) that can be readily monitored and reduced through port actions. The inventory of GHG emissions is broken down into the following six sectors (Port of San Diego, 2013):

- Electricity consumption
- Natural gas consumption
- On road transportation
- Off road transportation (e.g. Vessels and boats)
- Water Use
- Waste

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The baseline year of the CAP is 2006. The 2020, 2035 and 2050 emissions are projected from the baseline year by estimating the emissions impacts of future development projects and projected increases in cargo and cruise activity.

- **Scopes**

The scopes are not defined.

- **Methodology**

The CAP is developed through five main steps which are (Port of San Diego, 2013):

1. Measuring GHG emissions
    - Identifying GHG inventory
    - Quantifying major sources of GHG emissions
    - Providing the baseline
2. Implementing strategies and measures to achieve GHG reduction targets
3. Adapting Climate Change strategies
4. Implementing CAP which includes a combination of regulations, programs, incentives, outreach, and educational activities
5. Monitoring, Reporting and Updating CAP: The ongoing monitoring and reporting of GHG reduction impacts and their cost effectiveness will enable staff and the Board of Port Commissioners to make regular adjustments to the CAP.

Figure 2.8 shows the primary purposes of CAP. As it can be seen, the first purpose of CAP is providing a road map to achieve GHG reduction targets. The second purpose is confirming to California laws and regulations. To implement the general plan is the CAP's third purpose and its last purpose is providing CEQA tiering[21] for new development's GHG emissions.

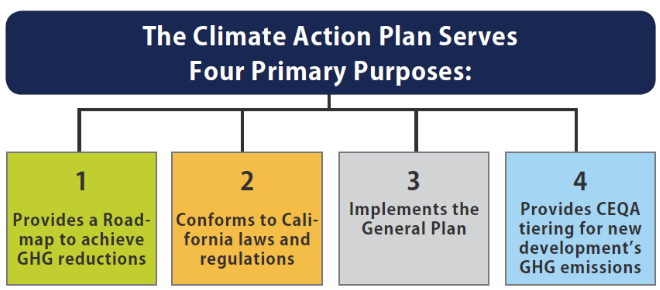


**Figure 2.8: The primary purposes of CAP (The city of San Diego, 2015)**

- **Results**

Table 2.3 and 2.4 are presented the results from 2006 (baseline year) until 2050. The 2020 Business As Usual (2020 BAU) scenario assumes that there will not be any adoption or implementation of new policies, plans, programs or regulations designed to reduce GHG emissions between now and 2020. Therefore, the 2020 BAU is the worst-case scenario. Apart from this, three other scenarios are considered: 2020, 2035 and 2050. These scenarios take into account the expected reduction impacts resulting from the federally mandated

[21]The tiering mechanisms include existing plans and associated programmatic Environmental Impact Reports (EIRs) that addressed plan-level GHG emissions, as well as a specific "plan for the reduction of greenhouse gas emissions" that meets specified criteria (ASCENT, 2018). The tiering is related to the California Environmental Quality Act (CEQA) which is a California statute passed in 1970. CEQA generally requires state and local government agencies to inform decision makers and the public about the potential environmental impacts of proposed projects, and to reduce those environmental impacts to a feasible extent.

higher vehicle fuel efficiency standards[22]. In addition, these scenarios also consider that the state mandate will increases the percentage of renewable energy provided by public utility companies (Port of San Diego, 2013).

As it can be seen in Table 2.3 in all scenarios the greatest amount of emissions is due to 'On road transportation'. 'Off road transportation' occupies the second position. 'Electricity' and 'Natural gas consumption' come after that respectively. In addition, both 'Electricity' and 'On road transportation' emissions are decreasing significantly in 2020 compared to 2020 BAU scenario due to the major GHG reduction impacts of the previously mentioned state and federal regulations. If the CAP measures are implemented and the estimated reductions are achieved, the Port will meet its GHG reduction goal of 10% less than the 2006 baseline levels by 2020. However, without the CAP measures, the amount of emissions from 'Off road transportation' will increase due to the raise up the traffic in this category (Port of San Diego, 2013).

**Table 2.3: GHG emissions scenarios by sector (Metric Tonnes "MT" of $CO_2$ equivalent per year) (Port of San Diego, 2013)**

| SECTOR | 2006 | 2020 BAU** | 2020* | 2035* | 2050* |
|---|---|---|---|---|---|
| Electricity | 173,192 | 208,231 | 147,133 | 147,133 | 147,133 |
| Natural Gas | 135,516 | 152,803 | 152,534 | 152,534 | 152,534 |
| On road transportation | 314,870 | 410,069 | 317,708 | 310,506 | 310,646 |
| Off road transportation (e.g. Vessels and boats) | 172,929 | 233,528 | 207,268 | 266,158 | 288,470 |
| Water Use | 13,166 | 14,630 | 10,406 | 10,406 | 10,406 |
| Waste | 16,757 | 20,439 | 20,439 | 20,439 | 20,439 |
| Total | 826,429 | 1,039,700 | 855,489 | 907,177 | 929,629 |

*Includes reduction impacts of known state and federal regulation.
** Business As Usual scenario assumes no new policies, plans, programs or regulations designed to reduce GHG emissions.

To meet the aforementioned Port's reduction goal, the Port's CAP includes a wide range of GHG reduction measures that have the potential to reduce GHG emissions from the projected 2020 scenario total of 855,489 (Table2.4) to 745,695 MT $CO_2$eq/yr. Given that 524.976 MT of the 2020 emissions are from the transportation sector and 299.667 MT from the electricity and natural gas sector, the CAP implementation strategy must focus on these sectors in order to achieve the Port's reduction goals (Port of San Diego, 2013).

**Table 2.4: GHG reduction targets - 2020 Climate Action Plan (Metric Tonnes "MT" of $CO_2$ equivalent per year)(Port of San Diego, 2013)**

| TARGETS | 2006 | 2020 BAU** | 2020* | 2020 CAP*** |
|---|---|---|---|---|
| Electricity and Natural Gas | 308.707 | 361.034 | 299.667 | 255.873 |
| Transportation: Off road and On road | 487.799 | 643.597 | 524.976 | 462.766 |
| Water Use | 13.166 | 14.603 | 10.406 | 9.759 |
| Waste | 16.757 | 20.439 | 20.439 | 17.296 |
| Total | 826.429 | 1.039.700 | 855.489 | 745.695 |

* Includes reduction impacts of known state and federal regulation.
** Business As Usual scenario assumes no new policies, plans, programs or regulations designed to reduce GHG emissions.
*** This column does not include the small 35 MT $CO_2$eq/yr GHG reduction resulting from measures that increase carbon capture and sequestration on Port owned lands.

[22]The Trump Administration announced, on April 2, 2018, its intent to revise through rule making the federal standards that regulate fuel economy and greenhouse gas (GHG) emissions from new passenger cars and light trucks. These standards include the Corporate Average Fuel Economy (CAFE) standards promulgated by the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) and the Light-Duty Vehicle GHG emissions standards promulgated by the U.S. Environmental Protection Agency (EPA). They are known collectively- along with California's Advanced Clean Car program—as the National Program (Congressional research service, 2019).

- **Strengths and weaknesses**

One of the strengths of this method is that the CAP can be used for environmental review of future projects as it includes elements for a GHG Emission Reduction Plan specified in current CEQA Guidelines. In addition, by using this method track progress towards State regulations is possible. Moreover, to evaluate the CAP's GHG measures, the Port will conduct performance assessments of each implemented reduction measure and track and monitor overall progress toward the CAP's 2020 and 2035 GHG reduction goals (Port of San Diego, 2013). Also, by adapting CAP, key vulnerabilities within the Port will be evaluated and prioritized. Another strength of this method is that emissions from all tenants and activities at the Port were calculated.

A weakness of this method is the fact that CAP is adopted from City's Climate Action Plan and therefore, it is not specific for ports. There are many aspects that are unique to Ports compared to cities or counties. For example, the Port does not have authority over many of the sources that are responsible for its GHG emissions in the same way that a city or county might have control over similar sources.

Another weakness is that explanation about the formulae and methods which are used for calculation GHG gases are not given. In addition, the scopes are not specified and it is not clear if the calculation of emission from the employees' commuting is included in on-road transportation or not. Moreover, based on the sources, emissions from natural gas consumption are not specified and it is not mentioned if the emissions from cargo handling equipment and construction equipment are calculated or not.

### 2.1.6. The Port of Rotterdam

The Port of Rotterdam (The Netherlands) is gradually becoming $CO_2$ neutral by the purchase of Gold Standard emission allowances[23]. The aim of this port is to come in line with the Paris Climate Agreement objectives. The port-based companies are encouraged to report their Carbon Footprint and the Port of Rotterdam Authority takes steps to reduce its own $CO_2$ emissions as well. The Port of Rotterdam Authority is trying to reduce $CO_2$emissions by the use of renewable energy, fuel saving measures for patrol vessels and electric lease cars for employees (Port of Rotterdam authority, 2013).

- **Boundaries**

The boundaries of the study include the Port of Rotterdam Authority and port-based companies.

- **Scopes**

$CO_2$ footprint calculation has been done within the three scopes (Port of Rotterdam authority, 2013):

- Scope 1: The fuel consumption of vessels and vehicles and the use of gas in buildings owned or rented
- Scope 2: Electricity consumption by operations and structures managed by the Port Authority, such as bridges and public lighting
- Scope 3: $CO_2$ emissions resulting from business flights and the employees' commuting

- **Methodology**

The methodology is not presented.

[23]Gold Standard emission allowance is an initiative that was established in 2003 by the World Wide Fund for Nature (WWF) and other international NGOs to ensure that the projects reduce carbon emissions under the UN's Clean Development Mechanism.

- **Results**

Over the period of five years, $CO_2$ emissions have fallen by 10%. The greatest contribution to this reduction comes from operational ships like patrol vessels that have reduced their fuel consumption. Electric lease vehicles also make a positive contribution. The Port Authority also stimulates businesses in the port to deal with the $CO_2$ emissions (Port of Rotterdam authority, 2013).

In 2017 the total $CO_2$ emissions in the port were 33.1 MT of $CO_2$. Table 2.5 shows the total $CO_2$ emissions by industry based in the port (Port of Rotterdam, 2017).

**Table 2.5: Total $CO_2$ emissions by industry based in the port in 2017 (MTof$CO_2$) (Port of Rotterdam, 2017)**

| **Industry** | **$CO_2$emission** |
|---|---|
| Refineries | 8.5 |
| Coal powered plants | 10.7 |
| Gas power plants | 3.9 |
| Waste processing | 1.6 |
| Other industries | 0.4 |
| Producers of industrial gases | 3.0 |
| Chemical companies | 5.0 |
| **Total** | **33.1** |

The Wuppertal Institute[24] was commissioned by the Port Authority to conduct further research in calculating and controlling $CO_2$ emissions from transport and logistics sector in 2018. Emissions from all shipping by sea and towards the hinterland with the Port of Rotterdam as departure or end destination were calculated.

As it can be seen in Table 2.6, the emission of $CO_2$ is 25 million tonnes per year. The majority (87%) can be attributed to marine transport. If nothing is done, it is expected that $CO_2$ emissions from shipping will increase between 50% and 250% by 2050 (Port of Rotterdam, 2017).

**Table 2.6: $CO_2$ emission from transport and logistics sector in 2018 (Port of Rotterdam, 2017)**

| Sector | $CO_2$ emissions Per year (%MT) |
|---|---|
| Maritime transport | 87% |
| Inland transport | 9% |
| Berthed ships | 2% |
| Container handling | 1% |
| Other | 1% |
| Total | 25 MT of $CO_2$ |

- **Strengths and weaknesses**

One of the strengths of this method is that emissions from maritime transport and berthed ships are taken into account. In addition, scopes are defined and classified separately; however, the results are not presented by scope and the emissions from tenants are not taken into account. Another weakness is that the methodology of calculation is not given. In addition, it is not mentioned if the emissions from cargo handling equipment and constructional equipment are calculated or not. Moreover, it is not clear if all the GHG emissions are included in the calculation or only $CO_2$ emissions are calculated.

[24]The Wuppertal Institute was founded in 1991. It undertakes research and develops models, strategies and instruments for transitions to sustainable development at local, national and international levels. Sustainability research at the Wuppertal Institute focuses on the resources, climate, and energy related challenges and their relation to economy and society.

### 2.1.7. The Port of Stockholm

Since 2012 Port of Stockholm (Sweden) has reported sustainability issue according to GRI (Global Reporting Initiative). The explanation of this initiative is presented in section 1.1 of this thesis (port of stockholm, 2017).

#### - Boundaries

The boundaries include a total of 14 km of quays and 1,100,000 $m^2$ of land at its three ports, Kapellskär, Stockholm and Nynäshamn. The company also administers around 80 buildings located close to the ports and the emissions related to them are calculated in scope 3 (Port of Stockholm, 2017).

#### - Scopes

The port of Stockholm has reported GHG emissions according to GRI in 3 scopes (port of stockholm, 2017):

- Scope 1 (Direct GHG emissions): Emissions from Vehicle fuel consumption, electricity and heating production
- Scope 2 (Indirect GHG emissions): Emissions from District heating, Town gas, District cooling, Property electricity, Operational electricity and emissions from Tenant electricity and vessels electricity consumption
- Scope 3 (Other indirect GHG emissions): Emissions from Business air travel and vessels within port areas

#### - Methodology

Emissions of GHG are calculated with WTW (Well To Wheel) system, which is based on a fuel-cycle model developed by Argonne National Laboratory (ANL)[25]. A WTW analysis includes many activities related to the production and transportation of feedstocks and fuels(Brinkman et al., 2005). The details of this method are not presented.

#### - Results

Emissions of GHG are reported as carbon dioxide equivalents. The gases that are included are $CO_2$, $CH_4$ and $N_2O$. Table 2.7 shows direct GHG emissions. As it can be seen, in 2017 direct emissions of GHG have decreased compared to 2016. This is due to a transition to a truck fuel containing HVO (Hydro treated Vegetable Oil), or in other words a fuel with higher renewable content than the previous ones (Port of Stockholm, 2017).

**Table 2.7: Direct GHG emissions (scope 1) (Port of Stockholm, 2017)**

| Source | Fuel type | Tonnes $CO_2$-eq 2015 | Tonnes $CO_2$-eq 2016 | Tonnes $CO_2$-eq 2017 |
|---|---|---|---|---|
| Fuel | Vehicle fuel | 773 | 881 | 863 |
| Own electricity production | Solar cells | 0 | 0 | 0 |
| Own heating production | Oil (boiler) | 40 | 39 | 30 |
| **Total** | | **813** | **920** | **893** |

Table 2.8 shows Indirect GHG emissions. The internal energy usage in 2017 is lower when comparing to 2016 and 2015 which results in lower $CO_2$-eq (Ports of Stockholm, 2017). However, the external emissions have increased in the last years.

[25]Argonne National Laboratory was founded in 1942, is a science and engineering research national laboratory operated by the University of Chicago Argonne for the United States Department of Energy. It is the largest national laboratory by size and scope in the Midwest.

**Table 2.8: Indirect GHG emissions (scope 2) (Port of Stockholm, 2017)**

| Source | Fuel type | Tonnes $CO_2$-eq 2015 | Tonnes $CO_2$-eq 2016 | Tonnes $CO_2$-eq 2017 |
|---|---|---|---|---|
| Heating | District heating | 589 | 529 | 440 |
| | Town gas | 0.14 | 35 | 32 |
| Cooling | District cooling | 0 | 0 | 0 |
| Electricity | Property electricity | 54 | 65 | 83 |
| | Operational electricity | 82 | 106 | 75 |
| **Total internal** | | **725** | **734** | **630** |
| Tenant electricity | | 57 | 58 | 61 |
| Vessel electricity | | 74 | 79 | 93 |
| **Total external** | | **131** | **137** | **154** |

Table 2.9 shows other indirect GHG emissions. For the Ports of Stockholm, this is an important statistic as the environmental impact from vessel emissions is very important. Vessel emissions are classified as other indirect emissions.

Emissions of GHG from vessels in port areas have increased in 2017. A likely reason is that a higher number of the vessels have remained in port longer and have had more powerful engines than in previous years.

Although the amount of business air travel varies from year to year depending on need, the amount of emissions decreased in 2017 compared to 2016. According to the Ports of Stockholm guidelines, business travel should be done by train whenever possible. Information regarding business air travel is sourced from the travel agencies entrusted (Port of Stockholm, 2017).

**Table 2.9:Other indirect GHG emissions (scope 3) (Port of Stockholm, 2017)**

| Source | Tonnes $CO_2$-eq 2015 | Tonnes $CO_2$-eq 2016 | Tonnes $CO_2$-eq 2017 |
|---|---|---|---|
| Business air travel | 74 | 96 | 88 |
| **Total internal** | **74** | **96** | **88** |
| Emissions from vessels within port areas | 98,384 | 98,203 | 104,000 |
| **Total external** | **98,384** | **98,203** | **104,000** |

- **Strengths and weaknesses**

The strength of this method is that all emission sources “direct emissions” and “indirect emissions” are taken into account.

The main weakness of this study is that the details of the methodology are not presented. In addition, in the direct emissions from the fuel it is not specified what kind of sources are included such as truck, harbor craft, power plants and ext. Concerning the employees’ commuting, only emissions from air travel are calculated. Emissions from waste operations such as incinerator are not taken into account.

### 2.1.8. The port of Gothenburg

The Port of Gothenburg (Sweden) is trying to contribute to sustainable transports by minimizing the environmental impact of shipping. Climate and air quality issues are at the top of its agenda. The Port Authority is climate-neutral and is working on an efficient environmental discount for ships, as well as increasing the onshore power supply (OPS). In 2000, the Port of Gothenburg was the first port to introduce a high-voltage onshore power supply for cargo vessels. Since 2012, this port calculates the 3 scopes of Carbon Footprint and reports them at the annual sustainability report (Port of Gothenburg, 2018).

- **Boundaries**

The boundaries of the study consist of the port authority and port tenants. The baseline year of the study is 2010.

- **Scopes**

The Port of Gothenburg has calculated all direct and indirect emissions considering the 3 scopes according to GHG protocol. The emission scopes are described below (Port of Gothenburg, 2018):

- Scope 1: It includes working vessels, production vehicles, heating of buildings and fire pumps
- Scope 2: It includes electricity and district heating used in buildings, street lights and the heating of pipes in the Energy Port
- Scope 3: It includes commercial vessel operations within Gothenburg municipality, some terminal companies: APM Terminals Gothenburg AB, Gothenburg Ro/Ro Terminal AB, and Logent Ports & Terminals AB as well as loading of petrol to vessels in the Energy Port and the emissions from the Gothenburg Port Authority’s business travels

- **Methodology**

GHG Protocol (WRI and WBSCD, 2004) was used to calculated Carbon Footprint in this port. This protocol was already presented in section 1.3.2 of this thesis. In scope 1, the data were obtained from the consumption Figures. Emissions factors for fuels and gas heating were obtained from suppliers. In scope 2, the data were obtained from the consumption Figures and emissions factors provided by Göteborg Energi (Port of Gothenburg, 2018).

In scope 3 the information on business travel was provided by the company's travel agency. Emissions from air travel were calculated for 2017 using the tool Atmosfair[26]. Emissions from shipping were calculated by IVL[27] in a study from Cooper & Gustafsson (2004). In this study, the source for the greenhouse gas emission factors based on call statistics are presented (Port of Gothenburg, 2018).

- **Results**

Table2.10 presents the results of GHG emissions in the port of Gothenburg in tonnes of carbon dioxide equivalents. As it can be seen, scope 1 GHG emissions have a decreasing trend from 2014 to 2018 compared to the baseline year. GHG emissions of scope 2 from 2014 to 2017 have also a decreasing trend, but in 2018 there is a slight growth. The GHG emissions due to scope 3 in 2018 increased compared to 2015, 2017 and the baseline year.

**Table 2.10: The results of GHG emissions in the port of Gothenburg ($tCO_2$/year) (Port of Gothenburg, 2018)**

| Scopes | Baseline year (2010) | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|
| Scope 1 | 590 | 380 | 160 | 220 | 240 | 220 |
| Scope 2 | 150 | 200 | 170 | 35 | 20 | 22 |
| Scope 3 | 900 | * | 169,000 | 187,000 | 177,000 | 178,000 |

* IVL's calculation model was updated in 2018 with an improved methodology. Therefore, the results from 2015-2017 have been recalculated for comparability. Since 2014Figures have not been recalculated, they are not reported.

[26]Atmosfair is an independent German non-profit organization founded in 2005. It offers offsets for GHG emitted by aircraft, cruise ships, long-distance coaches, and events. Atmosfair has developed an emission calculator that calculates the different GHG emitted when travelling and translates them into a corresponding amount of $CO_2$ based on their climate impact.

[27]IVL is the Swedish Environmental Research Institute. It is Sweden’s first and oldest environmental research institute Founded jointly by the Swedish government and the Swedish business sector in 1966.

### - Strengths and weaknesses

Although in this study the calculation has been done based on a standard method and all scopes are taken into account, the detail of methodology is not presented.

In addition, the emissions from cargo handling equipment and construction equipment are not included in the calculation. Another weakness of this method is that emissions from waste are not included in the footprint.

## 2.1.9. The Port of Barcelona

The Port Authority of Barcelona (Spain) has joined the Voluntary Agreements to reduce GHG emissions promoted by the Catalan Climate Change Office (CCCO)[28]. By signing this agreement in 2012, the Port committed to gradually reducing its direct and indirect emissions (Port of Barcelona, 2013).

### - Boundaries

The boundaries of this study include the Port Authority of Barcelona. Emissions from tenants are not taken into account.

### - Scopes

By joining the Voluntary Agreements to reduce GHG emissions promoted by CCCO, the port of Barcelona committed to reduce direct and indirect emissions in 2 scopes (Port of Barcelona, 2013):

- Direct Emission (Scope 1): Fuel consumption of its fleet of 120 vehicles, two boats, certain generators and Air Conditioner Energy consumption
- Indirect Emission (Scope 2): Electricity consumption

### - Methodology

The methodology is not presented.

### - Results

Table 2.11 shows the Direct and Indirect emissions in the Port of Barcelona. As it can be seen, emissions from energy consumption from fossil fuels and transport (direct emissions) are almost equal and indirect emissions (scope 2) in this port are 3 times more than direct emission.

**Table 2.11: Direct and Indirect emission from GHG (tonnes of $CO_2$-eq) in the port of Barcelona in 2013 (Port of Barcelona, 2013)**

| Direct emissions from GHG (tonnes of $CO_2$-eq) | | | Indirect emissions from GHG (tonnes of $CO_2$-eq) | | |
|---|---|---|---|---|---|
| Energy consumption | Fossil fuel | 254.50 | Energy Consumption | Electricity | 1.604.19 |
| Transport | Road | 248.35 | | Acquired heat, steam or cold | 0 |
| | Rail | 0 | | | |
| Fugitive fluorinated gas emission | | 0 | Total | | 1.604.19 |
| Total | | 502.85 | | | |

### - Strengths and weaknesses

An attempt to calculate $CO_2$ emissions in the Port Authority is done. However, the methodology is not explained. In addition, scope 3 (emissions from tenant and employees' commuting) is not taken into account. Emissions from energy consumption are not classified on sources and it is not clear which sources are

[28] The Catalan Office for Climate Change (OCCC) is the technical instrument of the Catalan Government to promote and coordinate mitigation plans and Climate Change strategies in Catalonia based on European commitments.

included and which ones are not. Moreover, emissions from vessels, waste operations and employees' commuting are not calculated.

## 2.1.10. Ports de la Generalitat

Ports de la Generalitat is a public company founded in 1998 which belongs to the Territory and Sustainability Department of the Catalan Government. It manages 26 ports (commercial, industrial and fishing ports) in the Catalonia region in Spain. Since 2012 they have joined the Voluntary Agreements Program for the reduction of GHG emissions (Ports de la Generalitat, 2018). In this regard, they started to calculate GHG emissions every year using the aforementioned tool developed by the Catalan Office for Climate Change (OCCC) in section 1.3.5.

### - Boundaries

The boundaries include the 26 ports along the Catalonia coast. These ports are divided in three areas: North, Central and South areas.

### - Scopes

Three following scopes were taken into account (Ports de la Generalitat, 2018):

- Scope 1 (Direct emissions): Energy consumption and transportation
- Scope 2 (Indirect emissions): Electricity consumption
- Scope 3 (Other indirect emissions): Water consumption

### - Methodology

The GHG calculation excel tool, which has been developed by OCCC is used in this study. This tool is used to calculate emissions associated with energy consumption in both stationary facilities and transport, fugitive emissions from fluorinated gases, emissions from municipal waste management and emissions produced by water consumption from urban networks. This tool is Excel based and free available (OCCC, 2019).

### - Results

Table 2.12 shows the results of the GHG emissions in these ports from 2015 to 2018 (Ports de la Generalitat, 2018). As it can be seen, the emissions for 3 scopes are calculated. The total amount of emissions has decreased from 2015 to 2018. There is only a slight increase from 2016 to 2017 which is related to the increase of emissions of scope 1 and 2.

**Table 2.12: The result of the GHG emission in the ports from 2015 to 2018 (tonnes $CO_2$eq) (Ports de la Generalitat, 2018)**

| Emission sources | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|
| Scope 1 (Transportation) | 36,91922 | 34,08013 | 36,46624 | 36,86002 |
| Scope 2 (Electricity consumption) | 518,43818 | 435,06094 | 448,87869 | 315,60970 |
| Scope 3 (Water consumption) | 9,21812 | 9,8331 | 8,30132 | 10,41299 |
| Total tonnes $CO_2$eq | 564,57552 | 478,97420 | 493,64625 | 362,88271 |

### - Strengths and weaknesses

The strength of this method is that the calculation has been done by the use of Excel based tool which has been developed based on standard methods and it is available for free. In addition, all GHG are taken in to account.

The weakness of this study is that emissions from scope 3, recommended by the international guidelines, are not calculated. Only the emissions from water consumption are taken into account in scope 3. In addition, this tool is not port specific.

### 2.1.11. The Port of Chennai

The Port of Chennai is one of the major ports in India situated on the Coram and el coast with a handling capacity of 86.04 million tonnes (Mt) per annum. In a research by Misra et al (2017) the GHG emissions of this port for the year 2014-2015 have been calculated.

#### - Boundaries

The boundary of GHG emissions in the Port of Chennai include the various facilities of the port along with the housing colony and fishing harbor which come under the management of the Port of Chennai (Misra et al., 2017).

#### - Scopes

The calculation of different sources has been done using scopes 1 and 2 (Misra et al., 2017):

Scope 1: Emissions from the utilization of diesel for transportation and operation of port-owned fleet vehicles (tugs, dredgers, and pilot and mooring launches), emissions due to merchant vessel operation inside the port, electricity generation through diesel generators and material-handling equipment such as cranes and forklift trucks. Also, the emissions from the fishing harbor and housing colony which fall under the management of the Port of Chennai were accounted under scope 1 emissions.

Scope 2: Emissions due to the purchased electricity for the operation of port-owned equipment such as cranes, pumps, reefer (refrigerated vessels) containers and machinery in the workshop, and for building air conditioning, lighting and other uses. Also, the emissions due to electricity consumption in the housing colony were considered in this scope.

**- Methodology**

The Carbon Footprint of the Port of Chennai was estimated for the year 2014-2015 based on the WPCI guidance document (WPCI, 2010). The following emissions from different sources are calculated in this port (Misra et al., 2017):

- Emissions from diesel consumption
- Emissions from merchant vessels
- Emissions from on-road vehicles

**❖ Emissions from diesel consumption**

The emissions due to diesel consumption were estimated using Equation (2.12) (Misra et al., 2017):

$$Emissions = \sum_{i=1}^{n} (Diesel\ consumption)_i \times EF \qquad \text{(Equation 2.12)}$$

Where:
<u>n</u>: The number of diesel consuming equipment
<u>Diesel consumption</u>: The amount of diesel consumption (L/year)
<u>EF</u>: The emission factor for diesel consumption is considered to be 2.68 kg of $CO_2$eq/L of diesel. The $CO_2$eqemission factor comes from adding the emission from $CO_2$ (2.67 kg of $CO_2$/L of diesel), $CH_4$ (0.000183 kg of $CH_4$/L of diesel) and $N_2O$ (0.00435 kg of $N_2O$/L of diesel)

- **Emissions from merchant vessels**

GHG emissions from merchant vessels were calculated based on the guidelines proposed by WPCI (2010). In this inventory, the emissions arising out of sea transit are not considered and only the emissions from maneuvering and berth hoteling within the boundary of the Port of Chennai are taken into consideration. Also, anchorage hoteling is not considered as hardly any merchant vessel is subjected to anchorage hoteling in the Port of Chennai. The maneuvering phase include the emissions from the main engine and from auxiliary engines and boilers. The emissions from the main vessel engine are estimated based on Equation (2.13) (Misra et al., 2017):

$$Emission = \sum_{i=1}^{n} (MCR \times LF\ X\ operating)_i \times EF \qquad \text{(Equation 2.13)}$$

Where:
n: The number of merchant vessels
MCR: The engine's maximum continuous rated power in Kw. The main vessel MCR are obtained based on the world fleet averages from WPCI(2010)
LF: The Load Factor which is the ratio of the engine's power output at a given speed to the engine's MCR power, estimated based on the propeller law and the respective equation is presented in Equation 2.14
Operating: The operating time or maneuvering time (hours) is taken as the sum of pre-berth time and outward navigation time and these data are obtained from the Chennai port authorities. It is assumed that the average manufacturing year of the merchant vessels that visited the Port of Chennai in the financial year 2014–2015 is 2000 or newer, and the propulsion type is the medium-speed direct drive. Vessels are assumed to operate their main engines on residual oil (RO) which is an intermediate fuel oil or one with similar specific actions, with an average sulfur content of 2.7%
EF: The GHG emission factor based on the above assumptions is 0.69 kg $CO_2$ e/kWh, based on a study from Cooper and Gustafsson (Cooper & Gustafsson, 2004)

To calculate the Load Factor parameter, the following equation is used:

$$LF = (\text{Maneuverings speed}/\text{Ship maximum speed})^3 \qquad \text{(Equation 2.14)}$$

Where:
Maneuverings speed: The maneuvering speed of merchant vessels within the boundary of the Port of Chennai is taken to be 4 knots
Ship maximum speed: Maximum speed are obtained based on the world fleet averages from the WPCI guidelines (WPCI, 2010)

The emissions from the vessels' auxiliary engine and boiler during the maneuvering phase are estimated using Equation (2.15). The details of the auxiliary engine and boiler capacity are obtained from the Port of Los Angeles (2012) inventory of air emissions (Misra et al., 2017):

$$Emissions = \sum_{i=1}^{n} (AS \times Act \times EF)_i \qquad \text{(Equation 2.15)}$$

Where:
i: Corresponds to auxiliary engine or boiler in operation
n: The number of AS in operation
AS: Auxiliary System (engine or boiler capacity) in Kw
Act: The operating/maneuvering time (hours). The maneuvering time is the same as that used for estimating GHG emission from the main engine during maneuvering

EF: Emission Factor for the auxiliary engine is 692.8 g $CO_2$eq/kWh and for the boiler is 994.8 g $CO_2$eq/kWh, based on WPCI guidance document (WPCI, 2010) and Cooper and Gustafsson (Cooper & Gustafsson, 2004).

❖ **Emissions from on-road vehicles**

Emissions from on-road vehicles include the emissions from trucks as the major part. GHG emissions are estimated by Equation (2.16). For heavy-duty vehicles such as trucks, the emission factor during the idle time is taken to be 4.65 kg$CO_2$eq/h, and during the on-terminal running activity, it is taken to be 1.02 kg$CO_2$eq/km (Misra et al., 2017).

$$Emissions = \sum_{i=1}^{N} (Act)_i \times EF$$

(Equation 2.16)

Where:
i: The counter for vehicles
n: The number of vehicles
Act: The operating time (hours)
EF: Emission Factor (kg$CO_2$eq/h or kg$CO_2$eq/km)

Other emissions based on scope 1 sources such as vehicles used for employees transportation and LPG (Liquefied Petroleum Gas) consumption in the housing colony were calculated based on Equation 2.16, and the emission factors for different fuels used are obtained from WPCI (WPCI, 2010).

The scope 2 emissions estimation (emission from electricity consumption) was calculated by Equation 2.17. The emission factor for end user consumption was found to be 1.13 kg $CO_2$e/kWh.

$$\text{Emission} = \text{Electrical Energy Consumption} \times \text{EF} \qquad \text{(Equation 2.17)}$$

Where:
Electrical Energy Consumption (kWh)
EF: Emission Factor (kg $CO_2$eq/kWh)

- **Results**

Table 2.13 shows total GHG emissions through fuel consumption by different sources under scope 1. The total amount of emissions for this scope is 249,656 t/year. As it can be observed from this Table, merchant vessels contribute62.3% of the total scope 1 GHG emissions, followed by fishing harbor activities (28.06%), crane operations in container terminals 1 and 2 (4.02%), port-owned vehicles (2.76%) and third-party user trucks/vehicles (2.54%). Other scope 1 emissions such as petrol usage in the housing colony and LPG consumption were insignificant in comparison with other source-based emissions (Misra et al., 2017).

**Table 2.13: Total GHG emissions through fuel consumption by port owned vehicles, port users and port tenant under scope 1 (Misra et al., 2017)**

| Source of emissions | GHG emissions (tonnes/yr) | GHG emissions (%) |
|---|---|---|
| Merchant vessels | 155,623 | 62.3 |
| Fishing harbour | 70,069 | 28.06 |
| Crane operation in container terminals 1 and 2 | 10,050 | 4.02 |
| Port-owned vehicles | 6896 | 2.76 |
| Trucks | 6343 | 2.54 |
| Other port users | 20 | 0.008 |
| Petrol usage | 17.3 | 0.069 |
| LPG consumption | 637.7 | 2.55 |
| Total | 249,656 | |

Figure 2.9 illustrate overall GHG emissions at the Port of Chennai. As it can be seen, the total emissions from

scope 1 and scope 2 are 280,558 t/yr. The total emissions from scope 1 are 249.656 t/yr. In the scope 1, Port tenants emit 242,760 t/yr and port owned vehicles and activities emit 6,896 t/yr. As it can be observed, most part of the emission in this scope is for the tenants. The total emissions from scope 2 (electricity consumption) is 30.902 t/ yr. Port tenants emit 24,513 t/yr and port owned vehicles and activities emit 6,389 t/yr (Misra et al., 2017).

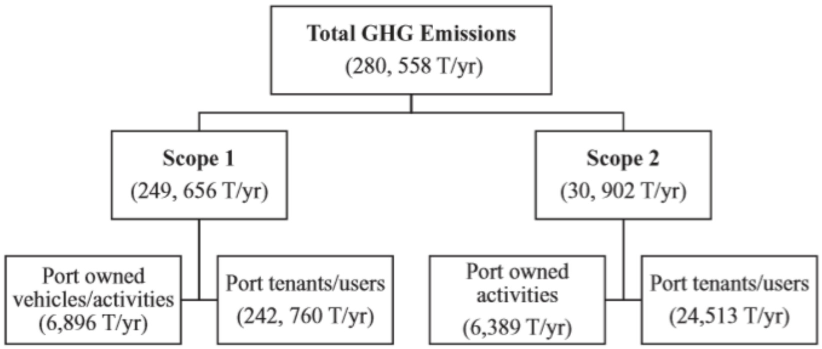


**Figure 2.9: Overall GHG emissions at the Port of Chennai (Misra et al., 2017)**

### -Strengths and weaknesses

The strength of this method is that the calculation has been done based on a standard method. The weakness of this method is, although many of the emission sources are taken into account, the scopes are not classified based on the WPCI guidance document. As it can be seen in Figure 2.9, emissions from the tenants are calculated within scope 1, which they should be calculated in scope 3, according to WPCI (WPCI, 2010). In addition, emissions from waste are not calculated and emissions from employees' commuting (Scope 3) are also not considered.

## 2.1.12. The Port Authority of Ferrol – San Cibrao

In 2007, the Port Authority of the Ferrol – San Cibrao (Spain) implemented its Environmental sustainability plan. In 2016, the Ferrol – San Cibrao Port Authority started to monitor its environmental aspects through the Integrated Quality and Environmental Management System. Within this frame, GHG emissions were calculated by the use of the Ecological Transition Ministry (MITECO) of the Spanish government tool (Puerto de Ferrol, 2017).

### - Boundaries

The boundary of the study includes just the Port Authority of the Ferrol – San Cibrao. The tenants are excluded from the calculation boundary.

### - Scopes

The Port Authority has calculated emissions of scope 1 and scope 2. Its definition of the scopes is described below (Puerto de Ferrol, 2017):

- Scope 1 (Direct emissions): Emissions of this scope include diesel consumption for heating and diesel and gasoline consumption for transportation.
- Scope 2 (Indirect emissions): Emissions of this scope include the emissions from electricity consumption.

### - Methodology

In order to calculate GHG emissions in this port, the MITECO tool of the Spanish government has been used. This tool has been explained in section 1.3.4.

### - Results

As it can be seen in Table 2.14, in 2016, the total GHG emissions in the Port Authority of the Ferrol-San Cibrao were close to700 t $CO_2$ eq. Around 84% of emissions were from electricity consumption.

**Table 2.14: GHG emissions in the Port Authority of the Ferrol – San Cibrao in 2016 (Puerto de Ferrol, 2017)**

| Scopes | Sources | Emissions (t $CO_2$eq) |
|---|---|---|
| **Scope 1** | Diesel consumption for heating | 81.07 |
| | Diesel consumption for transportation | |
| | Gasoline consumption for transportation | |
| **Scope 2** | Electricity consumption. | 588.19 |
| **Total** | | **699.26 (t $CO_2$eq)** |

### - Strengths and weaknesses

The main strengths of this methodology are that the calculation is done by the use of the standard tool and all the GHG are taken into account.

The main weakness is that the emissions of scope 3 are not calculated and many sources like emissions from vessels, employees' commuting and emissions from the waste operations are not taken into account.

## 2.1.13. Giurgiulesti International free port

In 2016, the Carbon Footprint Report for operational activities of Giurgiulesti International Free Port (Moldavia) on an annual basis was developed by the Danube Logistics. This company is the general investor and operator of Giurgiulesti International Free Port as well as the administrator of the Giurgiulesti Free Economic Zone. In order to calculate the Carbon Footprint Danube Logistics followed both control based and activity based approaches (Tucher and Stirbu, 2018).

### - Boundaries

Regarding organizational boundaries, the control approach is used for consolidating and reporting GHG emissions, and all emissions which the company can control and influence are considered.

Regarding operational boundaries, the total territory of the port (55 ha) is taken into account. The operational activities conducted within the following areas are included in the Carbon Footprint report:

- Dry bulk and container storage area, general cargo and container terminal
- Oil terminal area including tank farm, auto loading facility and railway facility; office park
- Danube Logistics workshop
- Infrastructure at port premises including roads, parking areas

The following areas are excluded:

- Grain terminal with access to Danube and Prut rivers
- Grain storage facilities
- Vegetable oil storage
- Business park areas leased by third parties

Development of a standardized tool to calculate Carbon Footprint in ports

The present inventory refers to the period from 1 January until 31 December 2018 (Tucher and Stirbu, 2018).

**- Scope**

WPCI Guidance Document (WPCI, 2010) is used to define the scopes. The focus of this report is on emissions within scope 1 and scope 2 (Tucher and Stirbu, 2018).

- Scope 1 (Direct emissions): Diesel and gasoline engines (kg $CO_2$/L) such as fuel used by cargo handling equipment, by on road and non-road vehicles, by harbor crafts (tug boat) and feeder vessel at the berth, fuel used by stationary sources, by employee's vehicles on the territory of the port, burning of natural gas (kg $CO_2/m^3$) such as natural gas used for heating the buildings of the port office park.
- Scope 2 (Energy indirect emissions): Consumption of electricity imported to the port (kg $CO_2$/kWh) such as electricity used by the office park and business park areas including deposits and lighting, electricity used by the pumping station of the oil terminal auto loading facility, by terminal areas including lighting, by other areas controlled by Danube Logistics.

- **Methodology**

GHG Protocol (WRI and WBSCD, 2004) is used to prepare the Carbon Footprint Report. This method is explained in section 1.3.2 of this thesis. The data analyzed relate mostly to energy production and consumption both in stationary and non-stationary emission sources. The emission sources included in the Carbon Footprint refer to generated $CO_2$ emissions, and other $CO_2$ equivalent emissions.

An activity-based approach has been applied for the calculation of GHG emissions. The total GHG emissions are calculated through each type of fuel/energy used (Tucher and Stirbu, 2018):

- The amount of natural gas and electricity consumption is measured using calibrated and certified meters.
- The amount of diesel is calculated by summing up the recorded amounts of fuel used by each piece of equipment used on the territory of the port. The supply of fuel for each piece of equipment is measured using a meter installed on the pump of the bunkering truck.

- **Results**

In 2017 the total estimated GHG emissions of activities generated by Danube Logistic at the Giurgiulesti International Free Port amount to 899.5 t $CO_2$eq increasing by 4.4% compared to 2016 (Table 2.15). As it can be seen in Table 2.16 emissions from scope 1 are 56.8% of total emissions and emissions from scope 2 are 43.2% of total (Tucher and Stirbu, 2018).

**Table 2.15: Total estimated GHG emissions (Tucher and Stirbu, 2018)**

| $CO_2$eq in tonnes | 2016 | 2017 |
|---|---|---|
| $CO_2$ | 858.1 | 896.7 |
| $CH_4$ | 1.7 | 1.7 |
| $N_2O$ | 1.2 | 1.1 |
| Total $CO_2$eq | 861.0 | 899.5 |

**Table 2.16: Share of $CO_2$ Emissions by Scope in 2017 (Tucher and Stirbu, 2018)**

| Scope | $CO_2$ Emissions in tonnes | % |
|---|---|---|
| Scope 1 | 509.1 | 56.8 % |
| Scope 2 | 378.6 | 43.2 % |
| Total $CO_2$ | 896.7 | 100% |

- **Strengths and weaknesses**

One strength of the calculation of Carbon Footprint in this port is that more than 95% of the data used for the calculation of emissions are based on real measurements of fuel and energy consumption. This provides a high level of accuracy of the calculated emissions. In addition, Danube Logistics will further refine the recordings in the future in order to elaborate in more detail the relation between emissions and type of operational activity in the port.

The weakness of this method is that the calculation of the $CO_2$ footprint does not include the resident and tenant companies and the employees' commuting (scope 3). Moreover, emissions from waste are not calculated.

## 2.1.14. The Port of Taichung

The port of Taichung (Taiwan) received ECOPORTS certification from the European Sea Port Organization (ESPO) in November 2015 and November 2017. In 2016 the port of Taichung created a GHG emissions management and reduction plan by self-management method and it was approved by the Environmental Protection Bureau (EPB) of Taichung City (Tsai et al., 2018).

Tsai et al (2018) used the self-management approach to facilitate the control of the total quantity of GHG emissions from various sources in this port.

- **Boundaries and Baseline year**

The year 2014 was defined as the base year of emissions. The boundary includes the operation area of the Taichung Port, which encompasses statutory land and sea territories, covering a total area of 2073.68 $km^2$. The principles of division management and responsibility adopted in the self-management area are based on land use and industrial characteristics; therefore, the area is divided into regions of heavy industry (A1), export-processing (B1) and harbor areas (B2). A coal-fired power plant and a crude steel plant are located in the A1 area. The power plant is the largest coal-fire power station worldwide. The steel plant is the second-largest steel plant in Taiwan. Their GHG emission regulatory works are directly controlled by the EPB of Taichung City. The B1 area is an export-processing zone that belongs to the Industrial Development Bureau (IDB) at the Ministry of Economic Affairs of Taiwan and this area contained 76 factories in 2016. Due to the fact that both A1 and B1 areas are governed by their own competent authorities, their management of GHG emissions is not included in the self-management approach. However, including their emission data in the annual self-management report is necessary to provide a clear understanding of the pollution situation of the entire port area. The B2 area is composed of containerization cargo, bulk cargo, reclamation zones[29], logistics and warehousing, an industrial zone (II), a petrochemical industrial zone, a forest protection zone, and the statutory sea territory, this is the major area used to determine total quantity controls of GHG emissions in the self-management method. In 2016, the B2 area contained 93 factories, companies or administrative agencies (Tsai et al., 2018).

- **Scopes**

The scopes are not defined.

[29]In a reclamation zone, the dredged port mud and waste soils from area construction projects will be used to reclaim land from adjacent coastal waters.

- **Methodology**

Figure 2.10 presents the flowchart of the quantity control approach in the self-management method, which comprises three stages: inventory and check, guidance and improvement, and management–audit–reduction–review. The tasks of inventory and check stage include gathering the data of the four main axes which are industrial zones, harbor operations, ship operations and administrative works. In the guidance and improvement stage, it will be determined whether all of the sources are compatible with energy-saving/carbon-reduction measures and the best available control equipment will be adopted. If not, the related improvement strategies and guidance will be provided to them. The final stage includes systematic works of management, audit, reduction, and review. The energy usage and operating data of industries will be used to estimate the total emission amounts of GHG and air pollutants. When a new industry or process is added to a port, the observation of relevant regulations and environmental impact assessment (EIA) commitments will be required in the final stage. If the total emission amount of GHG or air pollutants are higher than the base-year amounts, the related plans and reduction strategies will be regulated for fitting the base-year amounts (Tsai et al., 2018).

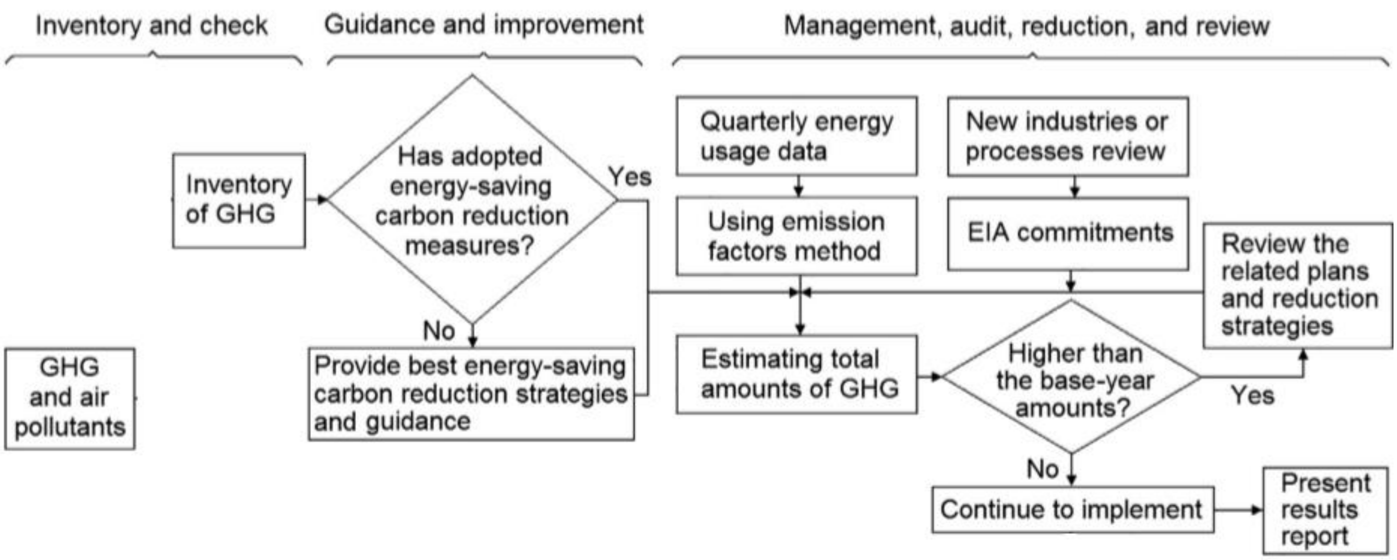


**Figure 2.10: Flowchart of control in the self-management approach (Tsai et al., 2018)**

The GHG inventory tools (based on ISO 14064) developed by the IDB and Environmental Protection Agency (EPA) of Taiwan were employed in the self-management approach. The raw data of cruise ship and administrative works were obtained from the related departments of Taichung Port (Tsai et al., 2018).

Figure 2.11 shows the inventory works layout for the GHG emission based on the self-managements approach. As it can be seen, the inventory has four main parts: industrial zones, harbor operations (including cargo trucks, rail transport, various vehicles, and handling equipment), ship operations (including cargo boat and cruise ship data, operation types, hours in port, and waiting for arrival), and administrative works.

Two vital checks are the activity type and intensity. Uncertainty assessment is based on the difference between the results of inventories and industrial annual emissions data from the EPB of Taichung City. An average uncertainty value lower than 5% is considered satisfactory. The final report must be presented to the self-management committee for review and then be submitted to the EPB of Taichung City for auditing in terms of the local environmental protection law called the "Taichung City Greenhouse Gas Emission Sources Self-Management Act." (Tsai et al., 2018).

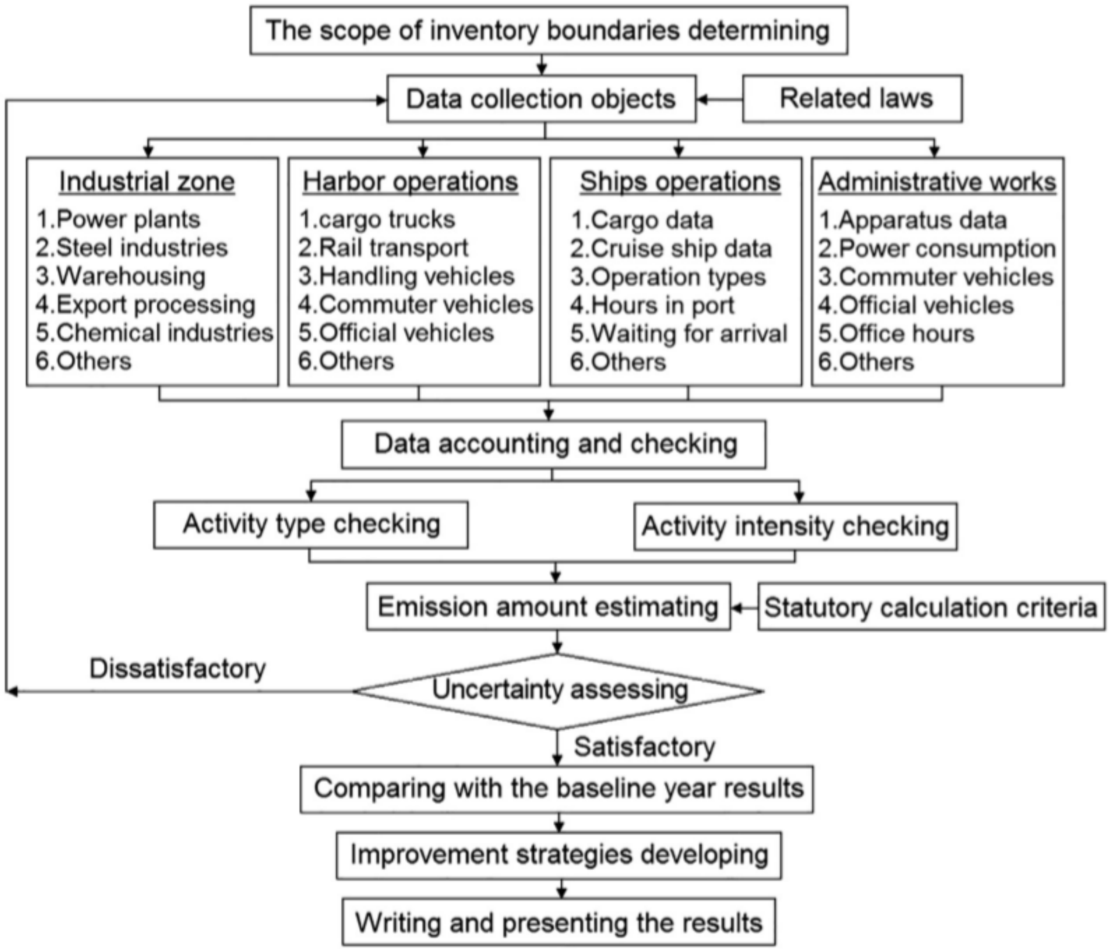


**Figure 2.11: Inventory works layout for the GHG emission based on self-management approach (Tsai et al., 2018)**

The equations below are recommended by Taiwan EPA or Air Resources Board of California (2006) to estimate the emission quantities of GHG and air pollutants to calculate emissions of ocean-going vessels, harbor ships, and diesel-handling equipment (Tsai et al., 2018):

(1) Ocean-going vessels, harbor ships, and diesel-handling equipment

$$E = HP \times LF \times Act \times EF \times FCF \qquad \text{(Equation 2.18)}$$

(2) Heavy-duty diesel vehicles and trains

$$E = NV \times Act \times EF \qquad \text{(Equation 2.19)}$$

(3) Electricity or other uses of energy

$$E = Act \times EF \qquad \text{(Equation 2.20)}$$

(4) Airborne dust from barren lands or open storage piles

$$E = GPA \times EF \times (1 - \eta) \qquad \text{(Equation 2.21)}$$

Where:

E: The emission quantity (ton $yr^{-1}$)

HP: Engine power (kW)

LF: Loading factor (dimensionless)

Act: Annual activity or usage time (h $yr^{-1}$)
EF: Emission factor (ton $kW^{-1}h^{-1}$, ton $ha^{-1}yr^{-1}$, or ton storage-$ton^{-1}$),
FCF: Fuel correction factor (dimensionless)
NV: Numbers of vehicles
GPA: Ground area (ha) or storage amount (ton $yr^{-1}$)
ŋ: Control efficiency (dimensionless)
The data for LF, EF, and FCF were obtained from the website of Taiwan EPA or US EPA (Tsai et al., 2018).

### - Results

Table2.17 shows the results of the GHG emissions by the self-managements approach at harbor area (B2), since it is the only area in which emissions could be calculated. The decrease in the total GHG emissions in 2016 compared to 2015 demonstrates that the self-management approach implemented in 2016 is practical, successful, and effective. The vessel speed reduction program and automated vehicle inspection systems are the two best actions in the reducing of GHG emissions, thus the two actions are recommended to other ports. In addition, Taichung Port also actively developed onshore wind power. Based on the positive experience of Taichung Port, the method is now being adopted in other industries and areas in Taichung City (Tsai et al., 2018).

**Table 2.17: Results of the GHG and air pollutant emission by the self-managements approach at harbor area (B2) (Tsai et al., 2018)**

| Source of emissions | 2014 GHG emissions (tonnes/yr) | 2015 GHG emissions (tonnes/yr) | 2016 GHG emissions (tonnes/yr) |
|---|---|---|---|
| **Stationary sources** | 250,165 | 273,959 | 274,471 |
| **Mobile sources** | 300,393 | 300,758 | 293,963 |
| **Total** | 550,558 | 574,717 | 568,434 |

### -Strengths and weaknesses

The strength of this method is the usage of an organized approach. The main weakness of this method is that the scopes are not classified and it is not clear what kinds of sources are included in each category. In addition, the A1 and B1 emissions are not included in the calculation since they are governed by their own competent authorities. Therefore, the GHG emissions of heavy industry (A1) zone which includes a coal-fired power plant and a crude steel plant are excluded from the calculation. In addition, the emissions from the export-processing (B1) zone which contains 76 factories are not taken into account. Moreover, emissions from waste operations are not calculated. Another weakness of this method is that used tool is not available.

### 2.1.15. The Port of Olympia

The Port of Olympia (The United States) is a municipal corporation, which is organized under Washington State law and governed by a locally-elected board of commissioners. In Washington State, ports provide and operate commercial marine transportation facilities, maintain and operate airports and marinas, and provide many other services to enhance economic development in the Port district.

The Port of Olympia is voluntarily conducting biennial GHG emissions inventories for its Downtown Olympia locations, Airport locations, and Lacey Properties (Port of Olympia, 2018).

### - Boundaries and Baseline year

The focus of this calculation is on the vehicle fleet and facilities at the Port's Downtown Olympia locations (Marine Terminal, Swan town Marina and others), Airport locations (Olympia Regional Airport and Clean water Centre), and Lacey locations (Commerce Business Center) (Port of Olympia, 2018).

The first GHG emissions inventory was conducted in 2013. This report was never finalized but the data was used for comparative purposes (Port of Olympia, 2018).

### - Scopes

Scope 1 and Scope 2 emissions were calculated for the 2017 inventory(Port of Olympia, 2018):

- Scope 1 (Direct emissions): Port-owned and port-operated fleet vehicles, including light and heavy duty on-road and off-road vehicles, and boats; and on-site stationary combustion of natural gas and diesel in Port-owned and pot-operated buildings.
- Scope 2 (Indirect emissions): Energy (electricity) purchased for use in Port-owned and port-operated buildings.

### - Methodology

Washington State Department of Ecology provides an Excel-based GHG calculator to estimate emissions. This tool was used to perform the GHG emissions inventory for the Port because it is specifically applicable to Washington State agencies and it is the most relevant one based on Port operations and estimated GHG emissions (Department of Ecology State of Washington, 2017).

There are six worksheets in the calculator tool:

- Worksheet1 is for the general information of the users (e.g. the total number of employees, total population which are served by the company and owned area)
- Worksheets 2 is for the amount of electricity consumption
- Worksheets 3 is for Fleet Energy Use (Light Duty, Heavy Duty and Off Road Fuels, Ferries, Boats and Aircrafts)
- Worksheet 4 will automatically generate a summary of users GHG emissions
- Worksheets 5 and 6 contain emission factors and conversion factors for user reference

### - Results

The Port (vehicle fleet and facilities combined) emitted approximately 1,239 MT $CO_2$eq in 2017. The overall GHG emissions for the Port are presented by source (vehicle location and fuel type or facility building) in Figure 2.12. The greatest sources of GHG emissions for the Port were the purchase of electricity for Port facilities (656 MT $CO_2$eq (53%), which belongs to scope 2), and diesel fuel vehicle use at Downtown Olympia properties (404 MT $CO_2$eq (33%), which belongs to scope 1). Stationary source combustion’s share in GHG emissions in this port is only 5% (Port of Olympia, 2018).

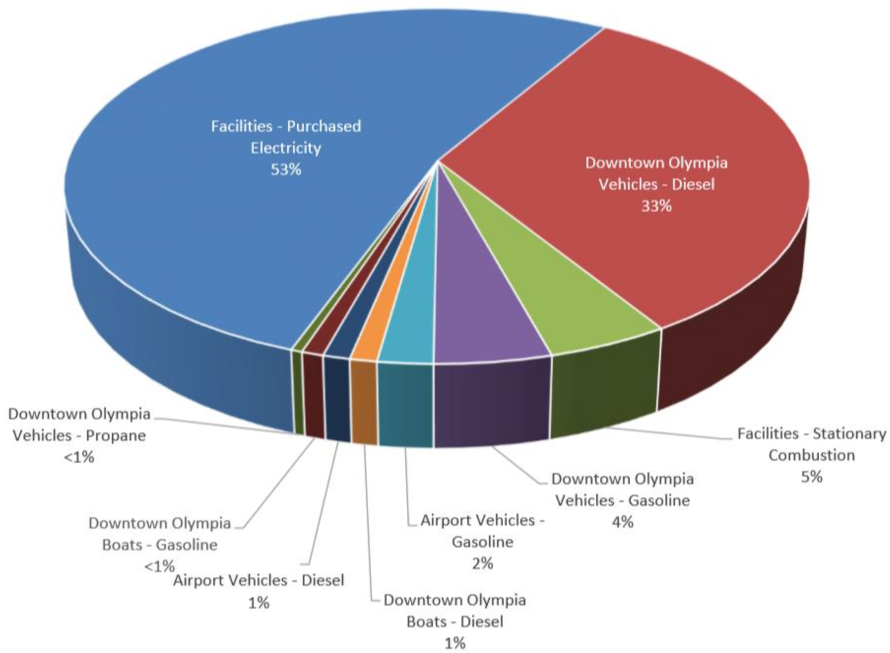


**Figure 2.12: Port of Olympia 2017 GHG Emissions Summary(Port of Olympia, 2018)**

#### - Strengths and weaknesses

The strength of this method is that the calculation has been done by using the Washington State Agencies GHG calculator (an Excel-based tool). However, the tool is not available and the method and the formulae for the calculation are not provided.

Another weakness of this method is that emissions from stationary combustion are not classified on sources and it is not clear if emissions from cargo handling equipment and construction equipment are calculated or not. In addition, scope 3 emissions (tenant activities and employees' commuting) and emissions from waste are not calculated.

## 2.2. Port Terminals

Besides the previous studies in the ports, several researches have also been done to calculate $CO_2$ emissions and Carbon Footprint in port terminals. The methodologies used in these port terminals do not provide any additional information for the objective of this thesis: the creation of a standard tool to calculate Carbon Footprint in ports. However, since they were also analyzed, they have summarized here.

### 2.2.1. Container Terminal Ports in Mumbai

In a study from Chowhan et al. (2012)the $CO_2$ emissions in four container terminals in Mumbai (India) were analyzed. $CO_2$ emissions were estimated using the formulae in a spreadsheet developed especially for computation of Carbon Footprint based on IPCC guidelines (IPCC, 2006). The data related to sources emitting GHG were collected from the respective terminals.

#### - Boundaries

This study includes the four container terminals in Mumbai, namely, Gateway Terminals India (GTI), Nhava Sheva Inland Container Terminal (NSICT), Jawaharlal Nehru Port Container Terminal (JNPCT) in Jawaharlal Nehru Port Trust (JNPT) as well as Indira Container Terminal (ICT) in Mumbai Port Trust

(MbPT). In this study only 2 km of the maritime boundary of the ports is used because this is the distance at which ocean going vessels stop using their main engines at full speed and start using auxiliary engines to enter the port (Chowhan et al., 2012).

### - Scopes

The GHG emission sources in these terminals include (Chowhan et al., 2012):

- Sea based emissions which include the vessel related emissions result from ocean going vessels (OGV) arriving and departing from the port, hoteling, and maneuvering
- Land-based emissions which include all the GHG emissions due to activities carried out in the port. These result in the consumption of electricity, fuel, and heating and generation of waste.

These sources are categorized into 3 scopes which are (Chowhan et al., 2012):

- Scope 1: On-site fuel consuming sources
- Scope 2: Electricity consuming sources
- Scope 3: Other sources usually rented by the ports

### - Methodology

The methodology adopted for this study is mainly from WPCI (2010), GHG protocol (WRI and WBSCD, 2004) and ISO 14064 (2006). In order to estimate emissions an excel file was developed using IPCC guidelines (2006) as the base reference. The collected data were converted to the suitable unit by making appropriate assumptions.

### - Results

The highest emissions in scope 1 were found due to the Rubber Tyre Gantry crane (RTGC) used to moves on rubber tires. It accounted for 63%, 92 %, 56% and 90% of total $CO_2$ emitted at GTI, JNPCT, NSICT and ICT terminals, respectively. Tractor Trailer (TT) was the second largest $CO_2$ emission source among the sources considered in Scope 1.

In the case of Scope 2 emissions, the refrigerated containers (reefers) accounted for maximum emission (47% and 65% of total $CO_2$ emitted for GTI and NSICT terminal respectively).

In the case of Scope 3, all the emissions were accounted together. For terminal GTI, NSICT and JNPCT it was estimated an emission value of 4.51 Gg $CO_2$ per annum per terminal. However, it was estimated that in scope 3 category, the auxiliary engine of the berthed ships contributed the most to the carbon foot printing (Chowhan et al., 2012).

### - Strengths and weaknesses

The strength of this study is that the calculation has been done based on the reliable guidelines and all the scopes are taken into account. However, the used formulae and the detail of the method are not presented. Another weakness of this method is that emissions from business travel and commuting of personnel are not calculated.

## 2.2.2. Container Terminal Ports in the Netherlands

A study from Van Duinand Greelings (2011) provides insight into the processes of container handling and transshipment at the terminals in the Netherlands and calculates the contribution of these processes to the $CO_2$ emissions.

### - Boundaries

For this study, the 12 terminals have been selected: The Delta, Home and Hanno terminals of ECT, the APM terminal, the Rotterdam Short sea Terminal (RST) and the Uni port Multi purpose Terminal (UNIPORT) in the Rotterdam region and three inland terminals Bossche Container Terminal (BCT), Container Terminal Nijmegen (CTN), and Wanssum Intermodal Terminal (WIT). The selection of the terminals was based on their willingness to provide the necessary data to validate the model (Van Duin & Geerlings, 2011).

### - Scopes

The scopes are not defined.

### - Methodology

An activity-based emission modeling was applied to develop a methodology for the calculation of emissions caused by the container terminals. This model includes a bottom-up calculation of the amount of work supplied by equipment, not using the amount of fuel as input, but as the result of the model. This study is based on a quantitative analysis of the energy consumption of terminal processes and the related $CO_2$ emissions (Van Duin & Geerlings, 2011).

### - Results

For the selected terminals the total $CO_2$ production is around 157 ktonnes. The analysis of the emission model shows that compared with the electrically powered equipment, the diesel-powered terminal equipment represents a large fraction of the total harbor wide $CO_2$ emissions by transshipment processes (Van Duin & Geerlings, 2011).

### - Strengths and weaknesses

One advantage, of this model is the usage of macro-level data such as the number of transshipments at the terminal and the deployment of various types of equipment, each with a different energy-consumption pattern, coupled with standard routes with average distances and average energy consumption.

The main weakness of this model is that scopes are not defined. Another weakness of this model is the rough estimates used for the energy consumption. In addition, many emission sources such as emissions from cargo handling equipment, construction equipment, harbor crafts and wastes are excluded.

## 2.2.3. Container Terminal in the port of Kaohsiung

In a research from Yang (2017),$CO_2$ emissions from two different container terminal (tire transtainers (TT) and rail transtainers (RT)) in the port of Kaohsiung (Taiwan) were investigated by the Carbon Footprint analysis. This research compared the emissions from April to June 2014.

### - Boundaries

The boundaries of this study include the berthing area, container yard and gate area of the two companies in the port of Kaohsiung (Taiwan).

### - Scopes

The scopes are not defined.

- **Methodology**

The total energy consumption of each type of equipment was calculated as the total working time of that equipment multiplied by the equipment's energy consumption per hour. The average energy consumption of equipment was calculated as the equipment's total energy consumption divided by the quantity of equipment. Finally, the $CO_2$ emissions of each piece of equipment were obtained from an average energy consumption for that piece of equipment multiplied by the $CO_2$ emission coefficient (Yang, 2017).

- **Results**

The results of this research show the carbon emissions of each operating model for each export container were 16.68 kg for the TT model and 12.3 kg for the RT model (Yang, 2017).

- **Strengths and weaknesses**

The strength of this method is that the calculation has been done based on a clear methodology. The main weakness of this method is that scopes are not defined and emissions from many sources such as vessels and wastes are excluded from the calculation. Another weakness of this method is that the emissions from import containers or transshipment containers are not taken into account and the sailing schedule is not taken into consideration either.

## 2.3. Ships

In this section, researches regarding the calculation of GHG emissions from ships and vessels are studied in more detail, since they could be useful for the development of the new tool.

### 2.3.1. $CO_2$ emissions from port vessel operations in the port of Incheon

In a paper from Chang et al (2013), GHG emissions from port vessel operations in the port of were measured. The GHG emissions were estimated based on the type and the movement of each vessel from the moment of its arrival to its docking, cargo handling and departure. The estimation was done by the use of the bottom-up approach based on individual vessels' characteristics and using data on vessels provided by the port in 2012.

- **Boundaries**

The boundaries include the movement of a vessel from the moment of its arrival to its docking, cargo handling and departure.

- **Methodology**

Chang et al (2013) estimated GHG emissions by individual vessels at every stage of their movement from the moment of their port entry to their departure. To capture fuel consumption and the corresponding GHG emissions across these stages, the paper first estimated how much fuel a vessel consumes during its movement based on various vessel characteristics. The fuel consumption of vessels was estimated based on the characteristics of the main engines and auxiliary engines by navigating distances. The fuel consumption by a vessel at each stage of its port movement is denoted as (Chang et al., 2013):

$$F_{ijk} = \left[ MF_k \cdot \left( \frac{s_{1k}}{s_{0k}} \right)^3 + AF_k \right] \cdot \frac{d_{ij}}{24 s_{1k}} \qquad \text{(Equation 2.22)}$$

Where:
$F_{ijk}$: The amount of fuel consumed by a vessel k moving from point i to j (kg)
$MF_k$: The daily fuel consumption by the main engine (kg)
$s_{1k}$: The vessel's operating speed (nm/h)
$s_{0k}$: The vessel's design speed (nm/h)
$AF_k$: The daily fuel consumption by the auxiliary engine (kg)
$d_{ij}$: The distance from i to j

After the calculation of fuel consumption, $CO_2$ emissions were estimated based on fuel combustion. Although the type of fuel used by vessels can vary, it is generally accepted that marine bunker fuel (residual marine oil, a widely used type of fuel) contains 86.4% of carbon per unit weight. In addition, the ratio of $CO_2$ to carbon is known to be 44/12. Therefore, $CO_2$ emissions from fuel combustion can be estimated as follows (Chang et al., 2013):

$$CO_2 = (0.8645) \cdot (44/12) \cdot \sum_{i,j,k} F_{ijk} = 3.17 \cdot \sum_{i,j,k} F_{ijk}.$$ (Equation 2.23)

Where:
$F_{ijk}$: The amount of fuel consumed by a vessel k moving from point i to j (kg)

Finally, Equation 2.22 is inserted into equation 2.23 to estimate $CO_2$ emissions (Chang et al., 2013):

$$CO_2 = 3.17 \cdot \sum_{i,j,k} \left[ MF_k \cdot \left( \frac{s_{1k}}{s_{0k}} \right)^3 + AF_k \right] \cdot \frac{d_{ij}}{24 \cdot s_{1k}}$$ (Equation 2.24)

The data required for estimating GHG emissions based on Equation 2.24 (the same as explained in equation 2.22) include fuel consumption by the main engine ($MF_k$) and the auxiliary engine ($AF_k$) based on the type of vessel and the stage of the vessel's movement, the operating speed ($s_{1k}$) at each stage of the vessel's movement and the design speed ($s_{0k}$) by vessel type, and the navigation distance at each stage of vessel movement ($d_{ij}$).

The data were obtained from the Incheon Port Authority database, and included 13,829 vessels present at the POI from January to October 2012. The set included two navy vessels and 43 vessels with missing data; these vessels were excluded for the final sample of 13,784 vessels. Each vessel had information on the time of its port arrival, arrival point (anchorage area number) and its docking time, assigned berth number, undocking time, departure time, gross tonnage, nationality, vessel type, call number, cargo type, and cargo amount.

**- Results**

Based on the results of this research, the $CO_2$ emissions at POI for 10 months in 2012 were 370,000 tonnes. The results show that vessels passing through lock gates emit 210,000 tonnes of $CO_2$. Maneuvering to the dock after lock gates accounts for 140,000 tonnes. Therefore, these two activities account for 96% of the POI's $CO_2$ emissions. By contrast, maneuvering to lock gates after port entry produces only 11,000 tonnes, anchorage and approaching to the dock together 6600 tonnes and the docking process for cargo handling emits 2400 tonnes of $CO_2$.

The results indicate among various types of vessels, international car ferries are the heaviest emitters, followed by full container vessels and car carriers (Chang et al., 2013).

### - Strengths and weaknesses

The strength of this study is that a well-developed method and formulae for calculating the GHG emissions were used. However, emissions from the vessels passing through lock gates are not well defined, since it is not clear if they are occurring inside the port or just at its boundaries. In addition, only $CO_2$ emissions were calculated and other GHG were excluded.

## 2.3.2. GHG emissions from ships in the port of Gothenburg

In a research by Winnes et al. (2015), the potential reductions of ships' GHG emissions due to the implementation of different measures by ports were quantified. This research presents a case study of the ship traffic in the Port of Gothenburg in 2010.

### - Boundaries

The boundaries of this study include calculation of the emissions from diverse types of vessels operations in the traffic area, including fairway channel, at anchor, in the port basin, maneuvering and at berth (Winnes et al., 2015).

### - Methodology

In this research projections of ship emissions in the port area for 2030 were made, and four scenarios were analyzed (Winnes et al., 2015):

- Scenario1: Usage of an alternative fuel which include transition from fuel oil to LNG-fuel with a100-year time horizon
- Scenario 2: Usage of an alternative fuel which includes transition from fuel oil to LBG (Liquefied Bio Gas) fuel with a 20-year time horizon
- Scenario 3: Improvement of ship design to reduce $CO_2$ emissions
- Scenario 4: Improvement of operations such as speed reduction and lay time reduction at berth

These scenarios are compared to a business as usual (BAU) scenario.

The data used for the analysis include port call statistics and technical data for individual ships. The model differentiates between ship types and ship sizes, as well as between operational modes.

For each ship call, engine emissions are calculated as the product of an emission factor, the utilized engine power and time. Emissions of the GHGs due to $CO_2$, $CH_4$ and $N_2O$ are included and calculated as $CO_2$equivalents (Winnes et al., 2015).

### - Results

The amount of $CO_2$-eq emissions and the number of ship movements are presented in Table 2.18. These calculations are carried out on a 'per call' basis. As it can be seen, 31.4% of ship calls[30] are for 'ferry/RoRo' and 21.9% for 'Dry and liquid bulk' and these two are the ones with the highest amount of the $CO_2$-eq emissions (Winnes et al., 2015). However, when the ratio between the emissions of $CO_2$-eq and ship calls is applied, the type of the ships with the highest emissions are the 'Cruise' followed by the 'Dry and liquid bulk'. The total ratio of emissions per ship call is 15.3.

[30] Call: An intermediate stop for a ship on its scheduled journey for cargo operation or taking on supplies or fuel. For the cruise ship, it is the premier stop from where they take on passengers for their cruise holidays.

**Table 2.18: Number of ship movements of different ship categories and their $CO_2$-eq emissions in Port of Gothenburg 2010 (Adapted from (Winnes et al., 2015))**

| | Ferry/RoRo | Container | Dry and liquid bulk | Cruise | General cargo | Bunker ships | Other | Total |
|---|---|---|---|---|---|---|---|---|
| Number of ship calls including passing ships | 4297 (31.4%) | 1211 (8.8%) | 3007 (21.9%) | 41 (0.29%) | 1343 (9.8%) | 3600 (26.3%) | 177 (1.3%) | 13,676 (100%) |
| Emissions of $CO_2$-eq (tonnes), 2010 | 85,800 | 30,200 | 79,800 | 1450 | 4360 | 9330 | 3600 | 210,000 |
| Emissions/ number of ship calls ($CO_2$-eq tonnes per call) | 19.9 | 24.9 | 26.5 | 35.3 | 3.2 | 2.6 | 20.3 | 15.3 |

Another important aspect is the location of emissions in the port. Figure 2.13 shows how $CO_2$-eq emissions are divided into different operational modes. The majority of $CO_2$-eq emissions (53%) in the Port of Gothenburg are originated "at berth" mode. Emissions from ships in the fairway channel[31] account for 23% of total $CO_2$-eq emissions, whereas emissions from anchored ships, ships in the port basin, and ships maneuvering to and from quayside position account for 10%, 9% and 5%, respectively (Winnes et al., 2015).

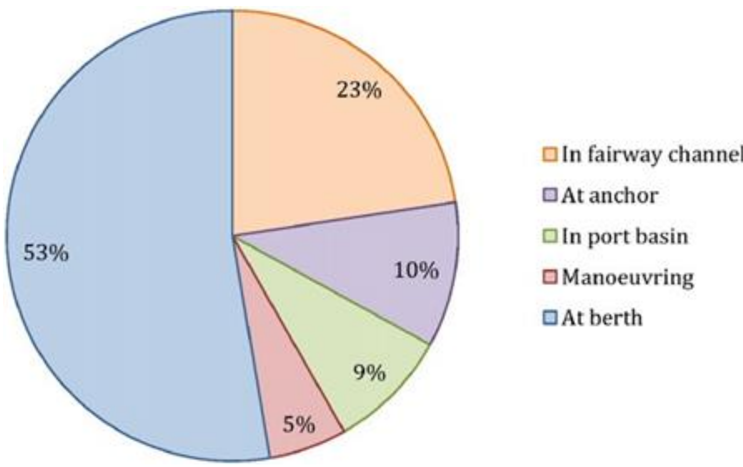


**Figure 2.13: $CO_2$-eq emissions based on different operational modes in the Port of Gothenburg in 2010 (Winnes et al., 2015)**

In Table 2.19, the total modeled emissions in 2030 from each ship type category are presented for the different scenarios. As it can be seen, the category "Dry and liquid bulk" contributes the highest to emissions in all scenarios. Largest emission reductions from this category occur in Scenario 3, 'Operation'. This scenario results in significantly higher reductions for each individual ship type than the other scenarios. The operational measures that contribute most to the emission reductions in the 'Operation' scenario are reduced speed and reduced lay time at berth. The later one depends on fuel consumption in auxiliary engines and boilers, and time at berth. $CO_2$-eq emissions show 3% reduction in Scenario 1 'Fuel' when considering the global warming potential with a 100-year time horizon. If viewed in a 20-year time horizon, it increases by 3% compared to BAU. Design scenario show a slight reduction compared to BAU (Winnes et al., 2015).

[31]A navigable deep-water channel in a river or harbor or along a coastline

**Table 2.19:Total emissions of $CO_2$-eq divided between ship type categories in the different scenarios, Port of Gothenburg 2030 (Winnes et al., 2015)**

| | Ferry/RoRo | Container | Dry and liquid bulk | Cruise | General cargo | Other | Total |
|---|---|---|---|---|---|---|---|
| Scenario “BAU” | 103,000 | 35,400 | 104,000 | 1810 | 5860 | 4880 | 255,000 |
| Scenario 1 “Fuel”—100 year time horizon | 99,300 | 33,700 | 102,000 | 1710 | 5750 | 4780 | 247,000 |
| Scenario 2 “Fuel”—20 year time horizon | 106,000 | 35,900 | 108,000 | 1820 | 6100 | 4980 | 262,000 |
| Scenario 3 “Design” | 102,000 | 35,000 | 103,000 | 1780 | 5590 | 4880 | 252,000 |
| Scenario 4 “Operation” | 89,400 | 30,600 | 98,000 | 1490 | 5260 | 4610 | 229,000 |

#### - Strength and weakness

The strength of this method is that calculation has been done for different scenarios and different time horizons. In addition, different types of ships are taken into consideration. The weakness of this study is that the method of calculation is not provided.

### 2.3.3. GHG emissions from shipping on the Thames and other navigable waterways in the Port of London

The Port of London Authority (PLA) and Transport for London (TfL) requested to Aether[32] and TNO[33] to prepare an inventory of air emissions from shipping on the Thames and other navigable waterways in the Port of London (Williamson et al., 2017).

#### - Boundaries

The geographical boundaries of this project comprise the Port of London, the Thames, its tributaries and connected waterways, between Teddington and Southend. The base year for this inventory is 2016 (Williamson et al., 2017).

#### - Methodology

Figure 2.14 provides an outline summary of the methodology of this study. As it can be seen, in the first step the required data were obtained from LLI data sources[34] and AIS[35].Standard emissions factors were adjusted according to ship and movement characteristics to produce near unique factors for each individual AIS message (Williamson et al., 2017).

Back calculations for 2010 and 2013 were made based on aggregated activity data on ship movements within the Thames Estuary, including some AIS data for 2013, combined with adjustments to emission factors based on changes in fuel quality and other sectoral trends. Forward projections for 2020, 2025 and 2030 were made (Williamson et al., 2017).

The outputs from these calculations were aggregated according to vessel type. The initial step is to split activity, as represented by AIS messages, into “sailing and maneuvering” and “at berth”. Vessels with a speed of less than 0.5 knots over a continuous period of over 15 minutes were assumed to be at berth.

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[32]Aether was founded in 2008 by senior members of the UK’s national emission inventory team. Aether provides consultancy in air quality and Climate Change emissions inventories, forecasting and policy analysis. They also provide air quality assessments for property developers.

[33]NederlandseOrganisatievoorToegepastNatuurwetenschappelijkOnderzoek (TNO: Netherlands Organization for Applied Scientific Research) was established in 1932. It is an independent research organization in the Netherlands that focuses on applied science.

[34](LLI)Lloyd's List Intelligence provides an interactive online service (www.lloydslistintelligence.com) offering detailed vessel movements, real-time AIS positioning, comprehensive information on ships, companies, ports and casualties as well as credit reports, industry data and analysis including short-term market outlook reports.

[35]The Automatic Identification System (AIS) is an automatic tracking system that uses transponders on ships and is used by vessel traffic services.

Regarding GHG emission, in this study $CO_2$ and $CH_4$ were calculated. $N_2O$ was not included as shipping was not considered a significant source according to Williamson et al (2017).

The calculated emissions were assigned to the geographical locations, based on AIS messages or known ship tracks, and those locations were matched to grid cells. The emissions for each grid cell were then aggregated to give a total for that cell for each vessel type, which were further aggregated to give total shipping emissions for each pollutant. The results of this aggregation process were then used to produce the Tables and charts and were also exported into a GIS program to produce the emission maps.

Emissions for 2016 are then used as a baseline from which to 'back cast'[36] emissions for previous years and to project forwards to estimate future emissions. A range of different factors affect emissions over time and these need to be accounted for producing back casts and projections (Williamson et al., 2017)


**Figure 2.14: An outline summary of the methodology (Williamson et al., 2017)**

[36] Back casting is a planning method that starts with defining a desirable future and then works backwards to identify policies and programs that will connect that specified future to the present.

### - Results

Table 2.20 shows the $CO_2$ emissions from shipping for all ship types, over the whole period (baseline, back years and forward projections). As it can be seen, RoRo Cargo/Vehicles are the ship type with the highest $CO_2$ emission rates in the baseline year (2016) and also back years (2010 and 2013). Regarding forward projections (2020, 2025 and 2030), container ships are the ones that emit more $CO_2$.The total emission of the baseline year decreased compared to 2010 but it increased compared to 2013. The total emissions in the forward projections (2020, 2025 and 2030) will increase compared to 2016 (Williamson et al., 2017).

The process of upgrading to newer ships and engines will generally exert a downward trend in emissions, as will the global trend towards larger, more efficient sea-going ships. However, these influences are generally outweighed by the increase in freight being handled through the port and the increase in passenger numbers forecast through the Thames Vision project. This is particularly prevalent for the case of container ships and passenger vessels that are doubling $CO_2$emissions from 2010 to 2013. The rate of increase in $CO_2$ emissions slows between 2025 and 2030 as a result of the introduction of more fuel-efficient ships (Williamson et al., 2017).

**Table 2.20: $CO_2$ emissions from shipping for all years and ship types (Williamson et al., 2017)**

| Ship type | Emissions of $CO_2$ (tonnes) | | | | | |
|---|---|---|---|---|---|---|
| | **2010** | **2013** | **2016** | **2020** | **2025** | **2030** |
| Bulk carrier | 4,970 | 4,900 | 4,993 | 5,110 | 5,787 | 5,745 |
| Chemical/LNG/LPG tanker | 26,859 | 8,712 | 11,142 | 10,878 | 10,989 | 10,134 |
| Container ship | 37,226 | 32,357 | 39,101 | 61,939 | 83,490 | 92,824 |
| Cruise ship | 1,136 | 969 | 4,467 | 4,832 | 6,050 | 7,169 |
| Fishing | 47 | 47 | 48 | 45 | 51 | 52 |
| General Dry Cargo | 7,465 | 7,932 | 10,589 | 14,159 | 18,275 | 19,905 |
| Non Merchant | 343 | 340 | 866 | 937 | 1,173 | 1,390 |
| Oil tanker | 31,177 | 18,993 | 19,431 | 18,986 | 19,114 | 17,572 |
| Passenger | 22,188 | 22,038 | 27,502 | 29,748 | 37,249 | 44,136 |
| Reefer | 80 | 30 | 31 | 29 | 33 | 34 |
| RoRo Cargo/Vehicle | 39,327 | 36,925 | 40,145 | 40,515 | 47,515 | 49,202 |
| Tug/Supply | 16,292 | 13,918 | 18,200 | 18,675 | 21,137 | 20,995 |
| Dredgers | 18,002 | 18,002 | 14,794 | 16,678 | 18,611 | 18,843 |
| Other miscellaneous | 4,633 | 4,480 | 4,042 | 4,546 | 5,078 | 5,161 |
| All Vessels | 209,743 | 169,643 | 195,350 | 227,075 | 274,553 | 293,162 |

### - Strength and weakness

The strength of this method is that a good study plan is provided. In addition, different types of vessels are taken into account.

The main weakness of this method is that the formulae of calculation are not presented. Although, it was mentioned that $CH_4$emissions were calculated, only the $CO_2$ emissions are presented in the result and the other GHG emissions are not included.

### 2.3.4. GHG emissions from port vessel operations at the Lagos and Tin Can ports of Nigeria

GHG emissions from port vessel operations in the Lagos and Tin Can ports of Nigeria were estimated by Olukanni and Esu (Olukanni & Esu, 2018). The estimate of emissions was carried out based on the type of the vessel and its movement. The calculation was done by using the bottom-up approach based on the characteristics of individual vessels and using data on vessels processed by both ports in the first and second quarters of the year 2017.

### - Boundaries

The boundaries include from the moment the vessel enters the port (Lagos and Tin Can ports of Nigeria) to the point of unloading and exit (Olukanni & Esu, 2018).

### - Methodology

In this study, the $CO_2$ emissions were calculated based on the fuel consumption by each type of vessel (fuel consumption by both the main and auxiliary engine) over it movement in the port.

Based on the success of previous works from Taiwan's Kaohsiung harbor and Korea's Port of Incheon (mentioned in sections 2.2.3 and 2.3.1) in calculating $CO_2$ emissions and the type of data available from the Nigeria Port Authority (NPA), their method was adopted to calculate the emissions from port vessel operations at the Lagos and Tin Can ports of Nigeria (Olukanni& Esu, 2018).

The data acquired from the NPA database show that a total of 1,275 vessels were processed from January to June (first and second quarter) of 2017: Lagos (595) and Tin Can ports (680), excluding Navy vessels (Olukanni & Esu, 2018).

### - Results

Table 2.21 shows the total $CO_2$ emissions based on the ship type. The data obtained covered 6-months (January to June) in 2017. As it can be seen, the total $CO_2$ emissions in these ports are 8,167,296 kg. Among various types of vessels, Premium Motor Spirit[37] (PMS) carriers are the heaviest emitters, followed by the container vessels and general cargo vessels (Olukanni & Esu, 2018).

**Table 2.21: The total $CO_2$ emissions based on the ship type (Olukanni& Esu, 2018)**

| Ship types | Total $CO_2$(kg) |
|---|---|
| LNG Carrier | 315,402.6 |
| LPG Carrier | 282,401.4 |
| Cement ship | 686,796.5 |
| PMS (Premium Motor Spirit) | 1,297,670 |
| General cargo vessel | 919,777 |
| Jet A-1 | 619,574.3 |
| AGO | 671,558.1 |
| Container vessel | 1,125,409 |
| Passenger ship | 305,252.1 |
| Used vehicle carrier | 856,532.1 |
| Dry bulk carrier | 306,576.8 |
| Chemical products | 375,827.1 |
| Other chemicals | 404,518.4 |
| **Total** | **8,167,296** |

### - Strength and weakness

The strength of this study is that the calculation method was chosen based on the success of previous works. In addition, different types of vessels were taken into account. The weakness of this method is that it is not clear if all GHG were calculated or just $CO_2$ emissions were taken into account.

[37] Premium Motor Spirit refers to petrol or gasoline which is used to power internal combustion engines mostly in vehicles and generators.

## 2.4. Comparison of the strengths and weaknesses of the different methodologies

As in can be seen in this chapter, in recent years many ports have started to calculate their Carbon Footprint and report it. However, each port uses each own method and this does not allow establishing a sector benchmark or comparing the results between different ports. There is no single, unified method to calculate Carbon Footprint in ports. The strengths and weaknesses of each methodology that have been presented previously are summarized in Table 2.22.

**Table 2.22: The strengths and weaknesses of the existing methodologies**

| Case Study | Strengths | Weaknesses |
|---|---|---|
| The port of Gijón | ✓All direct and indirect emissions are included<br>✓All scopes are included<br>✓The footprint from the consumption of all goods and services are taken into account<br>✓The footprint from the wastes generated by a company are calculated<br>✓The possibility of adding or modifying the factors used, are allowed in calculation sheet<br>✓The used method has been recognized by the Spanish Observatory for Sustainability as a valid methodology for assessing and reducing GHG emissions<br>✓ The good explanation of the methods are presented | × Only $CO_2$ emissions are calculated and other GHGs are not taken into account<br>× Regarding fuel consumption (direct emissions), the types of sources were not specified<br>× The emissions from the employees' commuting are not taken into account<br>× The emissions from the vessels (scope 3) are not taken into account |
| Ports of Long Beach and Los Angeles | ✓ The well-developed explanation of the calculation methods for each emission source are presented<br>✓ Emissions from vessels are taken into account<br>✓ All GHG are taken in to account | × The calculation is not classified in scopes<br>× Scope 2 (emissions related to electricity consumption) is not taken into account<br>× Emissions from construction equipment are not included in the calculation<br>× Emissions from waste are neglected<br>× Emissions from stationary sources are not included<br>× It is not clear if emissions from the employees' commuting (scope 3) is included or not |
| The Port of Oslo | ✓ The calculation has been done based on ISO 14064 standard that derives from GHG protocol<br>✓ The calculation includes all emission sources required by this standard<br>✓ All scopes are taken into account<br>✓ Emissions from vessels are taken into account | × The emissions resulting from energy use in rented out buildings are excluded from the Carbon Footprint<br>× The emissions from the terminal operators activities are not calculated<br>× emissions from waste operations are not calculated<br>× Activity data are partly based on measurement and partly based on estimates<br>× If the data were not available, expert estimates were made |
| Climeport | ✓ The calculation has been done by using a web-based tool and it has been developed based on the diverse standard methods (ISO 14064, IPCC and WPCI)<br>✓ The user guideline is freely available (MED, 2012b)<br>✓ The Climeport results have been quantified by means of dividing the total emissions by total cargo, which is an accurate and useful indicator and easy to manage by any organization<br>✓ Emissions from vessels are calculated | × Access to the tool is not available<br>× The scopes are not defined based on the standard guidelines<br>× The emission sources are not specified |
| The port of San Diego | ✓ This method be used for environmental review of future projects<br>✓By using this method track progress towards State regulations could be possible<br>✓By adapting CAP, key vulnerabilities within the Port will be evaluated and prioritized<br>✓ In this method emissions from all tenants and activities at the Port are calculated<br>✓Emissions from vessels are taken into account | × This method it is not specific for ports<br>× Explanation about the formulae and methods which are used for the calculation of GHG gases are not given<br>× The scopes are not specified<br>× It is not clear if the calculation of emission from the employees' commuting is included in on-road transportation or not<br>× Emissions from natural gas consumption are not specified based on the sources<br>× It is not mentioned if the emissions from cargo handling equipment and construction equipment are calculated or not |

| | | |
|---|---|---|
| The Port of Rotterdam | ✓ Scopes are defined and classified separately<br>✓ Emissions from maritime transport and Berthed ships are taken into account | × The results are not presented by scope<br>× The emissions from tenants are not taken into account<br>× Methodology of calculation is not given<br>× It is not mentioned if the emissions from cargo handling equipment and constructional equipment are calculated or not<br>× It is not clear if all the GHG emissions are included in the calculation or it is just $CO_2$ |
| The Port of Stockholm | ✓ All emission sources "direct emissions" and "indirect emissions" are taken into account<br>✓ All scopes are taken into account<br>✓ Emissions from vessels are taken into account | × The details of the methodology are not presented<br>× It is not specified what kind of sources are included in the direct emissions from the fuel<br>× Concerning the employees' commuting, only emissions from air travel are calculated<br>× Emissions from waste operations are not taken into account |
| The port of Gothenburg | ✓ The calculation has been done based on a standard method (GHG protocol)<br>✓ All scopes are taken into account<br>✓ Emissions from vessels are calculated | × The detail of the methodology is not presented<br>× It is not clear if the emissions from cargo handling equipment and construction equipment are calculated or not<br>× Emissions from waste are not included in the calculation |
| The Port of Barcelona | ✓ An attempt to calculate $CO_2$ emissions in the Port Authority is done<br>✓ All GHG are taken in to account | × The methodology is not explained<br>× Scope 3 (emissions from tenant and employees' commuting) is not taken into account<br>× Emissions from energy consumption are not classified on the later sources and it is not clear which sources are included and which ones are not<br>× Emissions from waste operations are not calculated |
| Ports de la Generalitat | ✓ The calculation has been done by the use of Excel based tool<br>✓ The tool has been developed based on standard methods<br>✓ The tool is freely available<br>✓ All GHG are taken into account | × Emissions from scope 3 are not calculated<br>× Only the emissions from water consumption are taken in to account in scope 3<br>× The tool is not port specific<br>× Scopes are not defined based on the standard methods |
| The Port of Chennai | ✓ The calculation has been done based on a standard method (WPCI guidance document)<br>✓ Emissions from vessels are calculated in scope 1<br>✓ All GHG are taken into account | × The scopes are not classified based on this guideline<br>× Emissions from the tenants are calculated in scope 1, where they should be calculated in scope 3, according to WPCI (WPCI, 2010)<br>× Emissions from waste are not calculated<br>× Emissions from employees' commuting (Scope 3) are not considered |
| the Port Authority of the Ferrol – San Cibrao | ✓ The calculation has been done based on a standard method (MITECO tool)<br>✓ All GHG are taken into account | × Scope 3 emissions are not calculated<br>× Many sources are excluded<br>× Emissions from waste are not taken into account<br>× Emissions from vessels are not calculated<br>× Emissions from employees' commuting (Scope 3) are not considered |
| Giurgiulesti International free port | ✓ More than 95% of the data used for the calculation of emissions are based on real measurements of fuel and energy consumption. This provides a high level of accuracy of the calculated emissions.<br>✓ All GHG are taken into account | × The calculation of the $CO_2$ footprint does not include the resident and tenant companies (Scope 3)<br>× Emissions from employees' commuting(scope 3) are not taken into account<br>× Emissions from waste are not calculated |
| The Port of Taichung | ✓ An organized approach (The GHG inventory tools) is used<br>✓ Emissions from vessels are calculated<br>✓ All GHG are taken into account | × The scopes are not classified and it is not clear what kind of sources are included in each category<br>× The GHG emissions of heavy industry (A1) zone which includes a coal-fired power plant and a crude steel plant are excluded from the calculation<br>× The emissions from the export-processing (B1) zone which contains 76 factories are not taken into |

| | | |
|---|---|---|
| | | account<br>× The used tool is not available<br>× Emissions from waste operations are not calculated |
| The Port of Olympia | ✓ The calculation has been done using the Washington State Agencies GHG calculator (an Excel-based tool)<br>✓ Emissions from vessels are calculated<br>✓ All GHG are taken into account | × The tool is not available<br>× The method and the formulae of the calculation are not provided<br>× Emissions from stationary combustion are not classified on sources<br>× It is not clear if emissions from cargo handling equipment and construction equipment are calculated or not<br>× Emissions from tenant activities (Scope 3) are not included in this GHG emissions inventory<br>× Emissions from employees' commuting are not calculated<br>× Emissions from waste are not calculated |
| Container Terminal Ports in Mumbai | ✓ The calculation has been done based on the reliable guidelines such as WPCI, GHG protocol and ISO 14064<br>✓ All the scopes are taken into account<br>✓ Emissions from vessels are taken into account | × The used formulae and the detail of the method are not presented<br>× Emissions from business travel and commuting of personnel are not calculated |
| Container Terminal Ports in the Netherlands | ✓ In this method, macro-level data are used such as the number of transhipments at the terminal and the deployment of various types of equipment, each with a different energy-consumption pattern, coupled with standard routes with average distances and average energy consumption | × The Scopes are not defined<br>× Rough estimates are used for the energy consumption<br>× Many emission sources such as emissions from cargo handling equipment, construction equipment, harbour crafts and wastes are excluded |
| Container Terminal in the port of Kaohsiung | ✓ The calculation has been done based on a clear methodology | × Scopes are not defined<br>× Emissions from many sources such as vessels and wastes are excluded from the calculation<br>× The emissions from import containers or transhipment containers are not taken into account<br>× The sailing schedule is not taken into consideration either |
| Port vessel operations in the port of Incheon | ✓ Well-developed method and formulae for calculating the GHG emissions | × Emissions from the vessels passing through lock gates are not well defined, since it is not clear if they are occurring inside the port or just at its boundaries<br>× Only $CO_2$ emissions were calculated and other GHG were excluded |
| Ships in the port of Gothenburg | ✓ The calculation has been done for different scenarios and different time horizons<br>✓ Different types of ships are taken into consideration<br>✓ All GHG are taken into account | × The method of calculation is not provided |
| Shipping on the Thames and other navigable waterways in the Port of London | ✓ A good study plan is provided<br>✓ Different types of vessels are taken into account | × The formulae of calculation are not presented<br>× Although it was mentioned that $CH_4$ emissions were calculated, only the $CO_2$ emissions are presented in the result |
| Port vessel operations at the Lagos and Tin Can ports of Nigeria | ✓ The calculation method was chosen based on the success of previous works<br>✓ Different types of vessels were taken into account | × It is not clear if all GHG were calculated or just $CO_2$ emissions were taken into account |

After reviewing all these methodologies, a set of conclusions about their main strengths and weaknesses were extracted and are summarized in Table 2.23 and explained below. The detail of how the percentages presented in this table have been obtained can be found in Appendix 2.

**Table2.23: The main strengths and weaknesses of the existing methodologies (Percentages)**

| Strengths and weaknesses of the existing methodologies | | Percentage (%) |
|---|---|---|
| Strengths | Inclusion of vessels 'emissions | 72.7 |
| | Consideration of the emissions from all the GHG | 63.6 |
| | Using standard methods | 59.1 |
| Weaknesses | No inclusion of all the emission sources | 94.4 |
| | No inclusion of the waste treatment emissions | 77.7 |
| | No classification of scopes based on the standards | 77.7 |
| | No inclusion of employees' commuting | 72.2 |
| | Using estimates for the calculation and not real data | 66.6 |
| | Exclusion of some of the recognized scopes or parts of them | 66.6 |
| | No inclusion of scope 3 in the calculation | 61.1 |
| | No access to the tool | 60 |
| | Not well-presented description of the method | 59.1 |

The main strengths of these studies are:

- In 72.7% of the methodologies, vessels' emissions are taken into account.
- In63.6% of the researches, not only $CO_2$ emissions are calculated, but also other GHG emissions are taken into account such as $CH_4$ and $N_2O$.
- In 59.1% of the cases, the calculation has been done based on standard methods such as GHG protocol, IPCC, WPCI and ISO14064.

The main weaknesses of these studies are presented below:

- In all of the cases, emissions from technical gases as a by-product of combustion and so called F-gases from cooling installations are neglected.
- In 94.4% of the studies, all the emission sources mentioned in standard guidelines (direct or indirect) are not calculated. Only some of these sources are taken into account.
- In 77.7% of the researches, emissions from waste operations that can take place in a port such as incinerators or waste water treatment plants are not included in the calculation.
- In 77.7% of the studies, scopes are not defined based on the standard methods.
- In 72.2% of the case, employees' commuting is not included.
- In 66.6% of the studies, estimation is used for the calculation and not real data.
- In 66.6% of the cases, some of the recognized scopes or parts of them are excluded.
- In 61.1% of the studies, the whole set of scope 3 emissions (i.e. emissions from tenant, vessels and employees' commuting) are not calculated.
- In 60% of the researches where a tool has been developed (five cases), the access to this tool is not possible.
- In 59.1% of the studies, the methodology is not fully described. Therefore, it is no possible to reproduce it.

Bearing in mind all these strengths and weaknesses, a new standardized tool will be developed. Such new tool will try to overcome all these weaknesses and include all the strengths. The development of the tool will be done based on the GHG protocol, IPCC and WPCI guidelines which will be described in more detail in the next chapter and the steps will be explained thoroughly to be reproducible. In addition, a well-developed explanation of the calculation methods will be presented.

Moreover, the three main GHG (carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$)) will be included in the new tool and the total amount will be presented as a $CO_2$eq, as it includes all three GHG emissions. In addition, the tool will provide options to select the scopes that are more suitable and applicable to each port.

As it has been presented, in some cases, the emissions from ships are excluded from the total $CO_2$ calculation. As the GHG emissions from international shipping in 2012 accounted for 2.2% of the total $CO_2$ emissions and that such emissions could grow by between 50% and 250% by 2050 (IMO,2014), it is necessary to include the calculation of emissions from waterborne vehicles in the new tool.

Moreover, the main weakness of these studies was that in most of the methods not all the emission sources mentioned in the standard guidelines (direct or indirect) were included in the calculation. In the new tool, the three scopes present in the guidelines and all the direct and indirect emission sources will be taken into account. However, emissions from technical gases as a by-product of combustion and so called F-gases from cooling installations will be neglected because these emissions have a negligible impact on the total Carbon Footprint since they are relatively small. That is the reason why most of the presented methodologies are not taken them into account.

In addition, in more than three fourths of the methods, emissions from waste treatment operations taking place in the port were not taken into account. The new methodology will also include emissions from waste treatment plants present in the port area such as incinerators, waste water treatment plants and others. They should be considered, where they exist, since they are sources of $CO_2$ emissions that should be counted in the total Carbon Footprint of a port.

The new tool will also take into account the emissions from employees' commuting that were neglected by some methods and it will include three different calculation options for the users as well, which will make the results more realistic.

This research also showed that there was not any unified and complete method to calculate GHG emissions and Carbon Footprint that allowed comparing results among different ports. Following the example of the successful experience of the CLIMEPORT project (MED, 2011), this new tool will allow to calculate the Carbon Footprint as a ratio between the total amount of $CO_2$eq and the total capacity of the port. This will enable comparing of the results of different ports standardizing on a common ground if they want to share these data. In addition, this tool will be freely available.

Finally, it should be mentioned that a paper with the results of this chapter has been published in the International Journal of Environmental Research and Public Health (Azarkamand et al., 2020b). It can be found in appendix 7.2 of this thesis.

# Chapter 3: Development of the tool

As mentioned before, in recent years, several international organizations and some ports have implemented measures to fight against Climate Change effects and to reduce $CO_2$ emissions. The review of different studies shows that in recent years many ports calculate their Carbon Footprint and report it but each port uses each own method. There is no standardized tool to do so. In addition, the emissions from some sources such as incineration plants, wastewater treatment plants and employees' commuting are excluded from calculation in many cases. There is not any unified and complete method to calculate Carbon Footprint that allows comparing results among different ports. This proves the need for such a methodology in ports. Therefore, a standardized tool has been developed to calculate GHG emissions for the three scopes in ports. The development of the tool has been done in Excel and Visual Basic software based on the WPCI (WPCI, 2010), IPCC guidelines (IPCC, 2006 and 2019b) and GHG Protocol (WRI and WBSCD, 2004). In this chapter, the used methods and standards for developing the new tool are introduced in more detail.

This chapter includes four main sections. In the first section, scopes and boundaries are explained based on the previously mentioned standards. The second section defines emission sources and pollutants. Then, the formulae used to develop the excel-based tool are presented. In the last part of this chapter, the new tool is introduced.

## 3.1. Defining scopes and boundaries of the tool

Among the different guidelines introduced in chapter 1 (section 1.3), the WPCI guidance document (WPCI, 2010) has been selected to define the scopes and boundaries due to its recognition in the port sector.

- **Scopes**

As mentioned in chapter 1, emission-producing activities for ports should be grouped into the following three scopes (WPCI, 2010):

**Scope 1**: Port Direct Sources. These sources are directly under the control and operation of the port administration entity and include port-owned fleet vehicles, port-administration owned or leased vehicles, buildings (e.g., boilers, furnaces, etc.), port-owned and operated cargo handling equipment, and any other emissions sources that are owned and operated by the port administrative authority.

**Scope 2**: Port Indirect Sources. These sources include port's purchased electricity for the port's administration owned buildings and operations. Tenant power and tenant energy purchases are not included in this Scope.

**Scope 3:** Other Indirect Sources. These sources are typically associated with tenant operations and include ships, trucks, cargo handling equipment, rail locomotives, harbor craft, tenant buildings, tenant purchased electricity, and the commuting of port authority and tenant-employees' commuting (train, personal car, public transportation, etc.).

### • Boundaries

An important consideration in the calculation of Carbon Footprint is the physical and operational area or domain that encompasses the activities. The boundary definition helps to answer the questions such as which activities are going to be included in the inventory. Boundary considerations for the three scopes are discussed below (WPCI, 2010):

**Scope 1 boundaries:** The boundary typically encompasses a local or regional area, where these sources are located and operate.

**Scope 2 boundaries**: They may be local or relatively close by, but they can also be remote from the port since electrical power can be transmitted over great distances.

**Scope 3 boundaries**: The boundary maybe global (for example, to include entire ocean voyages), national, regional or more local, such as a political border or the port's own administrative boundary.

## 3.2. Defining emission sources and pollutants

In order to define the emission sources of this tool, besides the WPCI guidance document (WPCI, 2010), the IPCC guidelines (IPCC, 2006 and 2019b) and the GHG protocol (WRI and WBSCD, 2004) have also been used to make the sourcing more complete. Pollutants have been chosen based on the WPCI guidance document (WPCI, 2010).

### • Recognition of the emission sources

Emission sources in ports are divided into four main groups: Mobile sources, Stationary sources, Purchased electricity and Employees' commuting which are described below (WPCI, 2010):

**- Mobile sources**

Greenhouse gas emissions are produced by mobile sources as fuels are burned. The mobile sources in ports are divided into six main groups (WPCI, 2010):

- Cargo handling equipment: backhoes, container handlers, cranes, forklifts, sweepers and yard tractors.
- On road vehicles: compressed natural gas (CNG) heavy duty truck, liquefied natural gas (LNG) heavy duty truck, propane heavy duty truck, diesel heavy duty truck and cars.

- Railroad locomotives: line haul locomotives and switchers locomotives[38].
- Port owned Vessels: assist tugboats, cleaning boats, commercial fishing vessels, crew boats, excursion vessels, Integrated/Articulated tug and barge, local ferries, pleasure craft, work boats, towboats and push boats and others.
- Ocean-Going Vessels (OGVs): auto carriers, containerships, dry bulk carriers, general cargo, integrated/articulated tug and barge, miscellaneous vessels, passenger cruise ships, passenger vehicle ferries, refrigerated vessels (Reefer), roll-on roll-off vessels (RoRos) and tankers.
- Construction equipment: It includes the equipment needed for port funded wharf and breakwater construction, channel and berth deepening dredging and maintenance, terminal development and redevelopment, street improvements, etc. Construction activities can involve various types of mobile and portable equipment, some of which are specialized for construction such as: portable concrete and asphalt batch plants, dredges (clamshell, excavator, pan, cutter-suction head, etc.), earth moving equipment (excavators, bulldozers, scrapers, trenchers, etc.), paving equipment and Portable worksite generators.

**- Stationary sources**

Stationary sources are the second group of sources emitting GHG found at ports. They typically account for significantly less GHG emissions than mobile sources. Stationary source emissions come from fixed, particular, identifiable, localized sources or facilities that use combustion processes. The main stationary sources in ports are (WPCI, 2010):

- Power plants: Industrial facilities used to generate electric power with the help of one or more generators that convert different energy sources into electric power. Some ports purchase electricity and some have power plants to produce it. Therefore, the scope of the calculation would be different.
- Boilers: Closed vessels in which water or other liquid are heated. As a consequence, steam or vapor is generated by the direct application of energy from the combustion of fuels or electricity which generates emissions.
- Portable or emergency generator: It can keep power running in an emergency.

Besides these groups, based on the IPCC guidelines (IPCC, 2006 and 2019b), two other stationary sources can be found in ports are: incineration plants and wastewater treatment plants. In addition, stationary sources include all other facilities that use combustion processes.

- Incineration plants: Waste incineration is defined as the combustion of solid and liquid waste in controlled incineration facilities. Different incineration types are: continues stocker, continues fluidized bed, Semi-Continues incineration stocker, Semi-Continues fluidized bed, Batch type stocker, batch type fluidized bed (IPCC, 2006 and 2019b).
- Other Facilities: All other facilities that use combustion processes.

[38]Line haul locomotives tend to be large (3,000 to 4,000 hp) and are used to move cargo over relatively long distances as goods are either picked up for transport to destinations across the country or dropped off for shipment overseas. In contrast, switching locomotives tend to be smaller (1,200 to 3,000 hp) and perform relatively short distance rail movements such as assembling and disassembling of trains at various locations in and around the Port and the hauling of rail cargo within the port.

- Wastewater treatment plant: There exist different types of waste water treatment plants such as untreated waste water treatment plant, aerobic treatment plant, aerobic treatment plant overloaded, anaerobic digester for sludge, anaerobic reactor, anaerobic shallow lagoon, anaerobic deep lagoon (IPCC, 2006 and 2019b).

**- Purchased electricity**

Purchased electricity includes buildings, lighting, reefer power demand, electrified cargo handling equipment, other terminal electrical demands, etc. Electricity consumption at the ports includes the energy used in the routine operation of the port authority and in the tenant facilities (i.e., lighting, instrumentation, comfort cooling, computers, ventilation, electrical vehicles, etc.), electrified cargo handling equipment (electric wharf cranes, electric rail-mounted gantries, electric rubber tired gantries, etc.), shore powering of vessels, tenant industrial facilities and reefer plugs. Even though electrified cargo handling equipment is typically thought of as mobile sources, from a GHG perspective, due to their electrification, the emissions from their operations are estimated based on purchased electricity.

**- Employees’ commuting**

As employees’ commuting is one of the main sources of GHG emissions in scope 3, based on the GHG protocol, this source was also included in the new tool. This category includes emissions from the transportation of employees between their homes and their worksites and business travels. Emissions from employees’ commuting may arise from automobile travel, bus travel, rail travel, air travel another modes of transportation (e.g., subway, bicycling, walking) (WRI and WBSCD, 2013).

Figure 3.1 demonstrates the relationship between all the scopes and emission sources that have been taken into account in the new tool. Emission sources in scope 1 are divided into mobile sources and stationary sources both related to the port authority. Scope 2 represents the emissions produced by the electricity purchased by the port authority. Scope 3 includes four main groups of sources related to tenants: mobile, stationary, purchased electricity and employees’ commuting. It should be mentioned that in scope 3, mobile sources, stationary sources and purchased electricity are the same as those presented for scope 1 and 2, just belonging to different generators (tenants in the case of scope 3). The only difference is the inclusion of ‘Ocean-Going Vessels’ in the mobile sources category of scope 3, whose emissions are not part of the port authority.

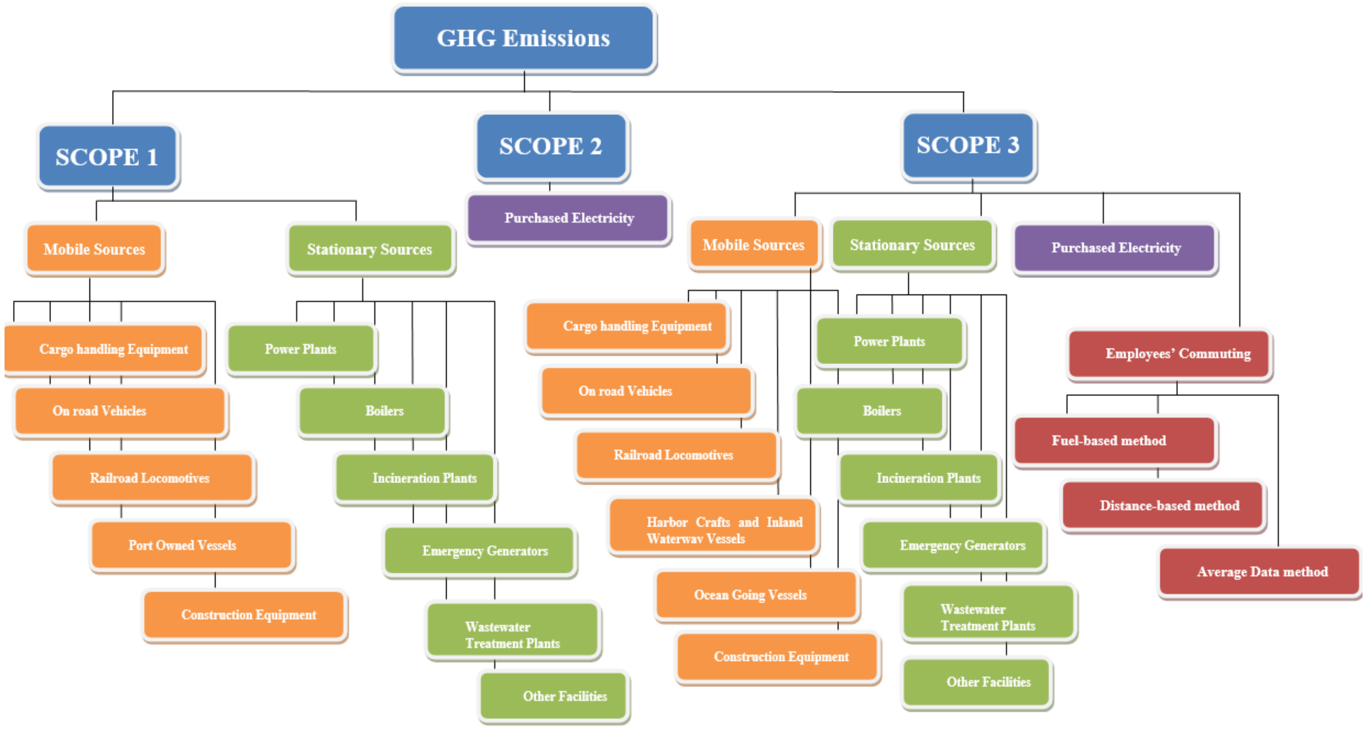



**Figure 3.1: Scopes and Sources of the tool**

- **Pollutants**

Numerous gases have been identified as having the potential to contribute to global Climate Change. The most common greenhouse gases associated with port-related operations are Carbon dioxide ($CO_2$), Methane ($CH_4$) and Nitrous oxide ($N_2O$)(WPCI, 2010). The new tool will include all three of them.

GHG vary in terms of their effectiveness in influencing Climate Change. As a convention, the gases are rated in comparison to the effectiveness of $CO_2$, so they can be compared. The term $CO_2$ equivalent ($CO_2$eq) is used to include the total amount of GHG gases emitted. For each gas, a value has been assigned to each gas in comparison with the $CO_2$, which is known as its global warming potential (GWP). GWP value for $CO_2$ is equal to 1 for 100-year time horizon, for $CH_4$ is equal to 28 and for $N_2O$ is equal to 265 (IPCC, 2015a).

**Table 3.1: Global Warming Potential of GHG in 100 years' time horizon adapted from (IPCC, 2015a)**

| Pollutants | GWP over 100 years |
|---|---|
| $CO_2$ | 1 |
| $CH_4$ | 28 |
| $N_2O$ | 265 |

## 3.3. Methods and formulae

The new tool should be user-friendly and easy to use. Among the different guidelines and methodologies presented, the IPCC guidelines and GHG protocol have been selected to choose the formulae and develop the new tool. In addition, as it was mentioned in chapter 1, UNFCCC COP3 which was held in 1997 in Kyoto reaffirmed that the IPCC guidelines for National Greenhouse Gas Inventories should be used as "methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases" (IPCC, 1996).

Generally, the calculation has been done based on the IPCC (2006 and 2019b). The Equation 3.1 has been used to calculate total emission in each scope:

$$E_{total} = \sum_{i=1}^{3} E_{Scope\ i} \qquad \text{(Equation 3.1) (IPCC, 2006)}$$

Where:
$E_{total}$ = Total mass of $CO_2$eq emissions (tonnes)
$E_{Scopei}$= Total mass of $CO_2$eq emissions of each scope i (tonnes)

In the next section, the formulae which have been used to calculate GHG emissions in the three scopes are explained.

### 3.3.1. Scope 1: Port authority direct sources

The emission sources of scope 1 are divided into 2 main groups: Mobile sources and Stationary sources. The emission sources of scope 1 are presented in Figure 3.2.

The formulation to calculate the emissions from this scope has been extracted from IPCC guidelines (IPCC, 2006 and 2019b). The total emissions of this scope are calculated by using Equation 3.2:

$$E_{Scope} = \sum_{i=1}^{n} E_n \qquad \text{(Equation 3.2) (IPCC, 2006)}$$

Where:
$E_{Scope}$ = Total mass of $CO_2$eq emissions for the scope (tonnes)
$E_n$= Total mass of $CO_2$ eq emissions for each source of scope 1(tonnes)

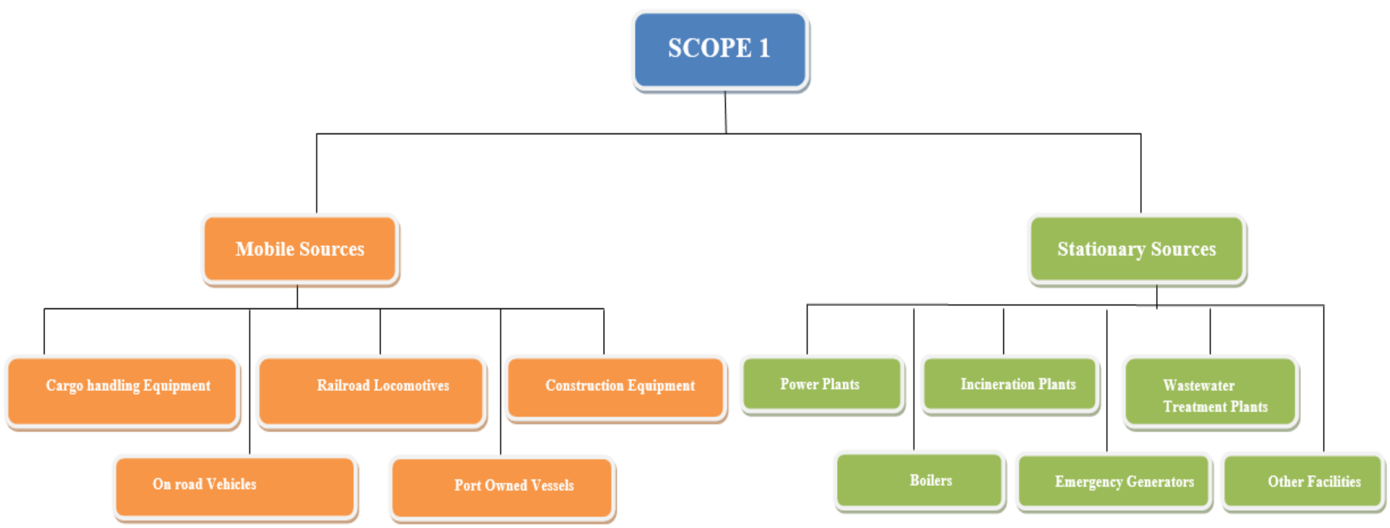



**Figure 3.2: The emission sources of scope 1**

Next, the formulae to calculate the mobile sources are presented.

## - Mobile sources (Scope 1)

The mobile sources related to scope 1 are presented in Figure 3.2. The calculation of $CO_2$eq emissions of these sources have been done by the use of Equation 3.3.

$$E_n = \sum_{i=1}^{3} E_n^i \qquad \text{(Equation 3.3)(IPCC, 2006)}$$

Where:

$E_n^i$ = Total mass of $CO_2$ eq emissions of sources in scope 1 (tonnes)
$E_n^i$ = Total mass of $CO_2$emissions of each source n (tonnes)

In order to calculate the $CO_2$ equivalent, Equation 3.4 has been used.

$$E_n^i(\, CO_2eq) = E_n^i \cdot GWP^{\ i} \qquad \text{(Equation 3.4)(IPCC , 2006)}$$

Where:

$E_n^i$ $(CO_2eq)$ = Total mass of $CO_2$eq (tonnes $CO_2$eq)
$E_n^i$ =Total mass of emissions of each gas i
$GWP^i$ = Global warming potential of each gas (tonnes $CO_2$eq/tonnes gas)

Finally, the calculation of the mobile sources emissions has been done by the use of Equation 3.5.

$$E_n^i = \text{Fuel Consumption} \cdot EF^i \qquad \text{(Equation 3.5)}$$

Where:

$E_n^i$ = Total mass of GHG emissions in each source (tonnes)
Fuel consumption = Amount of Fuel consumption (gal, l, $m^3$, kg, tonnes)
$EF^i$= Emission Factor for each gas (tonnes gas/ (gal, l, $m^3$, kg, tonnes))

Emission factors have been extracted from IPCC guidelines (IPCC, 2006). The calculation of emissions for each source is presented next.

## - Cargo Handling Equipment

Table 3.2 shows the emission factors to calculate the 3 main GHGs ($CO_2$, $CH_4$and $N_2O$) of Cargo handling equipment.

**Table 3.2: Emission factors for $CO_2$, $CH_4$ and $N_2O$ for the road transport (IPCC, 2006)**

ROAD TRANSPORT DEFAULT $CO_2$ EMISSION FACTORS AND UNCERTAINTY RANGES [a]

| Fuel Type | Default (kg/TJ) | Lower | Upper |
|---|---|---|---|
| Motor Gasoline | 69 300 | 67 500 | 73 000 |
| Gas/ Diesel Oil | 74 100 | 72 600 | 74 800 |
| Liquefied Petroleum Gases | 63 100 | 61 600 | 65 600 |
| Kerosene | 71 900 | 70 800 | 73 700 |
| Lubricants [b] | 73 300 | 71 900 | 75 200 |
| Compressed Natural Gas | 56 100 | 54 300 | 58 300 |
| Liquefied Natural Gas | 56 100 | 54 300 | 58 300 |

Source: Table 1.4 in the Introduction chapter of the Energy Volume.
Notes:
[a] Values represent 100 percent oxidation of fuel carbon content.
[b] See Box 3.2.4 Lubricants in Mobile Combustion for guidance for uses of lubricants.

ROAD TRANSPORT $N_2O$ AND $CH_4$ DEFAULT EMISSION FACTORS AND UNCERTAINTY RANGES [(a)]

| Fuel Type/Representative Vehicle Category | $CH_4$ (kg /TJ) | | | $N_2O$ (kg /TJ) | | |
|---|---|---|---|---|---|---|
| | Default | Lower | Upper | Default | Lower | Upper |
| Motor Gasoline -Uncontrolled [(b)] | 33 | 9.6 | 110 | 3.2 | 0.96 | 11 |
| Motor Gasoline –Oxidation Catalyst [(c)] | 25 | 7.5 | 86 | 8.0 | 2.6 | 24 |
| Motor Gasoline –Low Mileage Light Duty Vehicle Vintage 1995 or Later [(d)] | 3.8 | 1.1 | 13 | 5.7 | 1.9 | 17 |
| Gas / Diesel Oil [(e)] | 3.9 | 1.6 | 9.5 | 3.9 | 1.3 | 12 |
| Natural Gas [(f)] | 92 | 50 | 1 540 | 3 | 1 | 77 |
| Liquified petroleum gas [(g)] | 62 | na | na | 0.2 | na | na |
| Ethanol, trucks, US [(h)] | 260 | 77 | 880 | 41 | 13 | 123 |
| Ethanol, cars, Brazil [(i)] | 18 | 13 | 84 | na | na | na |

Sources: USEPA (2004b), EEA (2005a), TNO (2003) and Borsari (2005) CETESB (2004 & 2005) with assumptions given below. Uncertainty ranges were derived from data in Lipman and Delucchi (2002), except for ethanol in cars.

As it can be seen in the previous Table, the units are expressed in kg of GHG / TJ and, therefore, a conversion from Tera Joules to kg of the fuel is required. This conversion has been done using the Tables presented in appendix 3 (Table 1, 2 and 3), where the low heat value and the density of that fuel released by the combustion are given. In this way, Equations 3.6 and 3.7 can be applied:

$$E_n^i = Fuel\ consumption \cdot LHV \cdot FE^i \qquad \text{(Equation 3.6)}$$

Where:

$E_n^i$ = Total mass of GHG emissions in each source (tonnes)
Fuel consumption = Amount of Fuel consumption (kg or tonnes)
LHV = "LowHeatingValue" lower limit of the heat released by the combustion (TJ/(kg or tonnes of the fuel))
$FE^i$= Emission Factor (tonnes gas/ TJ)

By applying the relationship between mass, volume and density, the total mass of the GHG emissions is obtained (Equation 3.7).

$$E_n^i = V_{Fuel} \cdot \rho_{Fuel} \cdot LHV \cdot FE^i \qquad \text{(Equation 3.7)}$$

Where:

$E_n^i$ = Total mass of GHG emissions in each source (tonnes)
$V_{Fuel}$ = Volume of the fuel used (liters, gallons or cubic meters)
$\rho_{Fuel}$ = Density of used fuel (kg / liter, kg / gallon or kg / cubic meter)
LHV = "Low Heating Value" lower limit of the heat released by the combustion (TJ/(kg or tonnes of the fuel))
$FE^i$ = Emission Factor (tonnes gas/ (TJ))

**- On-Road Vehicles**

The emissions' calculation of this source is similar to Cargo Handling Equipment. Therefore, it can be found in the previous section.

**- Railroad Locomotives**

The emissions' calculation of this source has been done using also Equations 3.6 and 3.7. Emission factors have been extracted from Table 3.3. The conversion of the units has been done using the Tables in appendix 3 (Table 1, 2 and 3).

**Table 3.3: Emission factors for $CO_2$, $CH_4$ and $N_2O$ for Railroad Locomotives (IPCC, 2006)**

DEFAULT EMISSION FACTORS FOR THE MOST COMMON FUELS USED FOR RAIL TRANSPORT

| Gas | Diesel (kg/TJ) | | | Sub-bituminous Coal (kg/TJ) | | |
|---|---|---|---|---|---|---|
| | Default | Lower | Upper | Default | Lower | Upper |
| $CO_2$ | 74 100 | 72 600 | 74 800 | 96 100 | 72 800 | 100 000 |
| $CH_4$ [1] | 4.15 | 1.67 | 10.4 | 2 | 0.6 | 6 |
| $N_2O$ [1] | 28.6 | 14.3 | 85.8 | 1.5 | 0.5 | 5 |

Notes:

[1] For an average fuel consumption of 0.35 litres per bhp-hr (break horse power-hour) for a 4000 HP locomotive, (0.47 litres per kWh for a 2983 kW locomotive).(Dunn, 2001).

[2] The emission factors for diesel are derived from (EEA, 2005) (Table 8-1), while for coal from Table 2.2 of the Stationary Combustion chapter.

### - Harbor Craft and Inland Waterway Vessels

The emissions of Harbor Craft and Inland Waterway Vessels have been calculated also by Equations 3.6 and 3.7. The emission factor for $CO_2$ is presented in Table 3.4 and conversion factors can be found in appendix 3 (Table 1, 2 and 3). Emissions for $CH_4$ and $N_2O$ have been calculated by Equations 3.6 and 3.7. The emission factors can be found in appendix 3 (Table 1, 2 and 3).

**Table 3.4: Emission factors for $CO_2$ for Harbor Craft and Inland Waterway Vessels (IPCC, 2006)**

$CO_2$ EMISSION FACTORS

| | | kg/TJ | | |
|---|---|---|---|---|
| Fuel | | Default | Lower | Upper |
| Gasoline | | 69 300 | 67 500 | 73 000 |
| Other Kerosene | | 71 900 | 70 800 | 73 600 |
| Gas/Diesel Oil | | 74 100 | 72 600 | 74 800 |
| Residual Fuel Oil | | 77 400 | 75 500 | 78 800 |
| Liquefied Petroleum Gases | | 63 100 | 61 600 | 65 600 |
| Other Oil | Refinery Gas | 57 600 | 48 200 | 69 000 |
| Other Oil | Paraffin Waxes | 73 300 | 72 200 | 74 400 |
| Other Oil | White Spirit & SBP | 73 300 | 72 200 | 74 400 |
| Other Oil | Other Petroleum Products | 73 300 | 72 200 | 74 400 |
| Natural Gas | | 56 100 | 54 300 | 58 300 |

### - Construction Equipment

The Equations 3.6 and 3.7 have been also used to calculate emissions from Construction Equipment. The related emission Factors are presented in Table 3.5.

**Table 3.5: Emission factors for $CO_2$, $CH_4$ and $N_2O$ for ConstructionEquipment (IPCC, 2006)**

DEFAULT EMISSION FACTORS FOR OFF-ROAD MOBILE SOURCES AND MACHINERY [(a)]

| | $CO_2$ | | | $CH_4$ [(b)] | | | $N_2O$ [(c)] | | |
|---|---|---|---|---|---|---|---|---|---|
| Off-Road Source | Default (kg/TJ) | Lower | Upper | Default (kg/TJ) | Lower | Upper | Default (kg/TJ) | Lower | Upper |
| Diesel | | | | | | | | | |
| Agriculture | 74 100 | 72 600 | 74 800 | 4.15 | 1.67 | 10.4 | 28.6 | 14.3 | 85.8 |
| Forestry | 74 100 | 72 600 | 74 800 | 4.15 | 1.67 | 10.4 | 28.6 | 14.3 | 85.8 |
| Industry | 74 100 | 72 600 | 74 800 | 4.15 | 1.67 | 10.4 | 28.6 | 14.3 | 85.8 |
| Household | 74 100 | 72 600 | 74 800 | 4.15 | 1.67 | 10.4 | 28.6 | 14.3 | 85.8 |
| Motor Gasoline 4-stroke | | | | | | | | | |
| Agriculture | 69 300 | 67 500 | 73 000 | 80 | 32 | 200 | 2 | 1 | 6 |
| Forestry | 69 300 | 67 500 | 73 000 | | | | | | |
| Industry | 69 300 | 67 500 | 73 000 | 50 | 20 | 125 | 2 | 1 | 6 |
| Household | 69 300 | 67 500 | 73 000 | 120 | 48 | 300 | 2 | 1 | 6 |
| Motor Gasoline 2-Stroke | | | | | | | | | |
| Agriculture | 69 300 | 67 500 | 73 000 | 140 | 56 | 350 | 0.4 | 0.2 | 1.2 |
| Forestry | 69 300 | 67 500 | 73 000 | 170 | 68 | 425 | 0.4 | 0.2 | 1.2 |
| Industry | 69 300 | 67 500 | 73 000 | 130 | 52 | 325 | 0.4 | 0.2 | 1.2 |
| Household | 69 300 | 67 500 | 73 000 | 180 | 72 | 450 | 0.4 | 0.2 | 1.2 |

Source: EEA 2005.

Note: $CO_2$ emission factor values represent full carbon content.

In the next section, the formulae to calculate the emissions from stationary sources of scope 1 are presented.

## - Stationary sources (Scope 1)

In order to calculate emissions from stationary sources Equations 3.3, 3.4, 3.5 and 3.6 have been used. Emission factors for Power Plants, Boilers, Generators and other facilities (IPCC, 2006) are presented in Table 3.6.The conversion factors can be found in appendix 3 (Table 1, 2 and 3).

**Table 3.6: Emission factors for $CO_2$, $CH_4$ and $N_2O$ for the stationary combustion (IPCC, 2006)**

DEFAULT EMISSION FACTORS FOR STATIONARY COMBUSTION IN THE ENERGY INDUSTRIES
(kg of greenhouse gas per TJ on a Net Calorific Basis)

| Fuel | | $CO_2$ | | | $CH_4$ | | | $N_2O$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Default Emission Factor | Lower | Upper | Default Emission Factor | Lower | Upper | Default Emission Factor | Lower | Upper |
| Municipal Wastes (non-biomass fraction) | | n 91 700 | 73 300 | 121 000 | 30 | 10 | 100 | 4 | 1.5 | 15 |
| Industrial Wastes | | n 143 000 | 110 000 | 183 000 | 30 | 10 | 100 | 4 | 1.5 | 15 |
| Waste Oils | | n 73 300 | 72 200 | 74 400 | 30 | 10 | 100 | 4 | 1.5 | 15 |
| Peat | | 106 000 | 100 000 | 108 000 | n 1 | 0.3 | 3 | n 1.5 | 0.5 | 5 |
| Solid Biofuels | Wood / Wood Waste | n 112 000 | 95 000 | 132 000 | 30 | 10 | 100 | 4 | 1.5 | 15 |
| Solid Biofuels | Sulphite lyes (Black Liquor)[a] | n 95 300 | 80 700 | 110 000 | n 3 | 1 | 18 | n 2 | 1 | 21 |
| Solid Biofuels | Other Primary Solid Biomass | n 100 000 | 84 700 | 117 000 | 30 | 10 | 100 | 4 | 1.5 | 15 |
| Solid Biofuels | Charcoal | n 112 000 | 95 000 | 132 000 | 200 | 70 | 600 | 4 | 1.5 | 15 |
| Liquid Biofuels | Biogasoline | n 70 800 | 59 800 | 84 300 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Liquid Biofuels | Biodiesels | n 70 800 | 59 800 | 84 300 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Liquid Biofuels | Other Liquid Biofuels | n 79 600 | 67 100 | 95 300 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Gas Biomass | Landfill Gas | n 54 600 | 46 200 | 66 000 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Gas Biomass | Sludge Gas | n 54 600 | 46 200 | 66 000 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Gas Biomass | Other Biogas | n 54 600 | 46 200 | 66 000 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Other non-fossil fuels | Municipal Wastes (biomass fraction) | n 100 000 | 84 700 | 117 000 | 30 | 10 | 100 | 4 | 1.5 | 15 |

(a) Includes the biomass-derived $CO_2$ emitted from the black liquor combustion unit and the biomass-derived $CO_2$ emitted from the kraft mill lime kiln.
n indicates a new emission factor which was not present in the 1996 Guidelines
r indicates an emission factor that has been revised since the 1996 Guidelines

**Table 3.6 (Continuation): Emission factors for $CO_2$, $CH_4$ and $N_2O$ for the stationary combustion (IPCC, 2006)**

| Fuel | | $CO_2$ | | | $CH_4$ | | | $N_2O$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Default Emission Factor | Lower | Upper | Default Emission Factor | Lower | Upper | Default Emission Factor | Lower | Upper |
| Crude Oil | | 73 300 | 71 100 | 75 500 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Orimulsion | | r 77 000 | 69 300 | 85 400 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Natural Gas Liquids | | r 64 200 | 58 300 | 70 400 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Gasoline | Motor Gasoline | r 69 300 | 67 500 | 73 000 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Gasoline | Aviation Gasoline | r 70 000 | 67 500 | 73 000 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Gasoline | Jet Gasoline | r 70 000 | 67 500 | 73 000 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Jet Kerosene | | r 71 500 | 69 700 | 74 400 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Other Kerosene | | 71 900 | 70 800 | 73 700 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Shale Oil | | 73 300 | 67 800 | 79 200 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Gas/Diesel Oil | | 74 100 | 72 600 | 74 800 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Residual Fuel Oil | | 77 400 | 75 500 | 78 800 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Liquefied Petroleum Gases | | 63 100 | 61 600 | 65 600 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Ethane | | 61 600 | 56 500 | 68 600 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Naphtha | | 73 300 | 69 300 | 76 300 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Bitumen | | 80 700 | 73 000 | 89 900 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Lubricants | | 73 300 | 71 900 | 75 200 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Petroleum Coke | | r 97 500 | 82 900 | 115 000 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Refinery Feedstocks | | 73 300 | 68 900 | 76 600 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Other Oil | Refinery Gas | n 57 600 | 48 200 | 69 000 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Other Oil | Paraffin Waxes | 73 300 | 72 200 | 74 400 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Other Oil | White Spirit and SBP | 73 300 | 72 200 | 74 400 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Other Oil | Other Petroleum Products | 73 300 | 72 200 | 74 400 | r 3 | 1 | 10 | 0.6 | 0.2 | 2 |
| Anthracite | | 98 300 | 94 600 | 101 000 | 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Coking Coal | | 94 600 | 87 300 | 101 000 | 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Other Bituminous Coal | | 94 600 | 89 500 | 99 700 | 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Sub-Bituminous Coal | | 96 100 | 92 800 | 100 000 | 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Lignite | | 101 000 | 90 900 | 115 000 | 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Oil Shale and Tar Sands | | 107 000 | 90 200 | 125 000 | 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Brown Coal Briquettes | | 97 500 | 87 300 | 109 000 | n 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Patent Fuel | | 97 500 | 87 300 | 109 000 | 1 | 0.3 | 3 | n 1.5 | 0.5 | 5 |
| Coke | Coke Oven Coke and Lignite Coke | r 107 000 | 95 700 | 119 000 | 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Coke | Gas Coke | r 107 000 | 95 700 | 119 000 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Coal Tar | | n 80 700 | 68 200 | 95 300 | n 1 | 0.3 | 3 | r 1.5 | 0.5 | 5 |
| Derived Gases | Gas Works Gas | n 44 400 | 37 300 | 54 100 | n 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Derived Gases | Coke Oven Gas | n 44 400 | 37 300 | 54 100 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Derived Gases | Blast Furnace Gas | n 260 000 | 219 000 | 308 000 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Derived Gases | Oxygen Steel Furnace Gas | n 182 000 | 145 000 | 202 000 | r 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |
| Natural Gas | | 56 100 | 54 300 | 58 300 | 1 | 0.3 | 3 | 0.1 | 0.03 | 0.3 |

In order to calculate emissions from incinerators and wastewater treatment plants, special formulae are needed. These formulae are explained below.

**- Incinerators**

Emissions from incinerators for $CO_2$ have been calculated by Equation 3.8.

$$E^{CO_2} = \sum_i (SW_i \cdot dm_i \cdot CF_i \cdot FCF_i \cdot OF_i) \cdot \frac{44}{12} \qquad \text{(Equation 3.8)(IPCC, 2006)}$$

Where:

$E^{CO_2}$ = Total amount of $CO_2$ emissions (tonnes)
$i$= Type of incinerated waste
$SW_i$ = Total amount of incinerated waste (kg or tonnes)
$dm_i$ = Dry matter content in the component i of the incinerated waste (Fraction)
$CF_i$ = Fraction of carbon in the dry matter (i.e., carbon content) of component i
$FCF_i$ = Fraction of fossil carbon in the total carbon (Fraction)
$OF_i$ = Oxidation factor (Fraction)
$44/12$ = Conversion factor from C to $CO_2$

The values for dmi, CFi, FCFi and OFi are obtained from Table 3.7 and 3.8.

**Table 3.7: $dm_i$, $CF_i$, $FCF_i$ and $OF_i$values in general (IPCC, 2006)**

DEFAULT DATA FOR $CO_2$ EMISSION FACTORS FOR INCINERATION AND OPEN BURNING OF WASTE

| Parameters | Management practice | MSW | Industrial Waste (%) | Clinical Waste (%) | Sewage Sludge (%) Note 4 | Fossil liquid waste (%) Note 5 |
|---|---|---|---|---|---|---|
| Dry matter content in % of wet weight | | see Note 1 | NA | NA | NA | NA |
| Total carbon content in % of dry weight | | see Note 1 | 50 | 60 | 40 – 50 | 80 |
| Fossil carbon fraction in % of total carbon content | | see Note 2 | 90 | 40 | 0 | 100 |
| Oxidation factor in % of carbon input | incineration | 100 | 100 | 100 | 100 | 100 |
| | Open- burning (see Note 3) | 58 | NO | NO | NO | NO |

NA: Not Available, NO: Not Occurring

Note 1: Use default data from Table 2.4 in Section 2.3 Waste composition and equation 5.8 (for dry matter), Equation 5.9 (for carbon content) and Equation 5.10 (for fossil carbon fraction).

Note 2: Default data by industry type is given in Table 2.5 in Section 2.3 Waste composition. For estimation of emissions, use equations mentioned in Note 1.

Note 3: When waste is open-burned, refuse weight is reduced by approximately 49 to 67 percent (US-EPA, 1997, p.79). A default value of 58 percent is suggested.

Note 4: See Section 2.3.2 Sludge in Chapter 2.

Note 5: The total carbon content of fossil liquid waste is provided in percent of wet weight and not in percent of dry weight (GIO, 2005).

References: *GPG2000* (IPCC, 2000), Lead Authors of the *2006 Guidelines*, Expert judgement.

**Table 3.8: $dm_i$, $CF_i$, $FCF_i$ and $OF_i$ values for municipal waste (IPCC, 2006)**

DEFAULT DRY MATTER CONTENT, DOC CONTENT, TOTAL CARBON CONTENT AND FOSSIL CARBON FRACTION OF DIFFERENT MSW COMPONENTS

| MSW component | Dry matter content in % of wet weight [1] | DOC content in % of wet waste | | DOC content in % of dry waste | | Total carbon content in % of dry weight | | Fossil carbon fraction in % of total carbon | |
|---|---|---|---|---|---|---|---|---|---|
| | Default | Default | Range | Default | Range [2] | Default | Range | Default | Range |
| Paper/cardboard | 90 | 40 | 36 - 45 | 44 | 40 - 50 | 46 | 42 - 50 | 1 | 0 - 5 |
| Textiles [3] | 80 | 24 | 20 - 40 | 30 | 25 - 50 | 50 | 25 - 50 | 20 | 0 - 50 |
| Food waste | 40 | 15 | 8 - 20 | 38 | 20 - 50 | 38 | 20 - 50 | - | - |
| Wood | 85 [4] | 43 | 39 - 46 | 50 | 46 - 54 | 50 | 46 - 54 | - | - |
| Garden and Park waste | 40 | 20 | 18 - 22 | 49 | 45 - 55 | 49 | 45 - 55 | 0 | 0 |
| Nappies | 40 | 24 | 18 - 32 | 60 | 44 - 80 | 70 | 54 - 90 | 10 | 10 |
| Rubber and Leather | 84 | (39) [5] | (39) [5] | (47) [5] | (47) [5] | 67 | 67 | 20 | 20 |
| Plastics | 100 | - | - | - | - | 75 | 67 - 85 | 100 | 95 - 100 |
| Metal [6] | 100 | - | - | - | - | NA | NA | NA | NA |
| Glass [6] | 100 | - | - | - | - | NA | NA | NA | NA |
| Other, inert waste | 90 | - | - | - | - | 3 | 0 - 5 | 100 | 50 - 100 |

[1] The moisture content given here applies to the specific waste types before they enter the collection and treatment. In samples taken from collected waste or from e.g., SWDS the moisture content of each waste type will vary by moisture of co-existing waste and weather during handling.

[2] The range refers to the minimum and maximum data reported by Dehoust *et al.*, 2002; Gangdonggu, 1997; Guendehou, 2004; JESC, 2001; Jager and Blok, 1993; Würdinger *et al.*, 1997; and Zeschmar-Lahl, 2002.

[3] 40 percent of textile are assumed to be synthetic (default). Expert judgement by the authors.

[4] This value is for wood products at the end of life. Typical dry matter content of wood at the time of harvest (that is for garden and park waste) is 40 percent. Expert judgement by the authors.

[5] Natural rubbers would likely not degrade under anaerobic condition at SWDS (Tsuchii et al., 1985; Rose and Steinbüchel, 2005).

[6] Metal and glass contain some carbon of fossil origin. Combustion of significant amounts of glass or metal is not common.

In order to calculate $N_2O$ and $CH_4$ emissions, Equations 3.9 and 3.10 have been used.

$$E^i = \sum_j \left(SW_j \cdot FE_k^i\right) \text{(Equation 3.9)(IPCC, 2006)}$$

Where:

$E^i$ = Total amount of emission (tonnes)

$SW_j$=Total mass of the incinerated waste j (kg or tonnes)

$FE_k^i$ = Emission factor by the incineration method k (tonnes gas/(kg, tonnes))

Table 3.9 shows the emission factor for $CH_4$ based on the incineration method.

**Table 3.9: Emission factor for $CH_4$ based on the incineration method (IPCC, 2019a)**

| TABLE 5.3 CH₄ EMISSION FACTORS FOR INCINERATION OF MSW | | |
|---|---|---|
| **Type of incineration/technology** | | **$CH_4$ Emission Factors (kg/Gg waste incinerated on a wet weight basis)** |
| **Continuous incineration** | stoker | 0.2 |
| | fluidised bed Note1 | ~0 |
| **Semi-continuous incineration** | stoker | 6 |
| | fluidised bed | 188 |
| **Batch type incineration** | stoker | 60 |
| | fluidised bed | 237 |
| Note 1: In the study cited for this emission factor, the measured $CH_4$ concentration in the exhaust air was lower than the concentration in ambient air. Source: Greenhouse Gas Inventory Office of Japan, GIO 2004. | | |

Table 3.10 shows the emission factor for $N_2O$ based on the incineration method and waste types.

**Table 3.10: Emission factor for $N_2O$ based on the incineration method and waste types (IPCC, 2006)**

| TABLE 5.6 DEFAULT $N_2O$ EMISSION FACTORS FOR DIFFERENT TYPES OF WASTE AND MANAGEMENT PRACTICES | | | |
|---|---|---|---|
| **Type of waste** | **Technology / Management practice** | **Emission factor ($g\ N_2O$ / t waste)** | **weight basis** |
| **MSW** | continuous and semi-continuous incinerators | 50 | wet weight |
| **MSW** | batch-type incinerators | 60 | wet weight |
| **MSW** | open burning | 150 | dry weight |
| **Industrial waste** | all types of incineration | 100 | wet weight |
| **Sludge (except sewage sludge)** | all types of incineration | 450 | wet weight |
| **Sewage sludge** | incineration | 990 | dry weight |
| | | 900 | wet weight |
| Source: Expert judgement by lead authors of this chapter of *2006 Guidelines* | | | |

To facilitate the task for the user of the program, a global average value has been calculated in terms of the proportion of each type of material in the municipal waste (Table 3.11).

**Table 3.11: Proportions of materials for municipal waste by country (IPCC, 2006)**

MSW COMPOSITION DATA BY PERCENT – REGIONAL DEFAULTS

| Region | Food waste | Garden waste | Paper/cardboard | Wood | Textiles | Nappies | Rubber/Leather | Plastic | Metal | Glass | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Asia** | | | | | | | | | | | |
| Central Asia | 30.0 | 1.4 | 24.7 | 2.5 | 3.5 | 0 | 0 | 8.4 | 0.8 | 5.9 | 23.0 |
| Eastern Asia | 40.3 | 0.0 | 20.4 | 2.1 | 1.0 | 0.0 | 0.0 | 6.5 | 2.7 | 4.3 | 22.9 |
| South-Eastern Asia | 49.9 | 1.0 | 11.2 | 0.8 | 0.4 | 0.0 | 0.0 | 10.2 | 4.2 | 3.7 | 18.6 |
| Southern Asia | 66.1 | 0.0 | 9.2 | 0.0 | 1.2 | 0.0 | 0.4 | 7.0 | 0.9 | 1.5 | 13.9 |
| Western Asia | 42.2 | 3.2 | 15.3 | 0.8 | 3.0 | 0.4 | 0.3 | 17.2 | 2.5 | 3.4 | 11.8 |
| **Africa** | | | | | | | | | | | |
| Northern Africa | 50.4 | 0.0 | 12.1 | 0.0 | 5.8 | 0.0 | 0.0 | 13.8 | 4.4 | 3.3 | 10.5 |
| Eastern Africa | 44.4 | 6.9 | 10.4 | 0.5 | 3.0 | 0.0 | 0.4 | 8.0 | 2.6 | 2.1 | 21.7 |
| Middle Africa | 28.4 | 0 | 8 | 0 | 1.3 | 0 | 0 | 7.1 | 1.4 | 1.1 | 52.7 |
| Southern Africa | 24.0 | 0.0 | 14.5 | 0.0 | 5.5 | 0.0 | 0.0 | 26.5 | 6.5 | 9.0 | 14.0 |
| Western Africa | 53.9 | 0.0 | 7.5 | 0.0 | 1.9 | 0.0 | 0.0 | 6.4 | 2.7 | 1.3 | 26.5 |
| **Europe** | | | | | | | | | | | |
| Eastern Europe | 31.8 | 2.4 | 17.1 | 2.5 | 3.1 | 0.1 | 0.5 | 4.6 | 0.7 | 1.8 | 35.3 |
| Northern Europe | 30.3 | 5.2 | 13.8 | 1.8 | 3.2 | 1.2 | 0.0 | 4.9 | 1.4 | 4.3 | 34.0 |
| Southern Europe | 35.8 | 1.4 | 21.4 | 1.2 | 2.8 | 1.1 | 0.2 | 14.1 | 2.0 | 3.5 | 16.7 |
| Western Europe | 33.2 | 2.7 | 17.2 | 2.3 | 5.9 | 3.0 | 0.0 | 20.5 | 1.5 | 1.4 | 12.3 |
| **America** | | | | | | | | | | | |
| Central America | 62.7 | 0.0 | 12.6 | 0.3 | 2.2 | 0.0 | 0.0 | 10.3 | 2.7 | 3.3 | 6.0 |
| South America | 54.1 | 3.3 | 12.4 | 0.0 | 1.7 | 1.9 | 0.6 | 13.7 | 2.0 | 3.0 | 7.2 |
| Northern America | 20.2 | 6.8 | 23.3 | 4.1 | 3.9 | 0 | 1.6 | 15.8 | 6.4 | 4.2 | 14.0 |

MSW COMPOSITION DATA BY PERCENT – REGIONAL DEFAULTS

| Region | Food waste | Garden waste | Paper/cardboard | Wood | Textiles | Nappies | Rubber/Leather | Plastic | Metal | Glass | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oceania** | | | | | | | | | | | |
| Australia and New Zealand | 25.9 | 12.2 | 12.0 | 6.5 | 2.9 | 3.5 | 0.0 | 8.3 | 1.8 | 2.8 | 24.1 |

Note 1: Data are based on weight of wet waste of MSW without industrial waste at generation around year 2010.
Note 2: The region-specific values are calculated from national, partly incomplete composition data. The percentages given may therefore not add up to 100%. Some regions may not have data for some waste types - blanks in the table represent missing data.
Note 3: Data of rest of Oceania and Caribbean are not refined

- **WastewaterTreatment Plant**

Wastewater can be a source of methane ($CH_4$) when treated or disposed an aerobically. Carbon dioxide ($CO_2$) emissions from wastewater are not considered in the IPCC guidelines because these are of biogenic[39] origin and should not be included in national total emissions. $CH_4$ emissions are calculated by Equation 3.10.

$$E^{CH_4} = \sum_i [(TOW_i - S_i) \cdot EF_i - R_i]$$ (Equation 3.10)(IPCC, 2019a)

Where:

$E^{CH_4}$= $CH_4$ emissions in the inventory year (kg $CH_4$/yr)
$TOW_i$= Total organically degradable material in wastewater from industry i in the inventory year (kg COD/yr)
i= Industrial sector
$S_i$ = Organic component removed as sludge in inventory year (kg COD/yr)
$EF_i$ = Emission factor for the industry i (kg $CH_4$/kg COD)
$R_i$= amount of $CH_4$ recovered in the inventory year (kg $CH_4$/yr)

[39]A biogenic substance is a product made by or of life forms. The term encompasses constituents, secretions, and metabolites of plants or animals. In context of molecular biology, biogenic substances are referred to as biomolecules.

Note that only a few countries may have sludge removal data and $CH_4$ recovery data. The default for sludge removal is zero. The default for $CH_4$ recovery is zero (IPCC, 2006).

In order to calculate TOW, the equation 3.11 and the Table 3.12 have used.

$$\mathrm{TOW_i} = \mathrm{P_i} \cdot \mathrm{W_i} \cdot \mathrm{COD_i} \qquad \text{(Equation 3.11)(IPCC, 2019a)}$$

Where:

TOWi= Total organically degradable material in wastewater for the industry i(kg COD/yr)
i= Industrial sector
Pi = Total industrial product for the industrial sector i(t/yr)
Wi = Wastewater generated ($m^3$ /t $_{product}$)
CODi = Chemical oxygen demand (industrial degradable organic component in wastewater) (kg COD/$m^3$)

**Table 3.12: $W_i$ and $COD_i$ data by industry (IPCC, 2006)**

EXAMPLES OF INDUSTRIAL WASTEWATER DATA

| Industry Type | Wastewater Generation W ($m^3$/ton) | Range for W ($m^3$/ton) | COD (kg/$m^3$) | COD Range (kg/$m^3$) |
|---|---|---|---|---|
| Alcohol Refining | 24 | 16 – 32 | 11 | 5 – 22 |
| Beer & Malt | 6.3 | 5.0 – 9.0 | 2.9 | 2 – 7 |
| Coffee | NA | NA – | 9 | 3 – 15 |
| Dairy Products | 7 | 3 – 10 | 2.7 | 1.5 – 5.2 |
| Fish Processing | NA | 8 – 18 | 2.5 | |
| Meat & Poultry | 13 | 8 – 18 | 4.1 | 2 – 7 |
| Organic Chemicals | 67 | 0 – 400 | 3 | 0.8 – 5 |
| Petroleum Refineries | 0.6 | 0.3 – 1.2 | 1.0 | 0.4 – 1.6 |
| Plastics & Resins | 0.6 | 0.3 – 1.2 | 3.7 | 0.8 – 5 |
| Pulp & Paper (combined) | 162 | 85 – 240 | 9 | 1 – 15 |
| Soap & Detergents | NA | 1.0 – 5.0 | NA | 0.5 – 1.2 |
| Starch Production | 9 | 4 – 18 | 10 | 1.5 – 42 |
| Sugar Refining | NA | 4 – 18 | 3.2 | 1 – 6 |
| Vegetable Oils | 3.1 | 1.0 – 5.0 | NA | 0.5 – 1.2 |
| Vegetables, Fruits & Juices | 20 | 7 – 35 | 5.0 | 2 – 10 |
| Wine & Vinegar | 23 | 11 – 46 | 1.5 | 0.7 – 3.0 |

Notes: NA = Not Available.
Source: Doorn *et al.* (1997).

Finally, to obtain the $EF_i$ value, the equation 3.12 and the Table 3.13have been used.

$$EF_j = B_o \cdot MCF_j \qquad \text{(Equation 3.12)(IPCC, 2019a)}$$

Where:

$EF_j$ = Emission factor for each treatment j (kg $CH_4$/kg BOD)
j = Each treatment/discharge pathway or system
$B_o$ = Maximum $CH_4$ producing capacity (kg $CH_4$/kg BOD)
$MCF_j$ = Methane correction factor (fraction) (Table 3.12)

In the case of not being able to obtain the Bo values, according to(IPCC, 2006), it is recommended to take a value of 0.25 tonnes methane/tonnes COD. Table 3.12 shows $MCF_j$ values by type of treatment or system.

**Table 3.13: $MCF_j$ values by type of treatment or system (IPCC, 2006)**

DEFAULT MCF VALUES FOR INDUSTRIAL WASTEWATER

| Type of treatment and discharge pathway or system | Comments | MCF [1] | Range |
|---|---|---|---|
| **Untreated** | | | |
| Sea, river and lake discharge | Rivers with high organics loadings may turn anaerobic, however this is not considered here. | 0.1 | 0 – 0.2 |
| **Treated** | | | |
| Aerobic treatment plant | Must be well managed. Some $CH_4$ can be emitted from settling basins and other pockets. | 0 | 0 – 0.1 |
| Aerobic treatment plant | Not well managed. Overloaded | 0.3 | 0.2 – 0.4 |
| Anaerobic digester for sludge | $CH_4$ recovery not considered here | 0.8 | 0.8 – 1.0 |
| Anaerobic reactor (e.g., UASB, Fixed Film Reactor) | $CH_4$ recovery not considered here | 0.8 | 0.8 – 1.0 |
| Anaerobic shallow lagoon | Depth less than 2 metres, use expert judgment | 0.2 | 0 – 0.3 |
| Anaerobic deep lagoon | Depth more than 2 metres | 0.8 | 0.8 – 1.0 |

[1] Based on expert judgment by lead authors of this section

### 3.3.2. Scope 2: Port authority Indirect Sources

These sources include port purchased electricity for port administration owned buildings and operations. As it was mentioned before, tenant power and tenant energy purchases are not included in this Scope.

Generally, in this step, the emissions are calculated as the electricity consumed by the port authority. Both mobile and stationary sources, which require an electric source to operate or charge, are included in this scope.

Using the values of electricity consumption and the emission factor of the country where the electricity was generated, it is possible to obtain the $CO_2$ emissions. Depending on the country this generation was generated, there is a significant difference in the value of the emission factor per kWh produced. The calculation has been done using Equation 13:

$$E_{Scope\ 2} = \sum Electricity\ Consumption \cdot FE \qquad \text{(Equation 3.13)}$$

Where:

$E_{Scope\ 2}$= Total amounts of $CO_2$ emissions (tonnes)
$\sum$ Electricity Consumpion = Total amount of Electricity Consumption in the port authority (kWh)
FE= $CO_2$ Emission Factor per country (tonnes $CO_2$/kWh)

Emission factors have been extracted from Carbon Footprint( 2019) and they are presented in appendix 4.

### 3.3.3. Scope3: Other Indirect Sources

In this scope, tenants' emissions are calculated. Emission sources are divided into four main groups (Figure 3.3):

- Mobile sources
- Stationary sources
- Purchased electricity
- Employees' commuting.

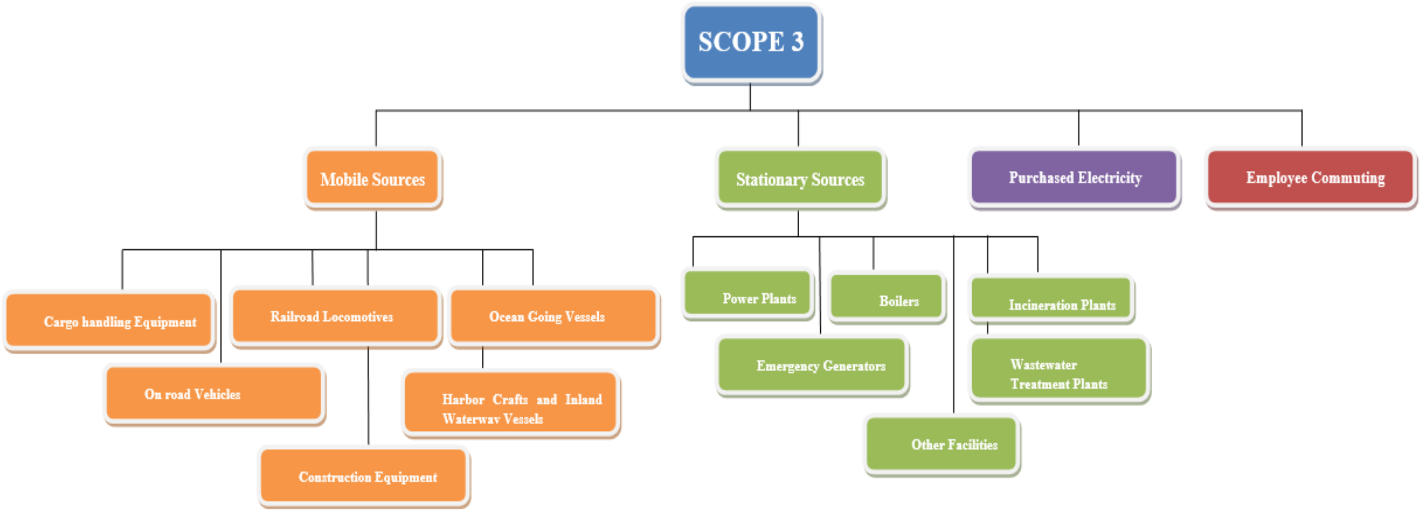



**Figure 3.3: The emission sources of scope 3**

- ## Mobile Sources (Scope 3)

The calculation of emissions of mobile sources in scope 3 is similar to scope 1, only Ocean Going Vessels are added. Their calculation is explained below:

### - Ocean-Going Vessels

In order to calculate emissions from these sources Equations 3.6 and 3.7 have been used. In order to convert units, the Tables presented in appendix 3 (Table 1, 2 and 3) have been used and Emission Factors have been extracted from Table 3.14.

**Table 3.14: Emission factors for $CO_2$, $CH_4$ and $N_2O$ (IPCC, 2006)**

$CO_2$ EMISSION FACTORS (kg/TJ)

| | Fuel | Default | Lower | Upper |
|---|---|---|---|---|
| Gasoline | | 69 300 | 67 500 | 73 000 |
| Other Kerosene | | 71 900 | 70 800 | 73 600 |
| Gas/Diesel Oil | | 74 100 | 72 600 | 74 800 |
| Residual Fuel Oil | | 77 400 | 75 500 | 78 800 |
| Liquefied Petroleum Gases | | 63 100 | 61 600 | 65 600 |
| Other Oil | Refinery Gas | 57 600 | 48 200 | 69 000 |
| Other Oil | Paraffin Waxes | 73 300 | 72 200 | 74 400 |
| Other Oil | White Spirit & SBP | 73 300 | 72 200 | 74 400 |
| Other Oil | Other Petroleum Products | 73 300 | 72 200 | 74 400 |
| Natural Gas | | 56 100 | 54 300 | 58 300 |

DEFAULT WATER-BORNE NAVIGATION $CH_4$ AND $N_2O$ EMISSION FACTORS

| | $CH_4$ (kg/TJ) | $N_2O$ (kg/TJ) |
|---|---|---|
| Ocean-going Ships * | 7 ±50% | 2 +140% -40% |

*Default values derived for diesel engines using heavy fuel oil.
Source: Lloyd's Register (1995) and EC (2002)

- ## Stationary Sources (Scope 3)

The calculation is the same as the calculation of stationary sources in scope 1 (Equations 3.3 to 3.6).

- **Purchased Electricity (Scope 3)**

The emissions due to electricity consumption by tenants have been calculated in the same way as in Scope 2 emissions (Equation 3.13).

- **Employees' Commuting (Scope 3)**

Employees' Commuting emissions have been calculated based on the availability of data. Figure 3.4 offers a decision tree for selecting a calculation method for scope 3 emissions from employees' commuting.

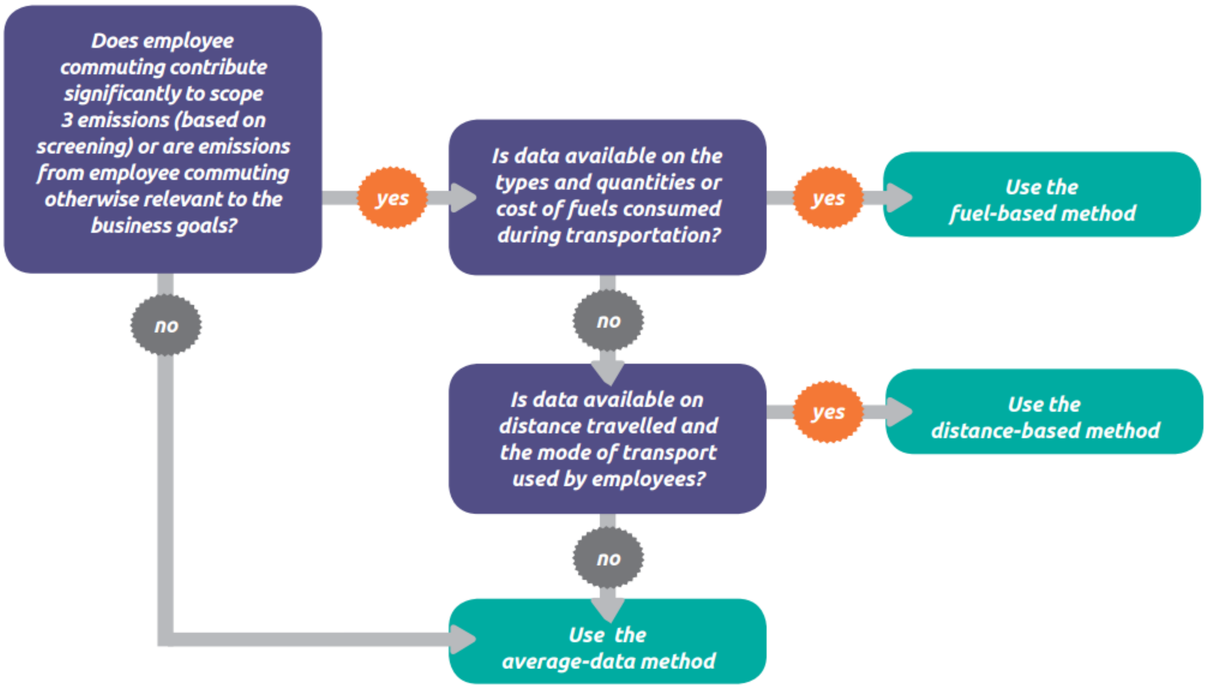



**Figure 3.4: Decision tree to select a calculation method for emissions from employees' commuting (WRI and WBSCD, 2013)**

Ports may use one of the following methods (WRI and WBSCD, 2013):

• **Fuel-based method**: This method involves determining the amount of fuel consumed during commuting and applying the appropriate emission factor for that fuel. In this category, the calculation is the same as calculating emissions from mobile sources in scope 1 and scope 3. Therefore, Equations 3.6 and 3.7 can be used.

• **Distance-based method**: This method involves collecting data from employees on commuting patterns (e.g. distance travelled and mode used for commuting) and applying appropriate emission factors for the modes used.

In this category, the emission factor of each transport and GHG per km have been used to calculate the emissions for each gas, as it can be seen in Equation 3.14. In order to calculate the value of $CO_2$ equivalent, Equation 3.4 has been used.

$$E^i = \sum_{k=1}^{m} \sum_{j=1}^{n} 2 \cdot d_j \cdot FE_k^i \cdot Workingdays \qquad \text{(Equation 3.14)}$$

Where:
$E^i$= Total GHG emission (tonnes)
2= The one-way distance multiply by two for the daily return trip
$d_j$ = Distance travelled by the employee j (km o miles)
$FE_k^i$ = emission factor of GHG i based on the transportation method k (tonnes gas/(km o miles))
Working Days= Number of working days in the period of study
K= Type of mean of transport
The value of $FE_k^i$can be found inTable 4 of appendix 3.

• **Average-data method:** This method involves estimating emissions from employees' commuting based on average data on commuting patterns. Companies should collect data on:

- Number of employees
- Average distance travelled by an average employee per day
- Average breakdown of transport modes used by employees
- Average number working days per year

The company may collect average secondary data from sources such as national transportation departments, ministries or agencies, national statistics publications, and/or industry associations.

In this category, only four types of transport have been considered: car, walking, bus or train. The calculation has been done based on the percentage of the employees using each mean of transport with respect to the total number of employees' commuting and the average of the distances travelled by them. The emissions' calculation has been done using Equation 3.15.

$$E^i = Working\ days \cdot 2 \cdot Total_{employees} \cdot \left(\%_{car} \cdot \bar{d}_{car} \cdot FE_{car}^i + \%_{by\ foot} \cdot \bar{d}_{by\ foot} \cdot FE_{by\ foot}^i + \%_{bus} \cdot \bar{d}_{bus} \cdot FE_{bus}^i + \%_{train} \cdot \bar{d}_{train} \cdot FE_{train}^i\right) \qquad \text{(Equation 3.15)}$$

Where:

$E^i$ = Total GHG emission (tonnes)
Working Days= Number of working days in the period of study
$Total_{employees}$ = Total number of employees
% = Percentage of the employees using this method of transport compared with the total
$\bar{d}$ = Average distance made by employees using this method of transportation (km o miles)
$FE_k^i$ = Emission factor of GHG i based on the transportation method k (tonnes gas/ (km o miles))

The value of $FE_k^i$ can be found in Table 4 of appendix 3. The number 2 in the formula is related to the return trip, this means the one-way distance multiplied by two for the daily return trip.

## 3.4. Development of the tool

After defining the scopes and choosing all the formulae, a practicable, user-friendly and freely available tool for the calculation of Carbon Footprint in ports has been developed. This tool is specifically designed so that port authorities can calculate their Carbon Footprint and report it accordingly.

The tool provides options to select the scopes that are more suitable and applicable to each port. In addition, it allows for normalizing (standardize to a common ground) the total annual emissions in terms of total tonnes of cargo handled or annual TEUs. This is basically done to allow for a comparison of the results of different ports standardizing to a common ground. In this tool, all the emission sources gathered in the standard guidelines (i.e. IPCC, GHG protocol and WPCI) are taken into account in this tool.

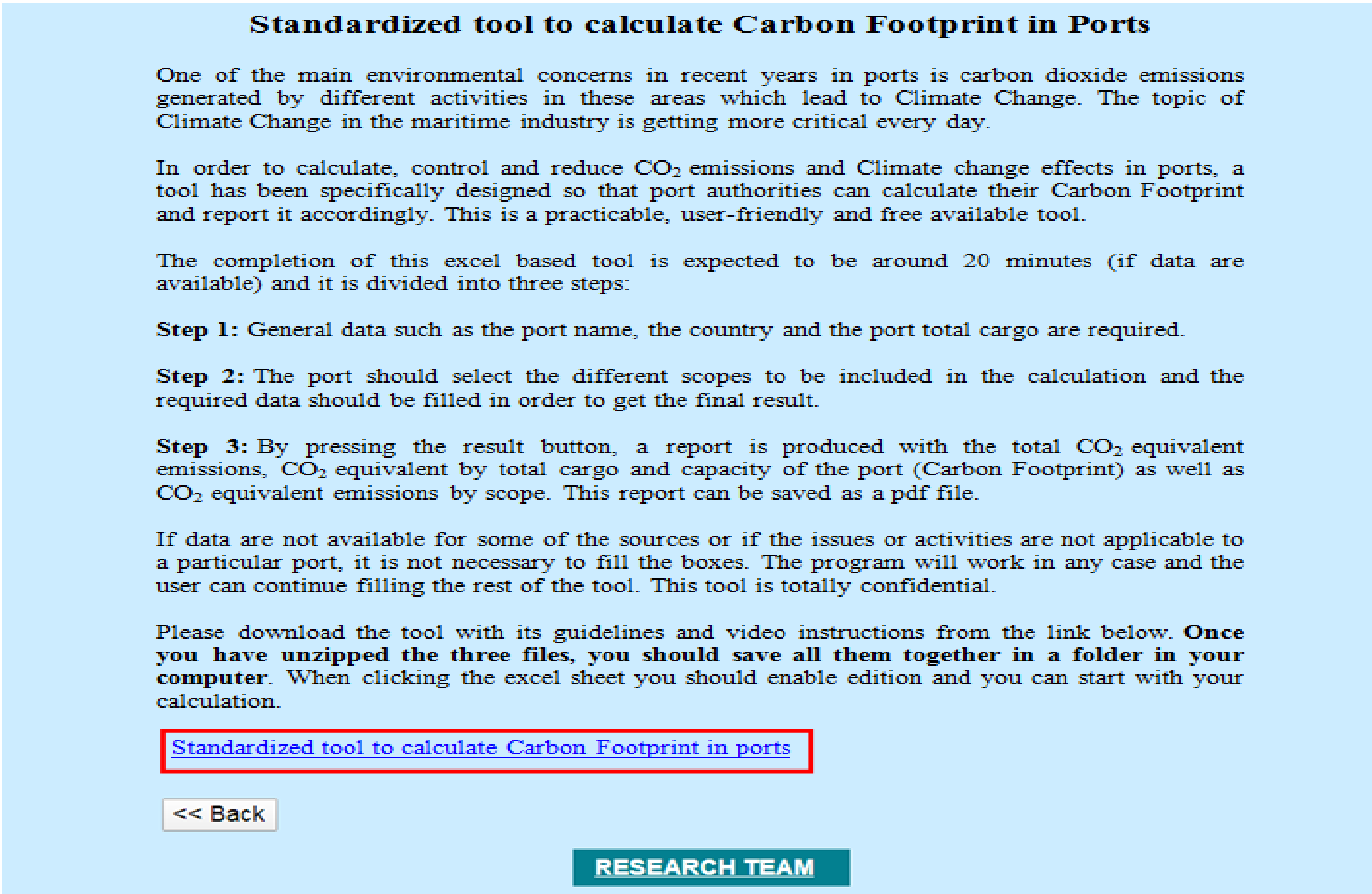
The development of the tool has been done by using Excel software and visual basic. The programming of the tool has been done in the framework of Mr. Guillem Ferré master thesis of (Ferré, 2020).

The completion of this excel based tool is expected to be around 20 minutes (if data are available) and it is divided into three steps:

- Step1: General data such as the port's name, the country and the port total cargo are required.
- Step 2: The port should select the different scopes to be included in the calculation and the required data should be filled in order to get the final result.
- Step 3: By pressing the result button, a report is produced with the total $CO_2$ equivalent emissions and also with emissions by capacity (Carbon Footprint) and by scope. This document can be saved as a pdf file.

It should be mentioned that if data are not available for some of the sources or if the issues or activities are not applicable to a particular port, it is not necessary to fill the boxes. The program will work in any case and the user can continue filling the rest of the tool.

The tool, the guidelines and the video can be downloaded from http://eports.cat/carboonfootprint. Once the user downloads the three files, he/she should save them all together in a folder. Then, the user could run the tool by enabling it. Figure 3.5 shows the screenshot of the website and the link of the tool.



**Standardized tool to calculate Carbon Footprint in Ports**

One of the main environmental concerns in recent years in ports is carbon dioxide emissions generated by different activities in these areas which lead to Climate Change. The topic of Climate Change in the maritime industry is getting more critical every day.

In order to calculate, control and reduce $CO_2$ emissions and Climate change effects in ports, a tool has been specifically designed so that port authorities can calculate their Carbon Footprint and report it accordingly. This is a practicable, user-friendly and free available tool.

The completion of this excel based tool is expected to be around 20 minutes (if data are available) and it is divided into three steps:

**Step 1:** General data such as the port name, the country and the port total cargo are required.

**Step 2:** The port should select the different scopes to be included in the calculation and the required data should be filled in order to get the final result.

**Step 3:** By pressing the result button, a report is produced with the total $CO_2$ equivalent emissions, $CO_2$ equivalent by total cargo and capacity of the port (Carbon Footprint) as well as $CO_2$ equivalent emissions by scope. This report can be saved as a pdf file.

If data are not available for some of the sources or if the issues or activities are not applicable to a particular port, it is not necessary to fill the boxes. The program will work in any case and the user can continue filling the rest of the tool. This tool is totally confidential.

Please download the tool with its guidelines and video instructions from the link below. **Once you have unzipped the three files, you should save all them together in a folder in your computer**. When clicking the excel sheet you should enable edition and you can start with your calculation.

Standardized tool to calculate Carbon Footprint in ports

<< Back

RESEARCH TEAM

**Figure 3.5: The screenshot of the website of the tool**

It is important to mention that Universitat Politècnica de Catalunya does not have access to any data provided by the port. The tool is totally confidential.

## 3.4.1. Tool's Introduction

As mentioned before, the development of the tool has been based on the WPCI and IPCC guidelines and the GHG Protocol. It should be mentioned that in this section, the last version of the tool is presented which includes the modifications suggested in the validation process, described in the next chapter.

The first screen of the tool presents a brief explanation about Climate Change and the different emissions scopes considered in the standard guidelines (Figure 3.6).

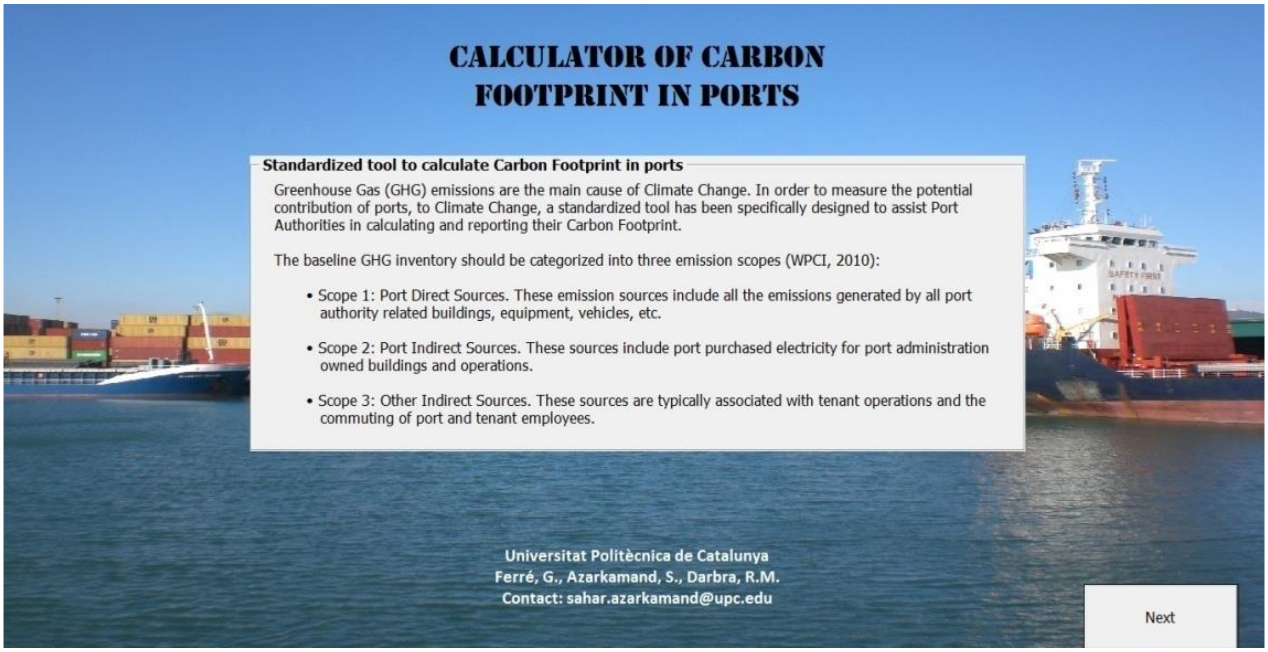



**Figure 3.6: Introductory screen**

By pressing the “next” button of this screen the next one appears, which includes a description of the different steps of the tool (Figure 3.7). By clicking on the “Instructions” button, the user will obtain a pdf file with guidelines on how to complete the tool. In addition, by pressing the “Video tutorial” box, a video will be displayed with instructions. By clicking the “Start calculation” button, the calculation of GHG emissions calculation of the port is initiated.

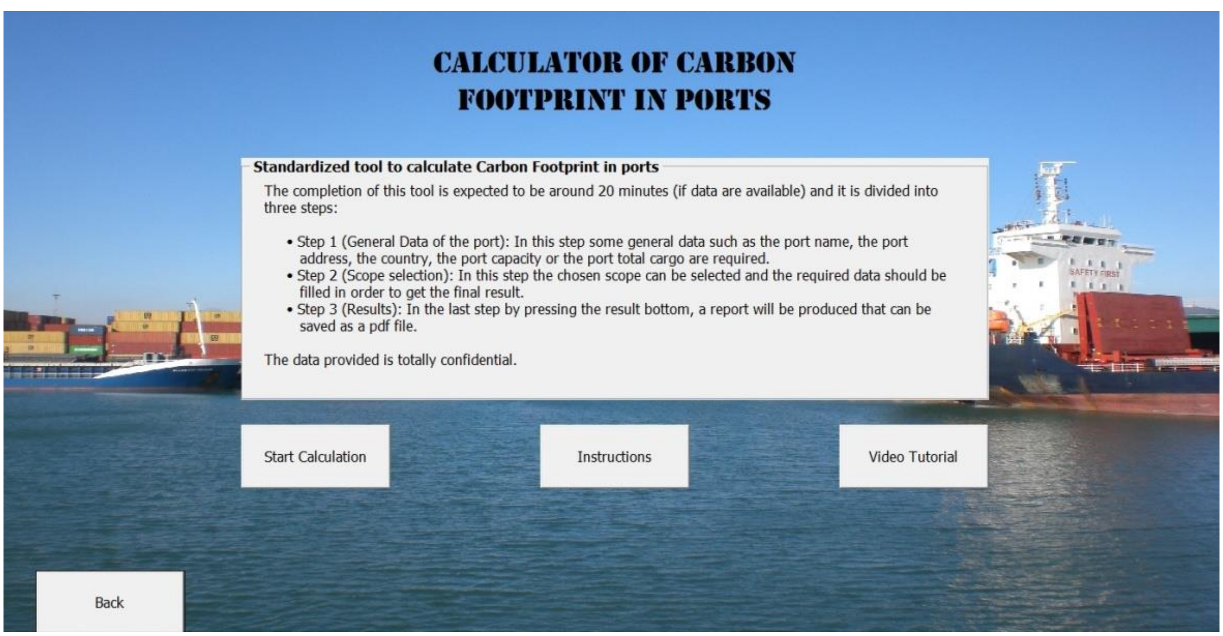



**Figure 3.7: Steps of the tool**

- **The port general data**

As it can be seen in Figure 3.8, the first step of the tool includes the completion of the port general data. Here, some specific information of the port before calculating the emissions is needed. These general data, which are optional, are:

- Port name
- Port address
- Country
- Capacity (TEU/ Year) or Total Cargo (Million tonnes/ Year)

As it is explained in the note 1 present in Figure 3.8, if data are not available for some of the sources or if any of the issues or activities are not applicable to a port, it is not necessary to fill in the boxes. The program will work in any case and the user can continue filling in the rest of the tool.

In addition, as mentioned in note 2, the boundaries of the tool are the port area, and therefore all the emissions calculated should be the ones that are occurring in this area, not outside.

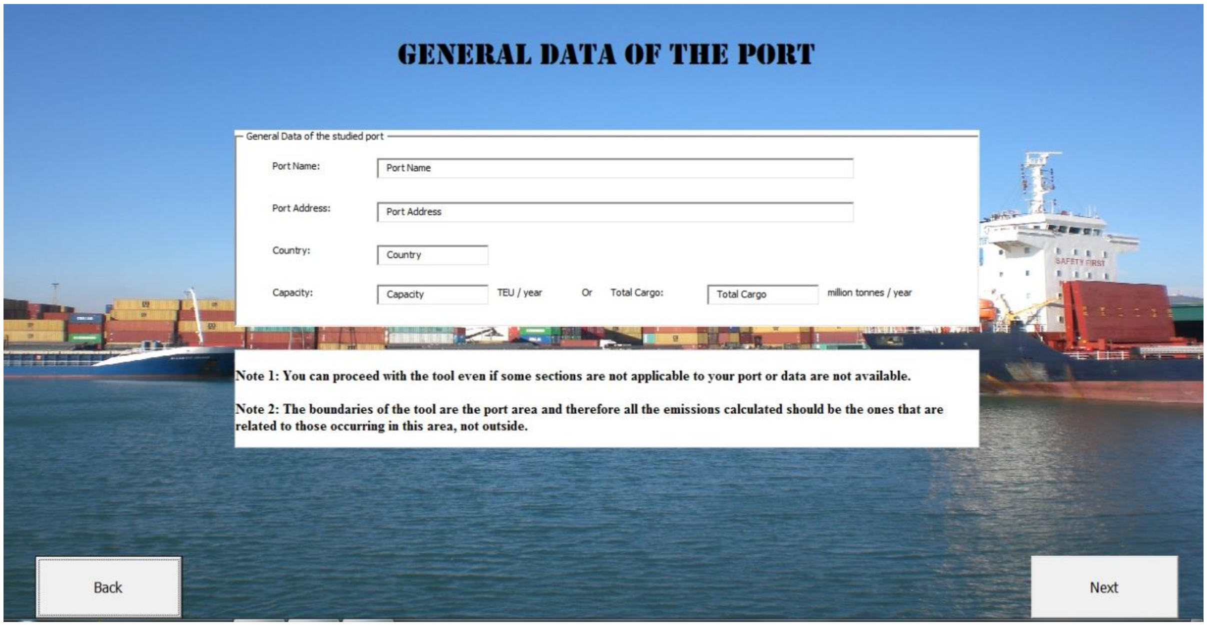



**Figure 3.8: General data of the port**

- **Scopes**

By clicking on the ‘Next’ button, a new screen for selecting the scope appears (Figure 3.9). In order to have a realistic overview of the Carbon Footprint of the port, it is recommended to the emission of all three scopes.It should be mentioned that the project can be saved in each stage by clicking on the ‘Save Project’ button. In addition, it is possible to clear all data by clicking on the ‘Clean Project’ button.

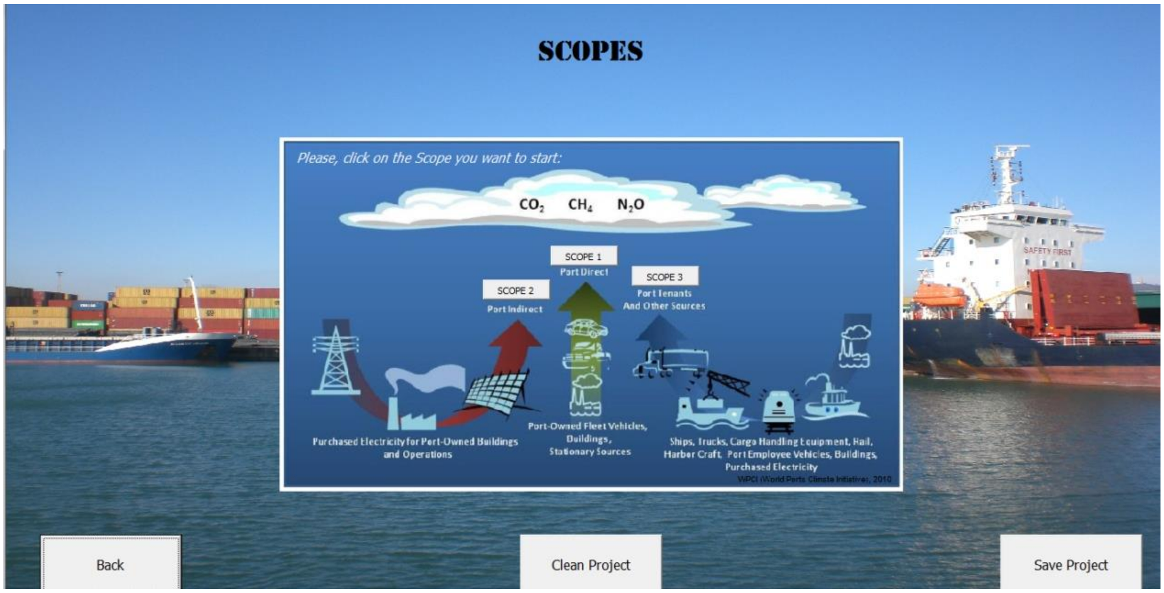



**Figure 3.9: Scopes' selection**

By clicking on scope 1, a brief explanation of scope 1 is presented (Figure 3.10). In this slide, it is also possible to download the guidelines.

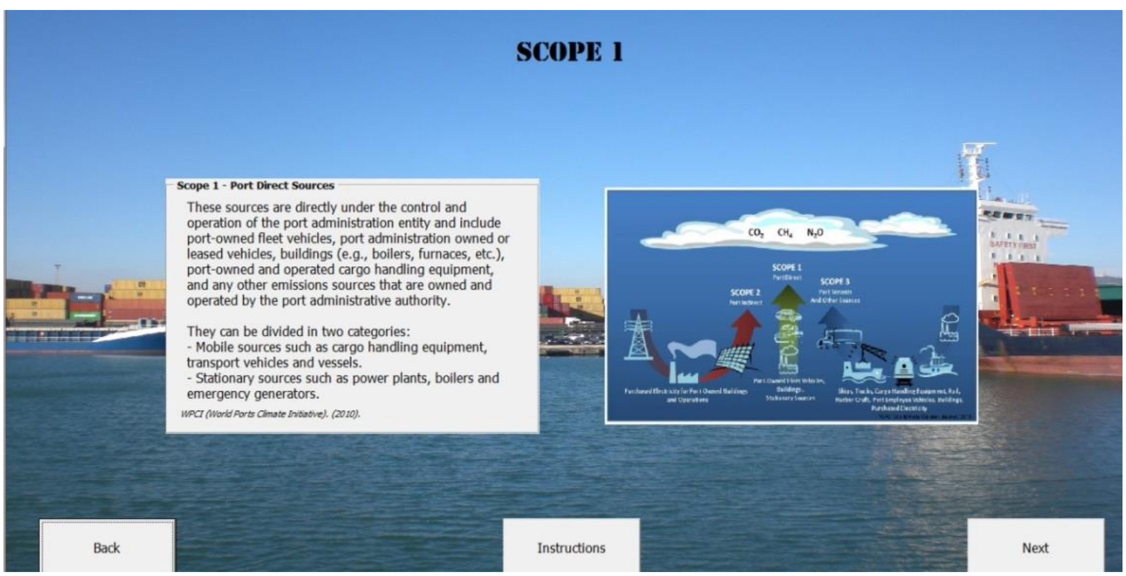



**Figure 3.10: Definition of scope 1**

In the next slides, the required data to calculate the emissions sources related to scope 1 are provided. Emission sources in this scope are divided into two main groups: mobile sources and stationary sources. As for the calculation of all sources of scope 1, the related cells should be filled with the appropriate data related to the port authority. There will be two screens pages for scope 1 (Figures 3.11 and 3.12) that belong to mobile sources and two screen pages that belong to stationary sources (Figures 3.13 and 3.14).
Figure 3.11 presents the first screen page for scope 1, where data related to three categories of the mobile sources should be filled (if they exist in the port):

- Cargo Handling Equipment
- On-Road Vehicles
- Railroad Locomotives

For each cell, the source type, fuel type, consumption amount and consumption unit should be provided. Then by pressing the 'Add' button, the source will be added to the list (see Figure 3.11). At the same time, by pressing the "delete" button, possible mistakes, if any, can be erased.

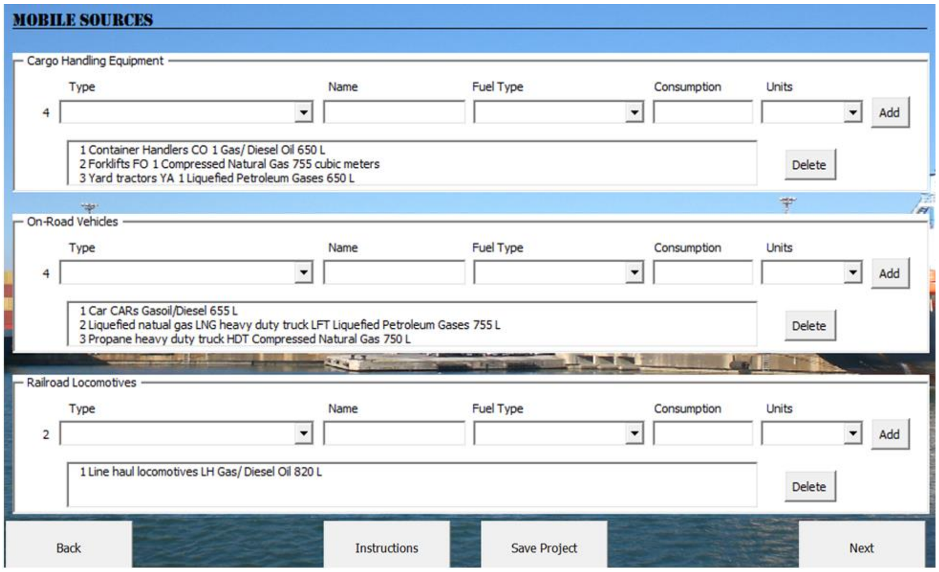



**Figure 3.11: First calculation screen of the mobile sources (scope 1)**

By clicking the 'Next' button, anew screen appears. In this slide of scope 1 (Figure 3.12), data related to two other categories of mobile sources should be filled (if they exist in the port), which are:

- Port owned vessels
- Construction Equipment

Again for each cell, the source type, fuel type, consumption amount and consumption unit should be provided. Then by pressing the 'Add' button, the source will be added to the list (see Figure 3.12).

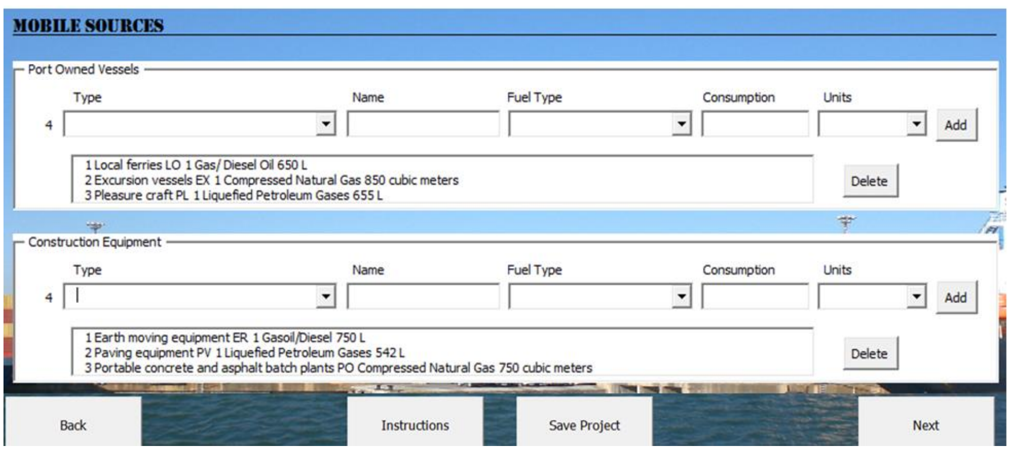



**Figure 3.12: Second calculation screen of the mobile sources (scope 1)**

Now by clicking on the “Next” button, the required data for stationary sources related to scope 1 should be provided (Figure3.13). The necessary data (fuel type, consumption amount and consumption unit) related to three groups of stationary sources should be filled (if they exist in the port), which are:

- Power plants
- Boilers
- Incineration plants

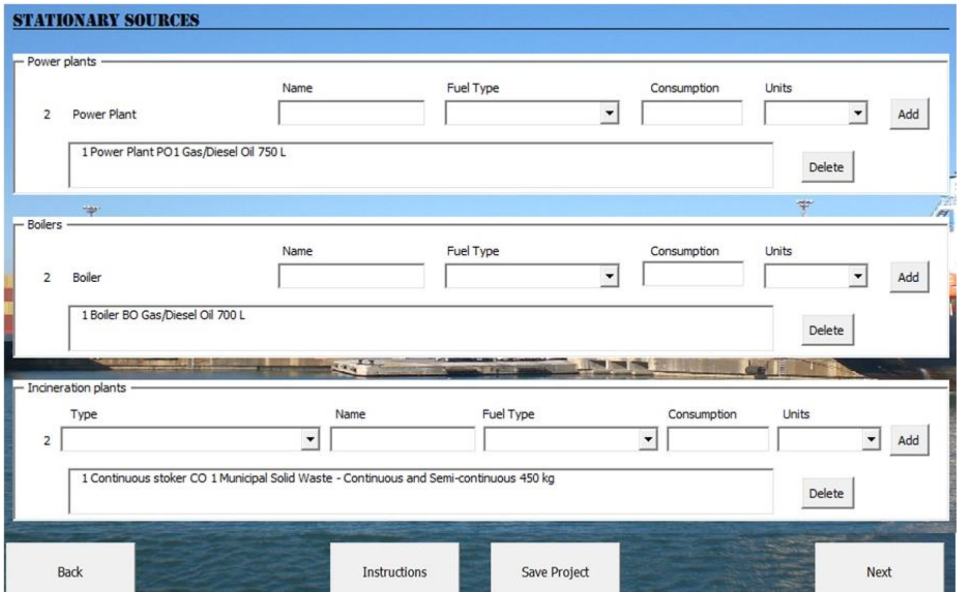



**Figure 3.13: First calculation screen of the stationary sources (scope 1)**

By pressing the ‘Next’ button, the last page of scope1 appears. In this screen (Figure 3.14), the required data (fuel type, consumption amount and consumption unit) related to three other groups of stationary sources should be completed (if they exist in the port), which are:

- Generators
- Facilities that use combustion processes
- Wastewater treatment plants

In the case of the wastewater treatment plants, the type of wastewater treatment plant and the type of industry this water comes from should be chosen. In addition in order to obtain the value, the data related to the “Organic component removed as sludge in inventory” and “Amount of $CH_4$ recovered in inventory” Should be filled.

Then the total emissions from scope 1 can be obtained by clicking the ‘Results’ button and it is possible to save it as a pdf file or to continue with the rest of the scopes and get the total amount of emissions at the end. In this case, the user should press the button ‘Go to Scope 2’.

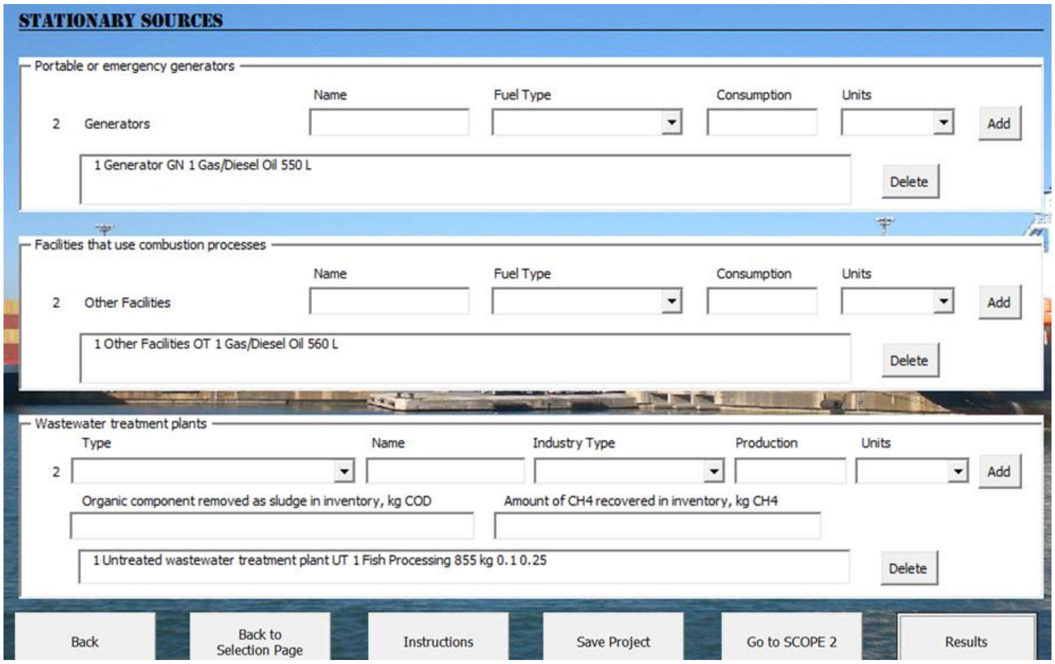



**Figure 3.14: Second calculation screen of the stationary sources (scope 1)**

Figure 3.15 presents the introduction screen to scope 2, where a brief definition of this scope is presented. By clicking the 'Next' button, the calculation page for scope 2 appears.

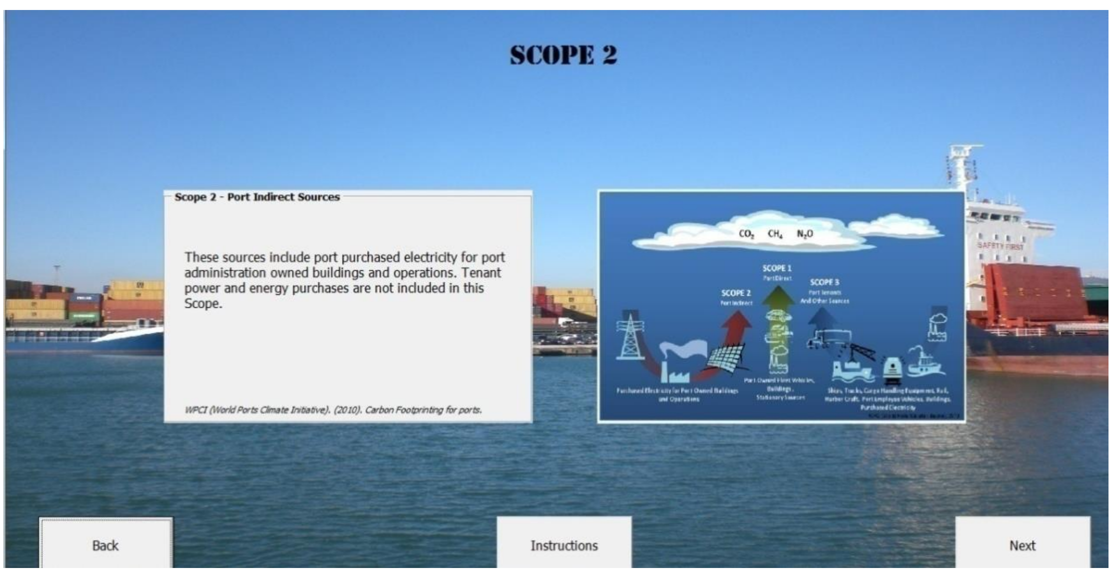



**Figure 3.15: Definition of scope 2**

In Figure 3.16, information on electricity data is required. The consumption amount has to be introduced and the intensity should be selected from a list according to the country. The mix of energy, and therefore the emissions, will vary depending on the country. If the name of a country is not on the list or if the user is not satisfied with the intensity value, "other option" should be chosen and the desired value should be added to the intensity box. Then, by pressing the 'Add' button, different sources can be added to the emission list. After that, the result of this scope can be obtained by clicking on the 'Results' button. Alternatively, the user can press the button 'Go to Scope 3' where these emissions will be calculated.

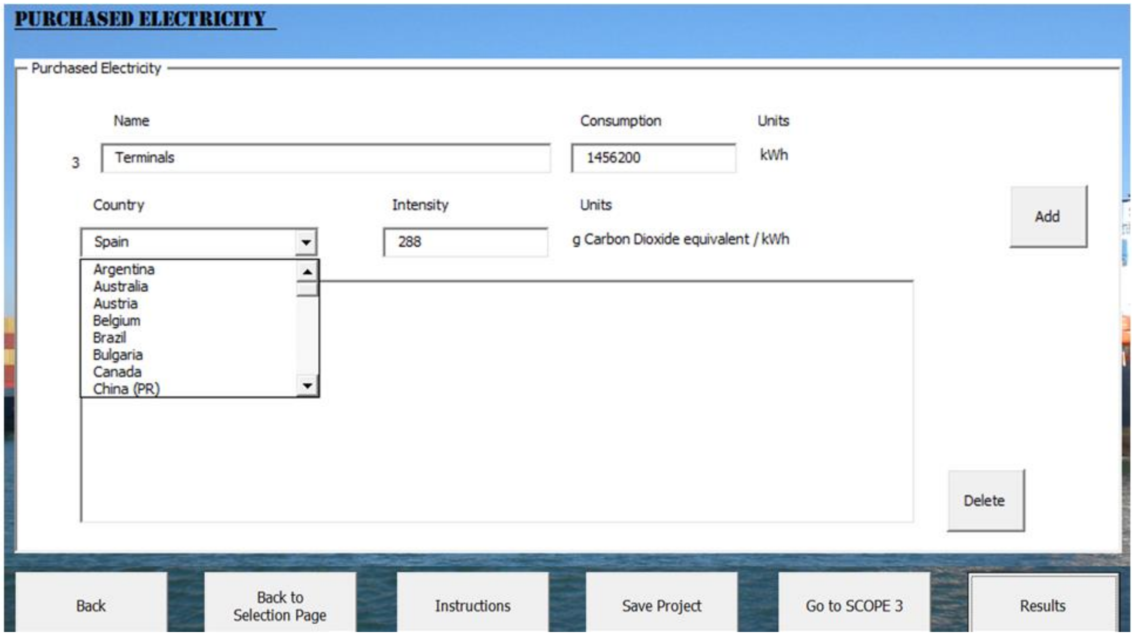



**Figure 3.16: Calculation screen of the scope 2**

Figure 3.17 shows a definition of scope 3. In this scope, the user should provide data related to tenants 'emissions and only from those emissions produced by their activities inside the port area, not outside as mentioned in the note present in this screen.

Such emissionsare divided into four main groups: mobile sources, stationary sources, purchased electricity and employees' commuting.The needed data of these four sources are presented in the coming screens of the tool (Figures 3.18- 3.26).

The slides on mobile sources, stationary sources and purchased electricity are the same as those presented for scope 1. The main difference is that the data should be filled with tenants' information and not with the port's authority data. Therefore, these slides will not be repeated. The only variation is the inclusion of 'Ocean-Going Vessels' in the mobile sources category.

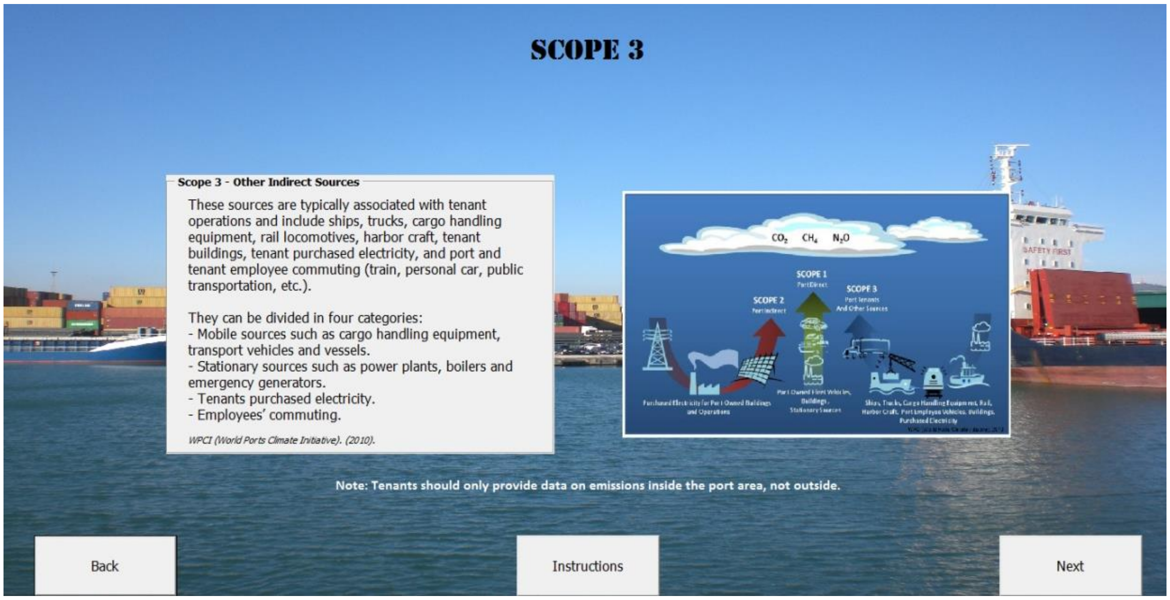



**Figure 3.17: Definition of scope 3**

By clicking on the 'Next' button in Figure 3.17, the emissions calculation of mobile sources of scope 3 will start. As it can be seen in Figure 3.18, data related to the following three categories of the mobile sources should be filled, (if they exist in the port):

- Cargo Handling Equipment
- On-Road Vehicles
- Railroad Locomotives

In this step, the required data are fuel type, consumption amount and unit selection. Then, by pressing the 'Add' button, all the sources will be added to the list. By clicking on the 'Next' button, the following calculation page of scope 3 appears.

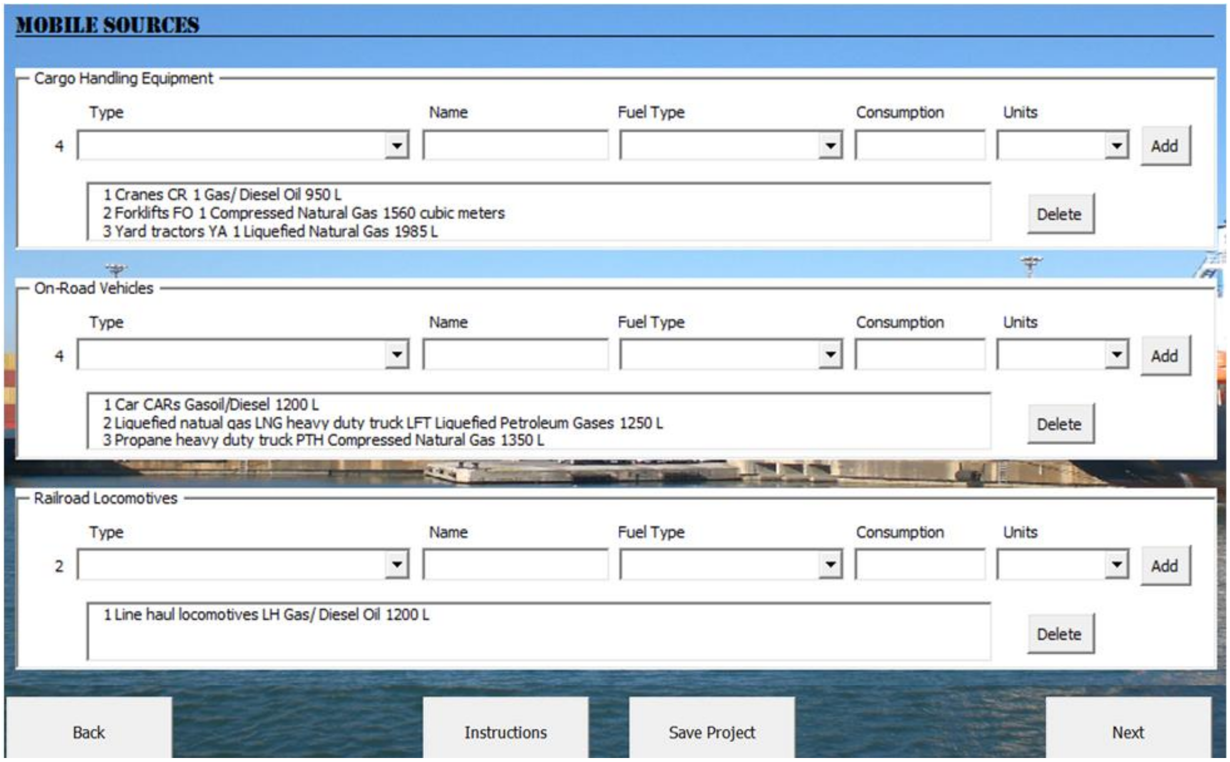



**Figure 3.18: First calculation screen of the mobile sources (scope 3)**

In the next page of the scope 3 (Figure3.19), the data related to the following three categories of mobile sources should be completed (if they exist in the port):

- Harbour craft and inland waterway vessels
- Ocean-going vessels
- Construction Equipment

Again for each cell, the source type, fuel type, consumption amount and consumption unit should be chosen.

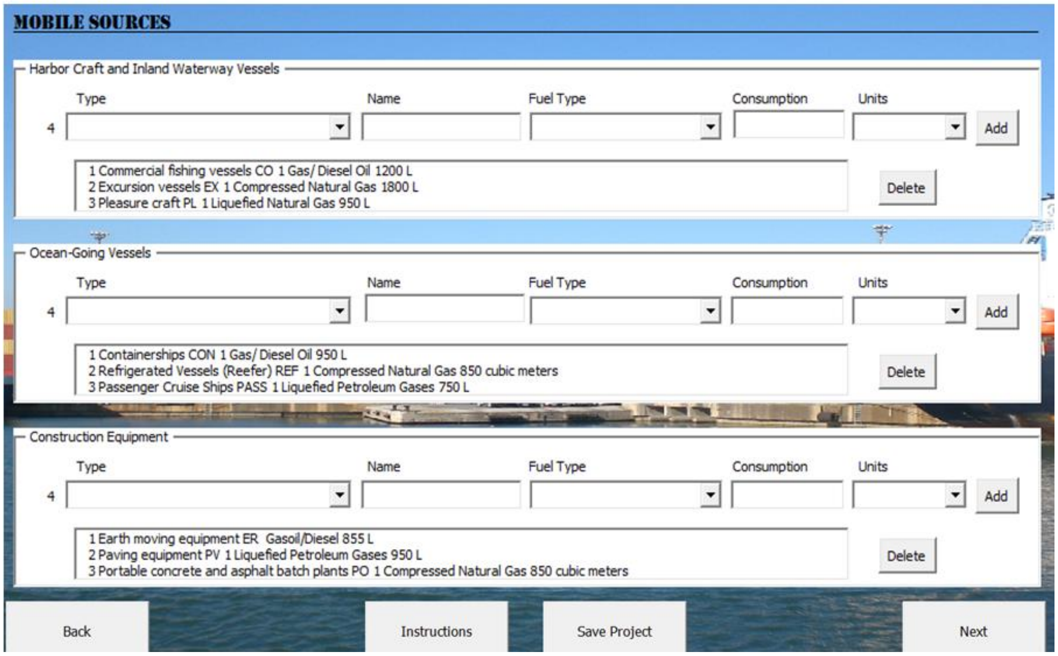



**Figure 3.19: Second calculation screen of the mobile sources (scope 3)**

At the next screen (Figure3.20), the required data (fuel type, consumption amount and consumption unit) related to three groups of stationary sources should be filled (if they exist in the port), which are:

- Power plants
- Boilers
- Incineration plants

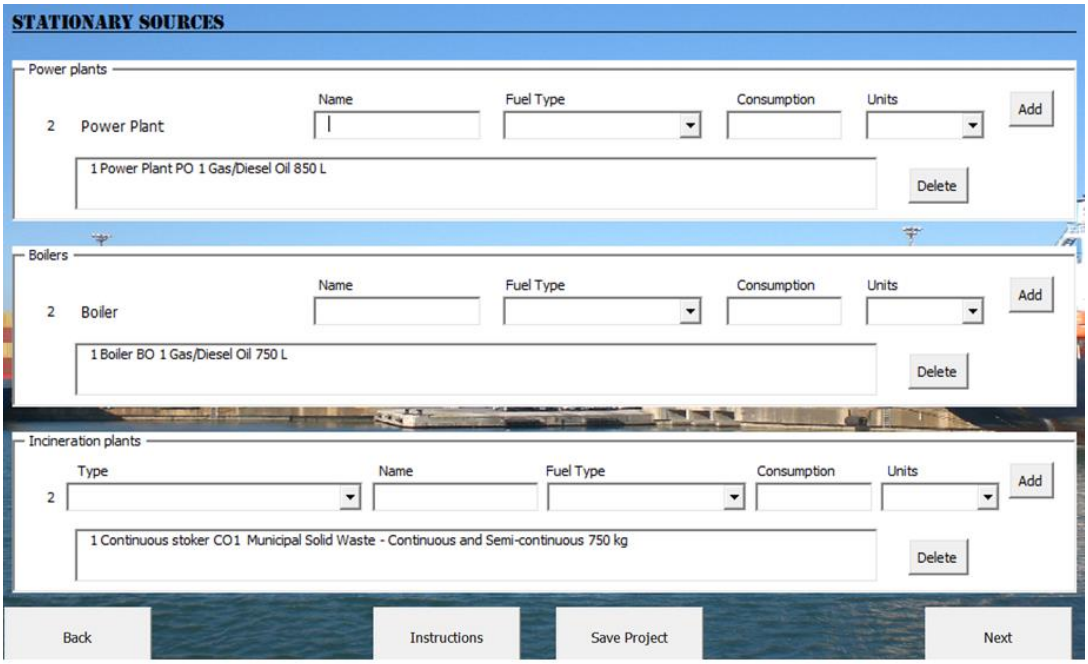



**Figure 3.20: First calculation screen of the stationary sources (scope 3)**

In the next screen (Figure 3.21), the required data (i.e. fuel type, consumption amount and consumption unit) related to three other groups of stationary sources should be completed (if they exist in the port):

- Generators
- Facilities that use combustion processes
- Wastewater treatment plants

As it can be seen, most of the mobile and stationary sources are the same as scope 1, apart from 'Ocean-going vessels' that is included in this scope since they do not belong to the port authority.

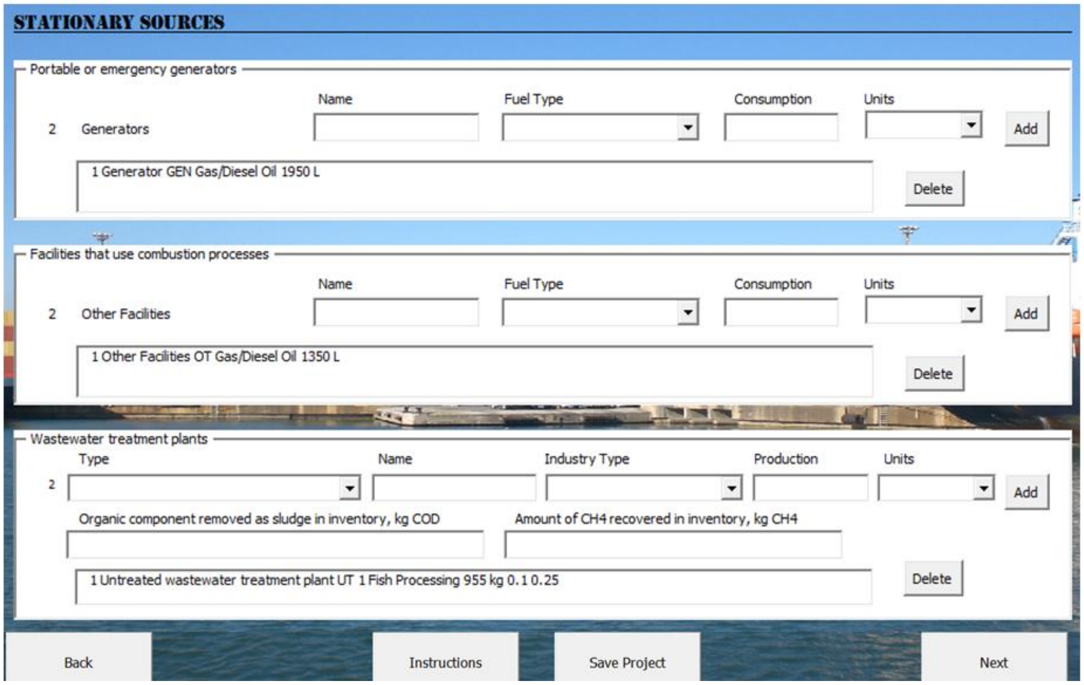



**Figure 3.21: Second calculation screen of the stationary sources (scope 3)**

By clicking on the 'Next' button, the emissions from tenant purchased electricity in scope 3 will be calculated. As in can be seen in Figure 3.22, the needed data of this stage are the consumption amount and the intensity which should be chosen based on the country, as explained before.

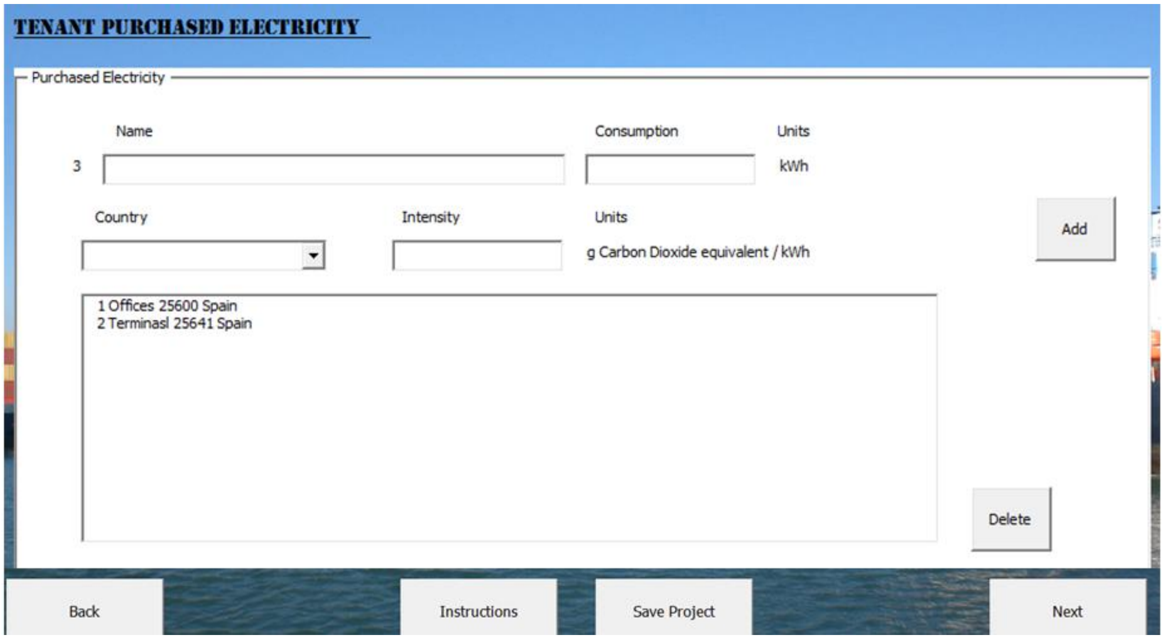



**Figure 3.22: Tenant purchased electricity emissions calculation screen (Scope 3)**

Finally, to calculate the emissions from employees' commuting, three methods according to the available type of the data are proposed as explained in section 3.3.3. Figure 3.23 offers a decision tree to select the most suitable calculation method for scope 3 emissions from employees' commuting. Ports may use one of the explained methods. By clicking on the method, the related calculation page will be presented.

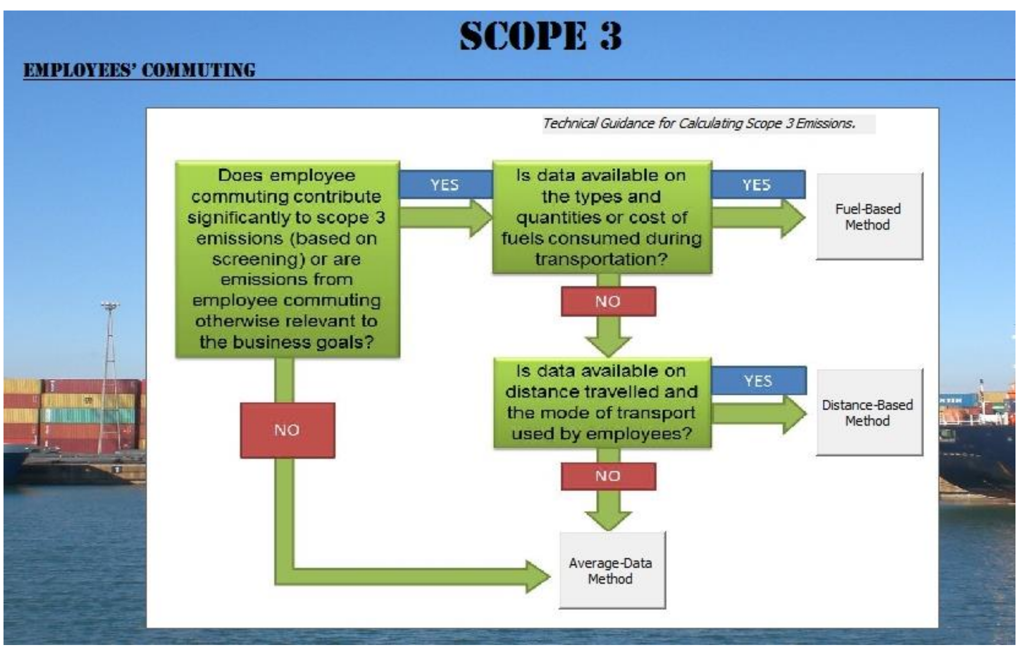



**Figure 3.23: Decision tree to select a calculation method for emissions from employees' commuting**

Figure 3.24 shows the calculation page of the Fuel-based method. As it can be seen, the required data are the type of vehicle, fuel type, consumption amount and unit. By clicking on the 'Add' button, the data will be added to the list.

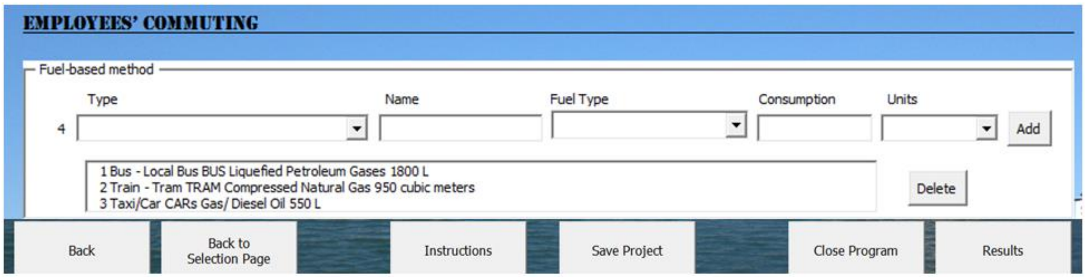



**Figure 3.24: Calculation screen of employees' commuting (Fuel-based method)**

Figure 3.25 shows the calculation page of the Distance-based method. As it can be seen, the required data are the type of vehicle, working days, distance and unit. By clicking on the 'Add' button, the data will be added to the list.

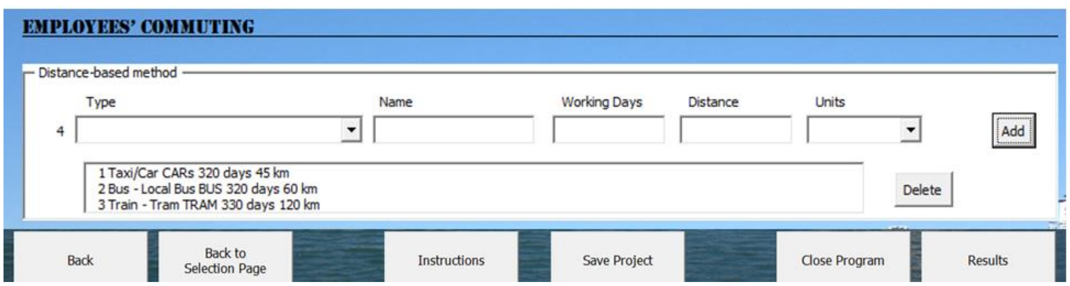



**Figure 3.25: Calculation screen of employees' commuting (Distance-based method)**

Figure 3.26 shows the calculation page of the Average-data method. As it can be seen, the required data are the total number of employees, working days, percentage of total commutes based on the vehicle type and average one-way distance. By clicking on the 'Add' button, the data will be added to the list.

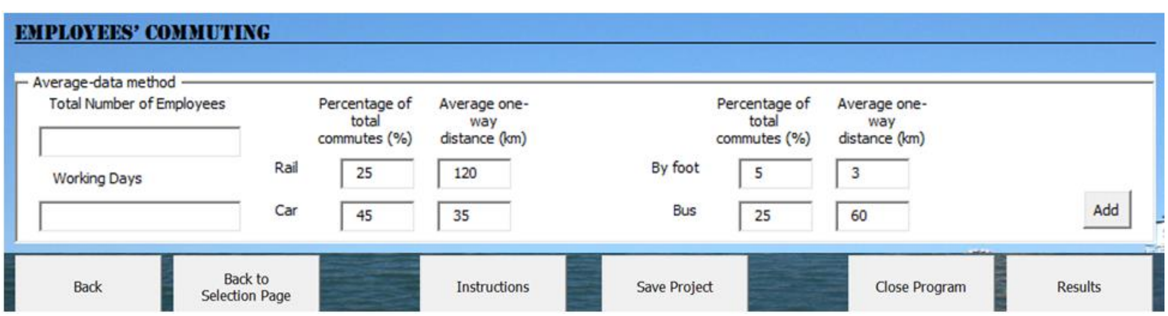



**Figure 3.26: Calculation screen of employees' commuting (Average-data method)**

- **Results' of the tool**

Finally, in the last screen by clicking the 'Results' button, the results for three scopes and the total GHG emissions can be obtained. The results can be saved as a pdf file. A sample of the results as a pdf file is presented in Figures 3.27 and 3.28.The values showed in these Figures for the Port are not real. The results of the tool are divided into four sections:

- **Total amount**

As it can be seen in Figure 3.27, the first information that is presented is the name of the port, followed by the port address, the country and the capacity (TEU or tonnes). Then the total $CO_2$eq emissions are presented as well as the emissions by capacity. In addition, total values per scopes are displayed, including also a pie chart.

- **Scope 1**

  In scope 1, the total amount of emissions and emissions of each of the mobile sources and stationary sources from this scope are presented including also two pie charts (Figure 3.27).

- **Scope 2**

  As it is presented in Figure 3.28, the total amount of emissions from purchased electricity is presented.

- **Scope 3**

  In this part, the total amount of emissions and the emissions of each of the mobile sources, stationary sources, purchased electricity and employees' commuting from scope 3 are presented and its representation in two pie charts is included (Figure 3.28).

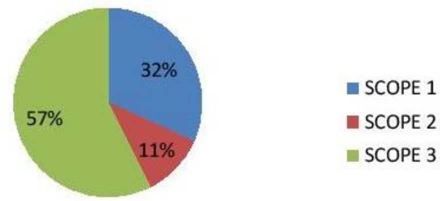
It should be mentioned a paper has been published in Science of the Total Environment (STOTEN) Journal (Azarkamand et al., 2020c) from the development of the tool and it can be seen in appendix 7.3. This tool also was presented at the 8th international conference on Maritime Transport in Barcelona (September 2020) (Azarkamand et al., 2020d) (appendix 7.4) and at the online meeting of the Digital and Green Route Community working group (June 2021).

# Port Name

Port Address
Country
Capacity 2550 TEU/yr. 18555 million tn./yr.

| | | |
|---|---|---|
| **TOTAL:** | 4866.281 $CO_2e$ tonnes | |
| **Carbon footprint:** | 1.908 $CO_2e$ tonnes/(TEU/yr.) | 0.3 $CO_2e$ tonnes/(million tn./yr.) |

| SCOPE | Emissions [$CO_2e$ tonnes] |
|---|---|
| 1 | 1547.035 |
| 2 | 529.321 |
| 3 | 2789.924 |
| TOTAL | 4866.281 |




Emissions by Scopes

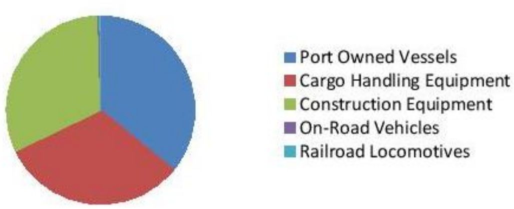
| | |
|---|---|
| **SCOPE 1:** | 1547.035 $CO_2e$ tonnes |

*Mobile Sources*

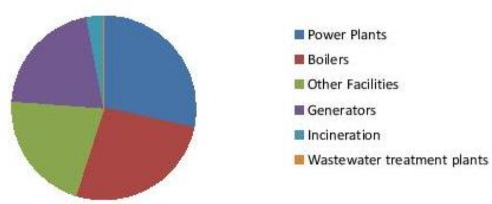
| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Port Owned Vessels | 482.069 | 35.92% |
| Cargo Handling Equipment | 428.502 | 31.92% |
| Construction Equipment | 425.775 | 31.72% |
| On-Road Vehicles | 3.454 | 0.26% |
| Railroad Locomotives | 2.423 | 0.18% |
| Total | 1342.223 | 100.00% |

*Stationary Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Power Plants | 58.218 | 28.43% |
| Boilers | 54.337 | 26.53% |
| Other Facilities | 43.469 | 21.22% |
| Generators | 42.693 | 20.85% |
| Incineration | 6.083 | 2.97% |
| Wastewater treatment plants | 0.011 | 0.01% |
| Total | 204.812 | 100.00% |




Emissions by Mobile Sources




Emissions by Stationary Sources

**Figure 3.27: Sample of the result (Page 1)**

| SCOPE 2: | 529.321 | $CO_2$e tonnes |
|---|---|---|

*Purchased Electricity*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Electricity | 529.321 |

| SCOPE 3: | 2789.924 | $CO_2$e tonnes |
|---|---|---|

*Mobile Sources*

| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Cargo Handling Equipment | 884.636 | 47.96% |
| Construction Equipment | 483.116 | 26.19% |
| OGV | 461.694 | 25.03% |
| On-Road Vehicles | 6.094 | 0.33% |
| Harbor Craft | 5.496 | 0.30% |
| Railroad Locomotives | 3.545 | 0.19% |
| Total | 1844.582 | 100.00% |

*Stationary Sources*

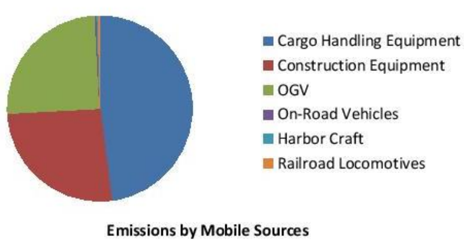
| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Generators | 151.367 | 38.76% |
| Other Facilities | 104.792 | 26.83% |
| Power Plants | 65.980 | 16.90% |
| Boilers | 58.218 | 14.91% |
| Incineration | 10.138 | 2.60% |
| Wastewater treatment plants | 0.015 | 0.00% |
| Total | 390.511 | 100.00% |

*Purchased Electricity*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Electricity | 14.757 |

*Employees' commuting*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Employees' commuting | 540.074 |



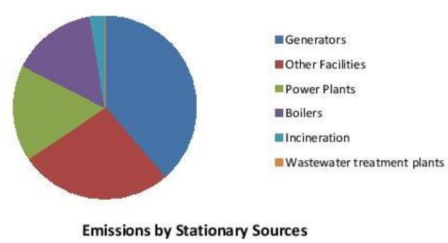




**Figure 3.28: Sample of the result (Page 2)**

### 3.4.2. User Guidelines

After developing the tool, user guidelines have been prepared to help users to complete the tool. By clicking on the "Instructions" button, in the tool, the user will download a pdf file with guidelines on how to complete the tool. Figure 3.29 presents the first page of the guidelines as a sample. The complete document of the user guidelines can be found in appendix 5. There, all the screens and their definitions are presented.

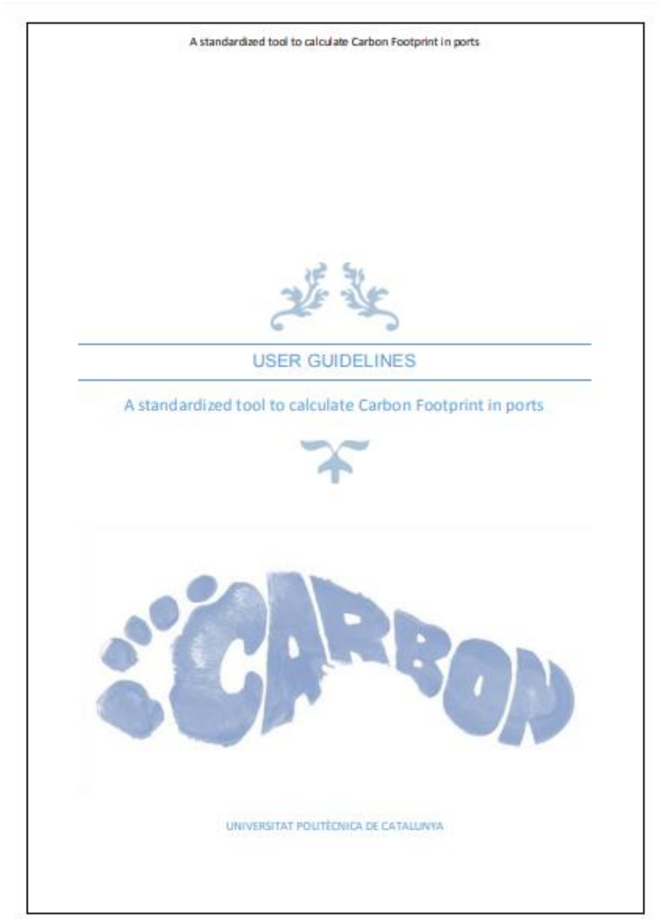



**Figure 3.29: The first page of the guidelines as a sample**

In addition, a Video file has been developed to help users to complete the tool. By pressing the "Video tutorial" box in the tool, a video is displayed with instructions. Figure 3.30 presents a screen of the video tutorial as a sample.

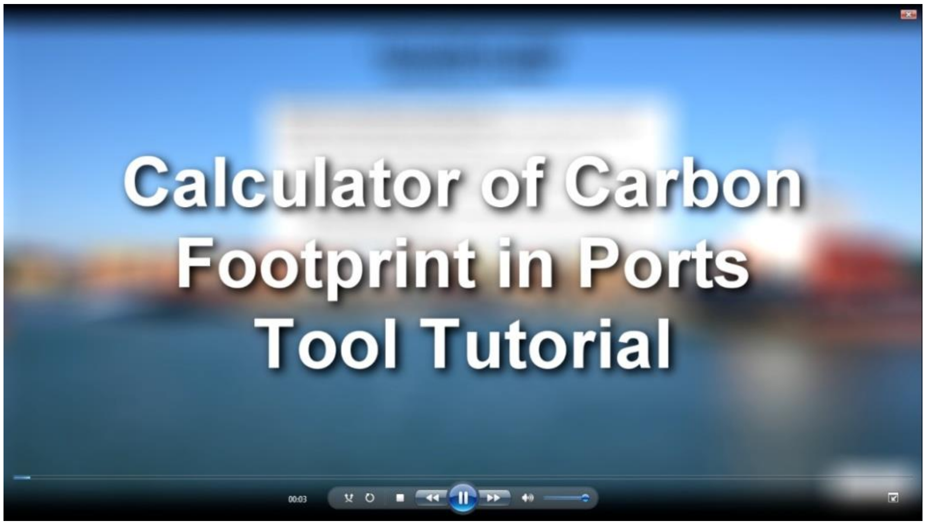



**Figure 3.30: A screen of the video tutorial**

# Chapter 4: Test and improvement of the tool

In this chapter, the tool presented in chapter 3 was tested by different reviewers. In first place, 30 students of the subject "Climate Change" from the Industrial Engineering Bachelor Degree of UPC tried the tool. It was presented to them in class and they were asked to test the tool with a case study. Their feedback was taken into account to improve the tool.

After this first enhancement of the tool, it was sent to 20 experts or reviewers: environmental port managers, environmental experts and port professionals all around the world. Feedback from 15 of them was obtained through personal visits, telephone calls or via email. Most of their suggestions were introduced in the tool through different amendments. Those comments that were not implemented have been justified in this section accordingly. Table 4.1 presents the participant entities to this validation phase and the positions of their respondents.

**Table 4.1: The list of participant entities and the position of their respondents**

| The participant entities | Position |
|---|---|
| Ports de la Generalitat (Spain) | Head of the Environmental Department |
| Port of Barcelona (Spain) | Head of the Environmental Department |
| Port of Hamburg (Germany) | Head of the Environment and Sustainability Strategy Department |
| Gothenburg Port Authority (Sweden) | Senior Environmental Manager. |
| ESPO (European Sea Ports Organization) | Senior Policy Advisor for Environment and Safety, |
| Cardiff University (United Kingdom) | EcoPorts Coordinator. |
| Port of Valencia (Spain) | Head of Environmental Policies |
| Port of Ferrol (Spain) | Head of the Sustainability Department |
| Veracruz University (Mexico) | Full professor and port expert |
| Port of Amsterdam (The Netherlands) | Program manager Corporate Social Responsibility |
| Ramboll Consultancy (United States of America) | Regional COO, West and Director of Strategy |
| Port of Le Havre (France) | Head of the Sustainable Development Department |
| Port of Copenhagen (Denmark) | Environmental, energy and climate consultant, project manager |
| Pireaus Port Authority (Thessaloniki) | Head of the environmental department |
| Universitat Politècnica de Catalunya (Spain) | Full professor and environmental expert |

The feedback obtained from the aforementioned experts and students has been classified based on the different sections of the tool. In first place, comments to each one of the first slides of the tool are introduced (i.e. introduction, steps' description and general data of the port). Then suggestions for each one of the scopes are presented. Finally, feedback concerning the results and the guidelines are also included.

The actions taken for each one of the comments are presented in the next sections. The accepted comments are represented by the tick sign (✓) and the rejected comments are represented by the cross sign (x).

## 4.1. Introduction to the tool

- The first slide of the tool was considered to be too detailed with too much information, as it can be seen in Figure 4.1. It was suggested to summarize this description.

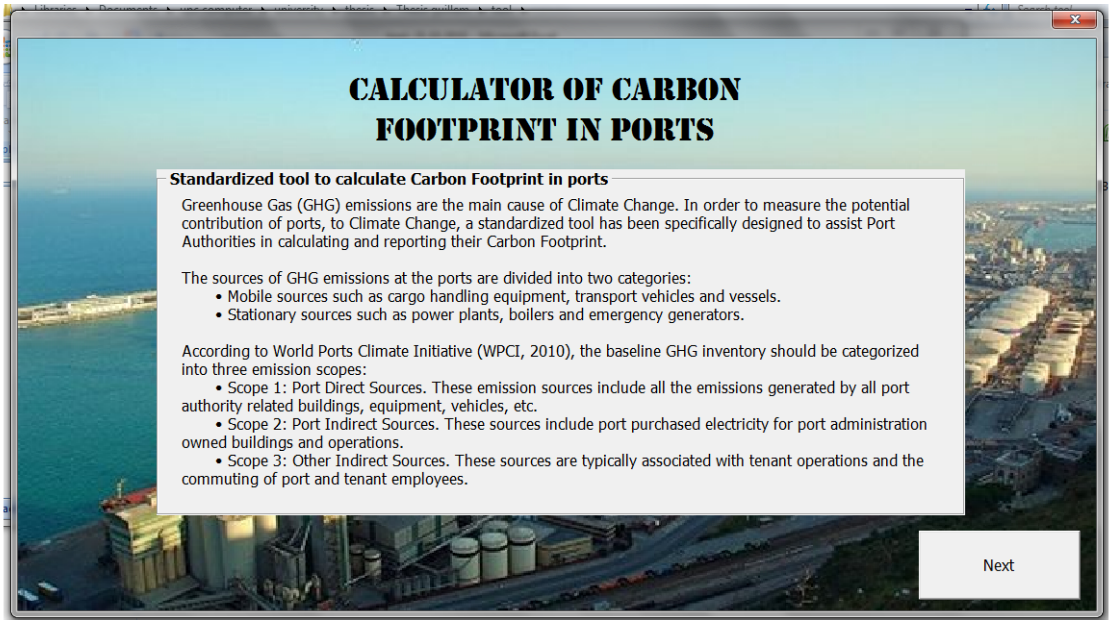



**Figure 4.1: Introduction slide in the first version of the tool**

- This suggestion was accepted and the modification was done, as it can be in Figure 4.2 (✓).

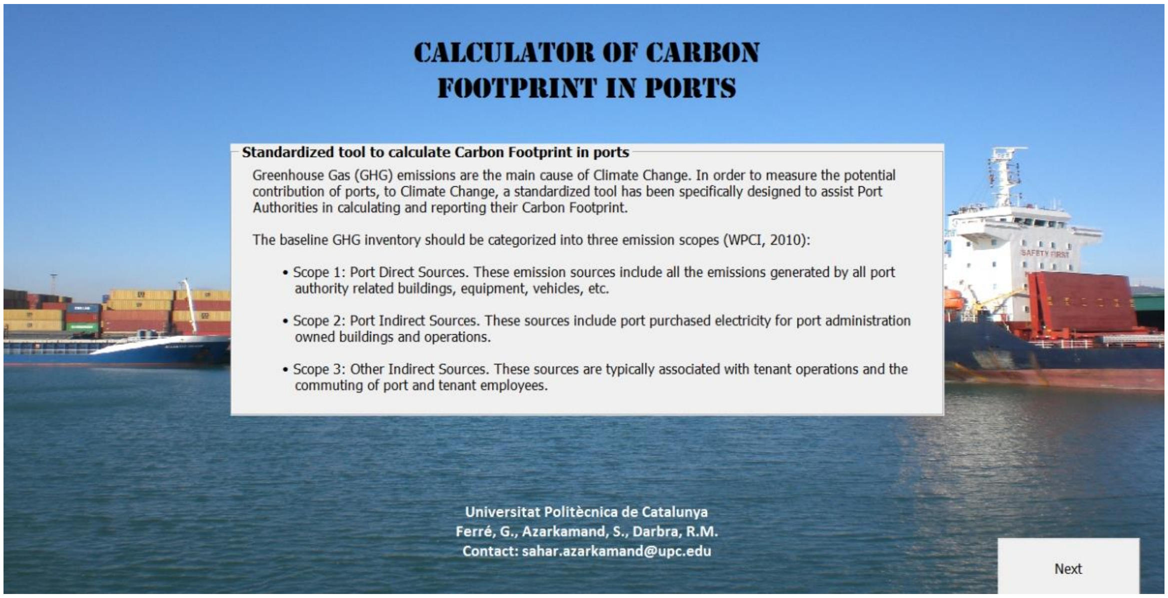



**Figure 4.2: Introduction slide in the final version of the tool**

- The original background photo (Fig 4.1) was from a particular port website and it was suggested to change it for one that belonged to the authors to avoid copyright issues.

    - This suggestion was accepted and a photo owned by one of the authors was used as a background for all the slides, as it can be seen in Figure 4.2.

## 4.2. Steps' description

- As it can be seen in this slide (Fig. 4.3), information about the confidentiality of the tool was not present. It was requested to highlight the fact that the information is confidential since this is a very important aspect for the users of the tool.

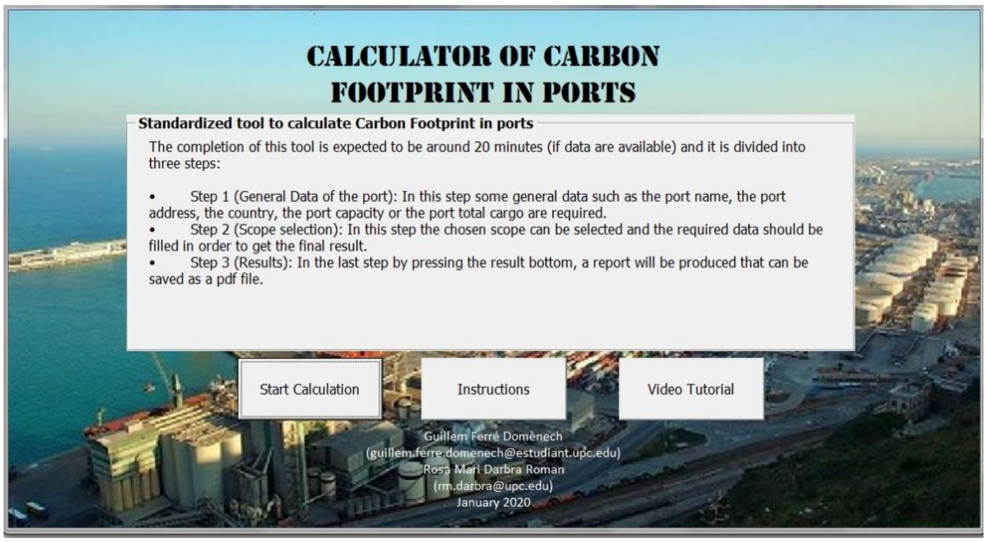



**Figure 4.3: Steps' description in the previous versions of the tool**

- This suggestion was accepted and a sentence was addedmaking clear that the information was totally confidential. This can be seen in Figure 4.4, highlighted in red colour (✓).

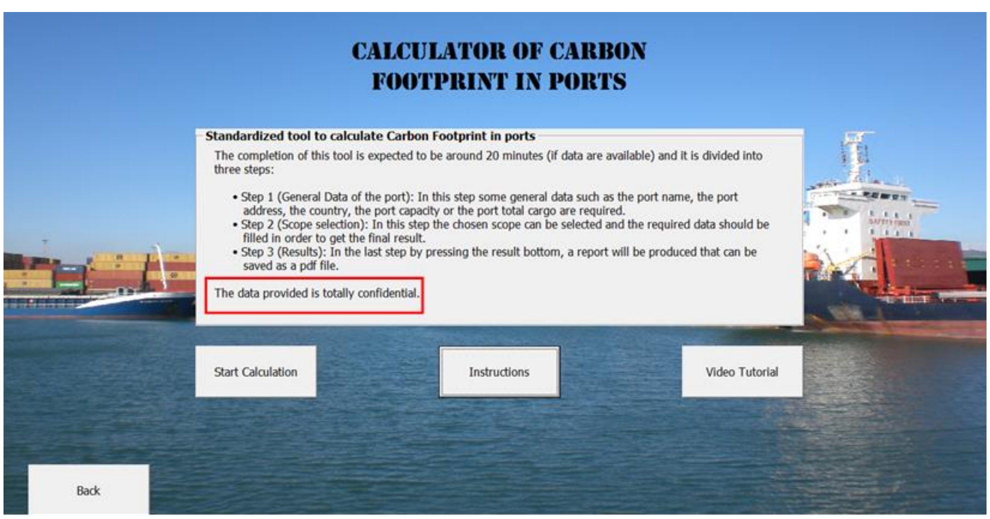



**Figure 4.4: Steps' description in the final version of the tool**

## 4.3. General port Data

The feedback related to general port data includes the following comments:

- In this slide (Figure 4.5), the only way to introduce the capacity of the port was (TEU/year). It was proposed to add another option to provide this information: the total cargo of the port (million tonnes/year).

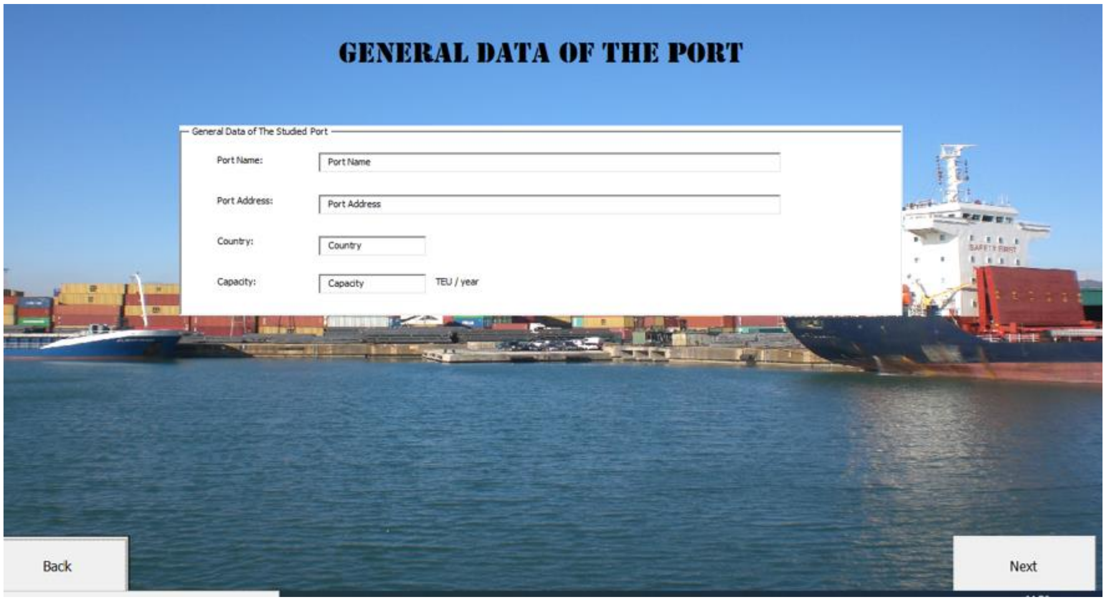



**Figure 4.5: General port data slide in the previous versions of the tool**

- This suggestion was accepted and a new box for total cargo was added as it can be seen in Figure 4.6 (✓).

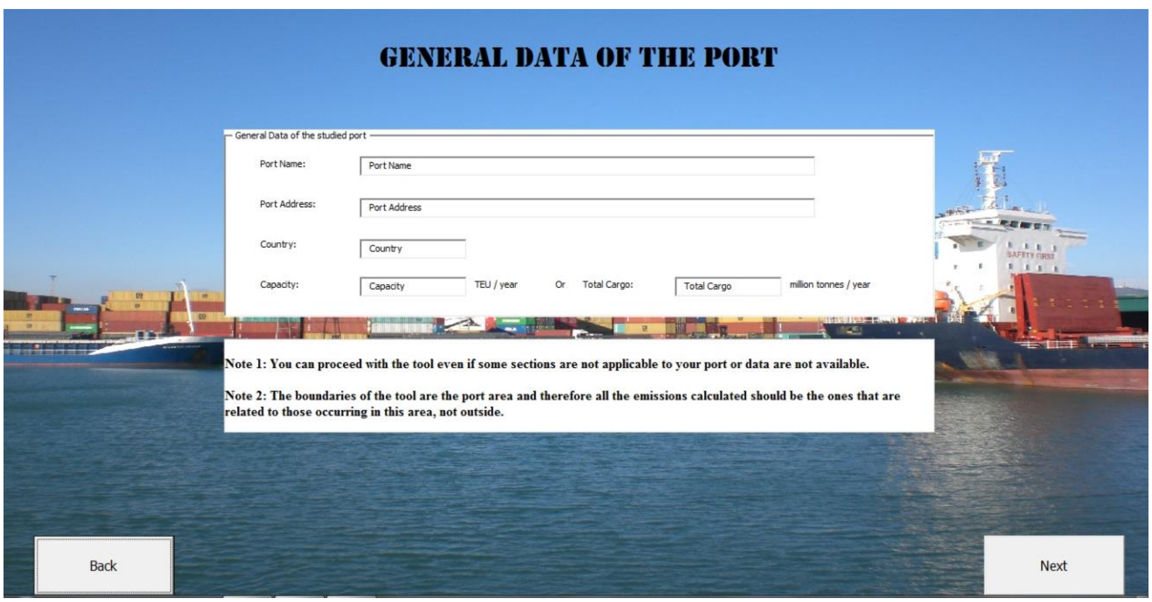



**Figure 4.6: General port data slide in the final version of the tool**

- It was suggested to mention the possibility to proceed with the tool even if some sections were not applicable to a specific port or data were not available.
    - This suggestion was accepted and note 1 was added in a new box to the "General data of the port" as it can be seen in Figure 4.6. In this way, the tool can be used even if some boxes are not filled in (✓).
- It was suggested to add an explanation to the "General data of the port" slide to clarify that the boundaries of the tool are the port area. As a consequence, it should be made clear that all the emissions calculated should be the ones that are related to those occurring in this area, not outside.
    - This suggestion was accepted and note 2 was added in a new box as it can be seen in Figure 4.6 (✓).

## 4.4. Scopes

In the scopes section, the related comments from the reviewers are presented below:

- It was proposed to provide the possibility to go from one scope to another without following a consecutive order and without needing to fill the three of them.
    - This suggestion was accepted and the modification was done. Now it is possible to move from one scope to another and go back (✓).
- When you put the mouse on the box of any scope in the first slide of the scopes (Figure 4.7), it appeared the definition of each scope. This was confusing for some reviewers. It was proposed to remove these explanations from this slide and provide the full explanation of each scope once the user entered inside the scope. If he/she is not interested in this particular scope after reading the description, there is a button to go back to the main selection page.

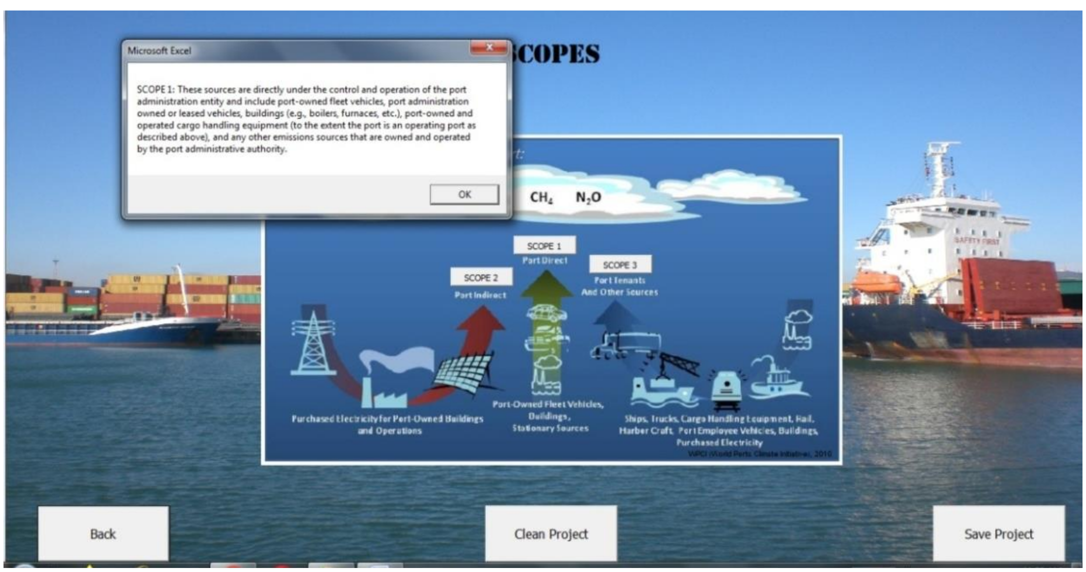


**Figure 4.7: Scopes' selection slide in the previous versions of the tool**

- This proposal was accepted, the definitions were removed from the scopes' first slide and new slides for defining each scope were added to the tool. Figure 4.8 shows a definition slide of scope 1 as a sample (✓).

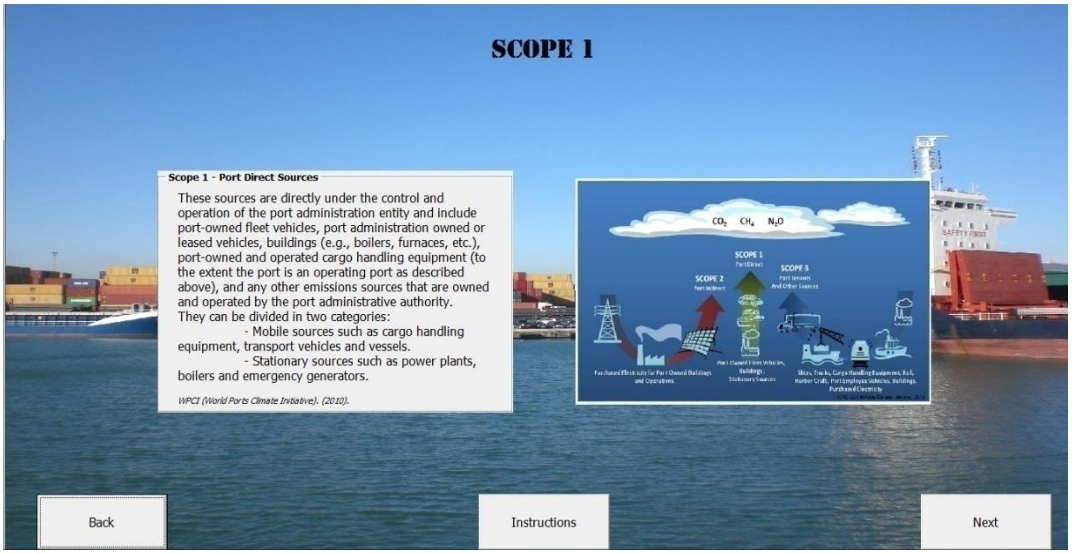



**Figure 4.8: Scopes' definition slide in the final version of the tool**

- As it can be seen in the first box of Figure 4.9 (highlighted in red colour), when introducing data on the box of cargo handling equipment (as an example), the titles of the cells such as fuel type or consumption disappeared. The title of the cells was replaced with data. It was proposed to provide the possibility of seeing the title of the cells after inserting related data in the box.

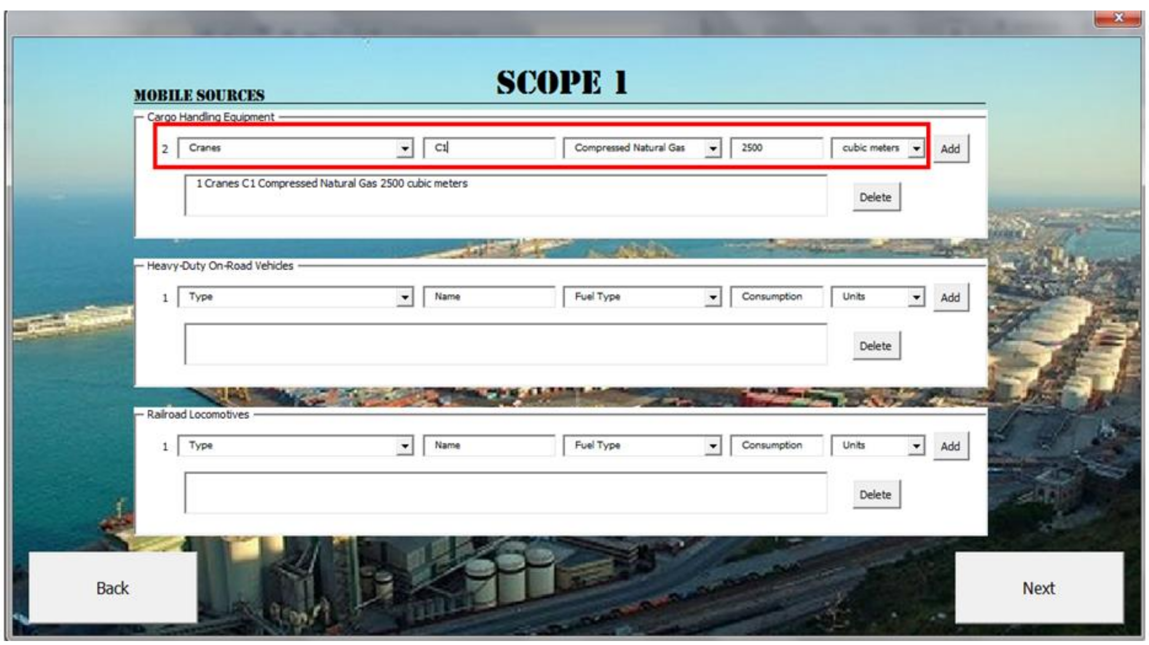



**Figure 4.9: A sample screen of the previous versions of the tool**

- This suggestion was accepted and the modification was done as it can be seen in Figure 4.10 (✓).

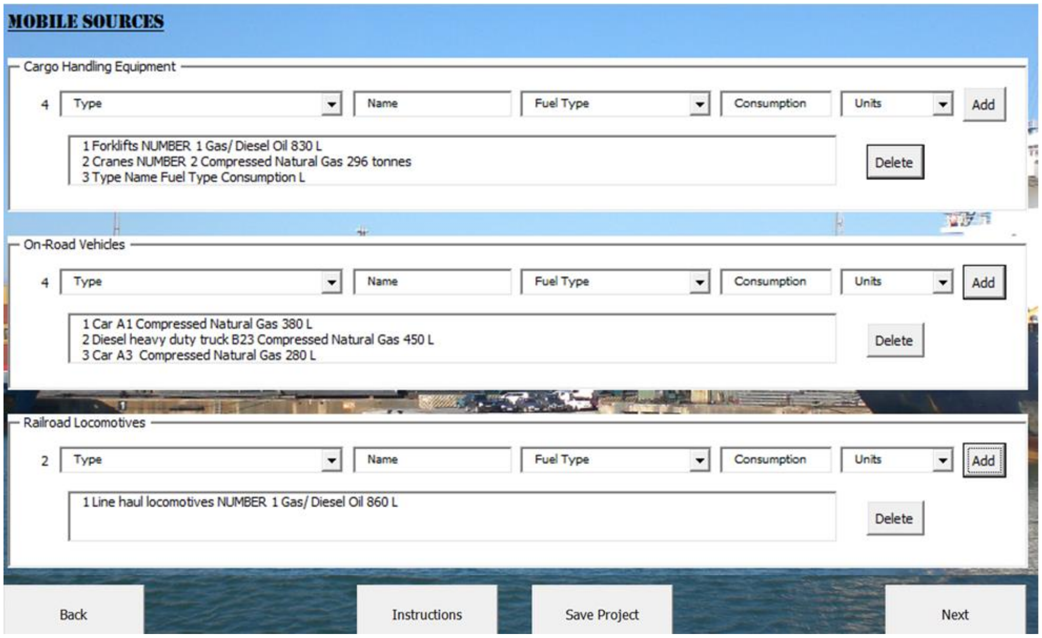



**Figure 4.10: A sample screen of the previous versions of the tool**

- Another comment made later related to this aspect was that now the titles of the cells were permanent and the user should erase cells to fill in data, as it can be seen in Figure 4.10. It was suggested to erase the name of the cells and put them on top of them to avoid their disappearance when moving inside the tool.
    - This suggestion was accepted and the modification was done as it can be seen in Figure 4.11(✓).

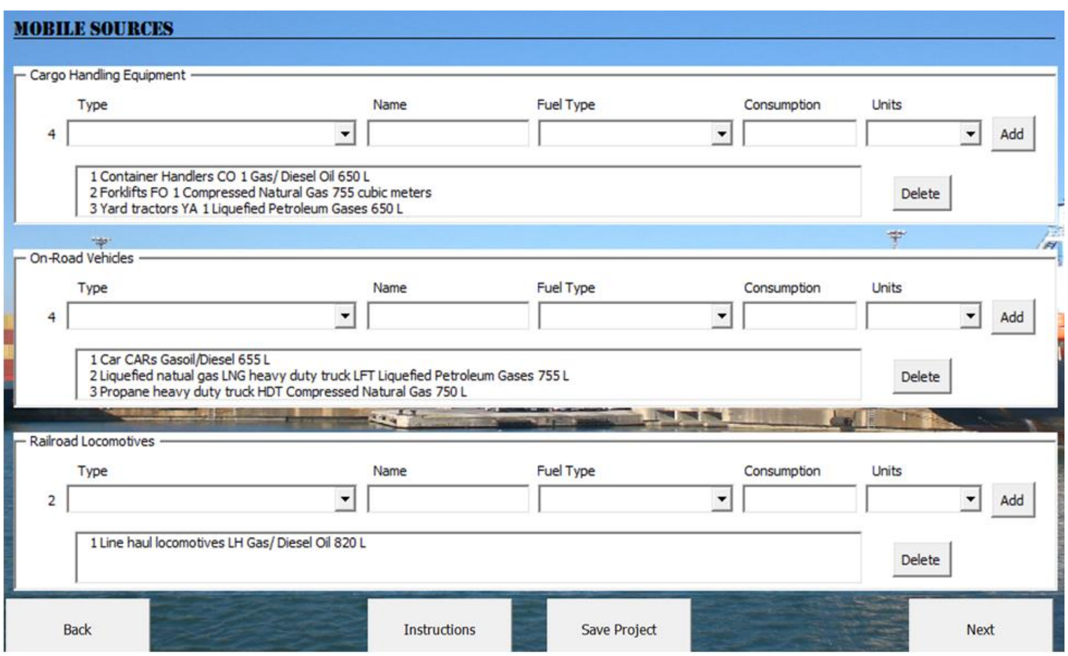



**Figure 4.11: A sample screen of the final version of the tool**

- One of the reviewers suggested that there are numerous difficulties and differences in setting the scopes, as some ports have their own unique definition of what should be considered scope 1, 2, and 3. It all depends on how the port sets up their authority, the lease agreements and other issues.
    - Although the tool provides a suggestion of what should be considered inside each scope according to the international standards, it is flexible enough to allow the user to decide what to put in each scope. In particular, scope 1 and 3 can be shaped by the user criteria since both scopes have all the activities. He/she just needs to decide where to locate each emission of the port activities. The problem is that then this port will not be able to compare results with another port, but it will be able to assess its trends over the years. Therefore, no action was taken since the tool is already prepared for this (×).

### 4.4.1. Scope 1

The reviewers' comments regarding scope 1 are summarized below:

- It was suggested to add "Electricity" as a fuel type for the on road vehicles, as some of them may use electricity.
    - This suggestion was rejected. The research team agreed that these emissions belong to scope 2, together with all the rest of electricity consumption data (×).
- It was suggested to add "Biogasoline" and "Biodiesels" as a fuel type for the on road vehicles in scope 1 and scope 3, as some ports may use them.
    - This suggestion was accepted and the modification was done as it can be seen highlighted in red colour in Figure 4.12 (✓).

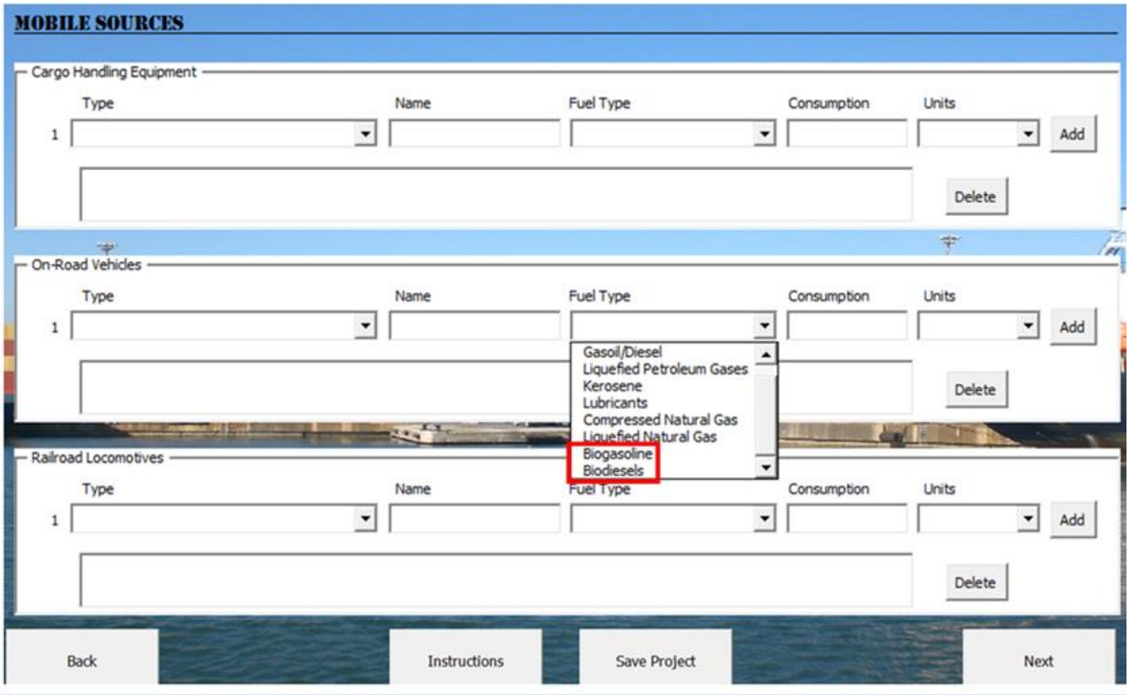



**Figure 4.12: Adding fuels type to the On-Road Vehicles in the final version of the tool**

- It was suggested to remove locomotives from the mobile sources list, as many ports do not have it.

- This suggestion was rejected as some ports might have locomotives. Therefore, it was considered to keep them in the tool in order to be more conservative. If it is not the case, the port just will leave the cell without being filled in and proceed with the calculation (X).

- It was proposed to add the emissions from other industrial waste treatment to the stationary emission sources apart from waste water treatment plants.

  - It is true that a port could have a different type of waste treatment plant in its area. However, since this is not very likely and also the fact that there is another box for "facilities that use other combustion processes" (Figure 4.13, marked in red colour), it was considered not necessary to add a new box for these types of facilities. They could be introduced in the box of other facilities (X).

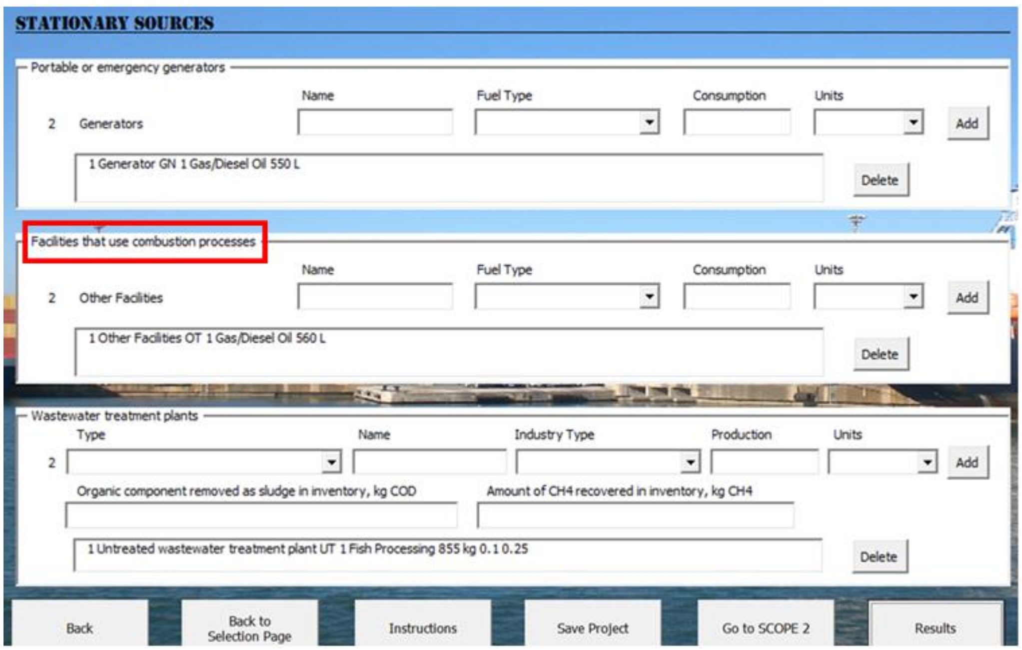



**Figure 4.13: A slide of scope 1 (showing other facilities) in the final version of the tool**

## 4.4.2. Scope 2

The feedback related to scope 2 is presented below:

- In the previous versions of the tool (Figure 4.14), the electricity emission factor was chosen by clicking on a data source button that took the user to a website (www.electricitymap.org) (Figure 4.15) where he/she had to select the country. This was a little bit confusing since the user was leaving the program to go to a website and then he/she needed to come back to the excel sheet. Therefore, it was proposed to select the electricity intensity according to the mix of the energy of each country with updated data without moving from the program.

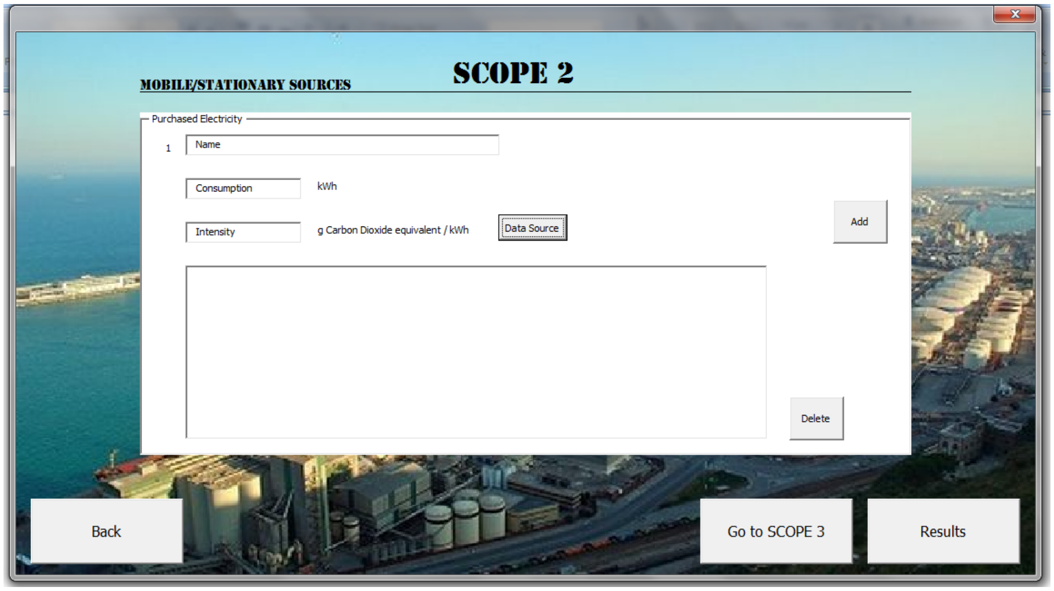



**Figure 4.14: Previous versions of the tool**
**(Selection of the electricity emission factor by clicking Data Source button)**

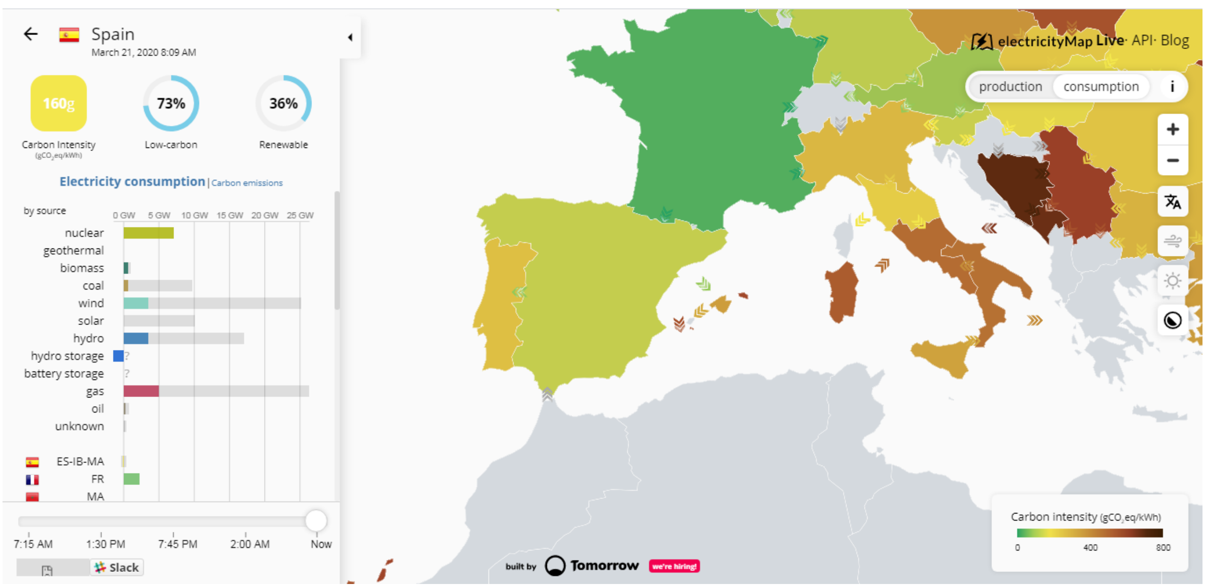



**Figure 4.15: A screen of the website for choosing electricity emission factor**

- This proposal was accepted and the modification was done. Figure 4.16 presentsa screenshot of the new slide where the user selects the electricity emission factor from a list of countries (✓).

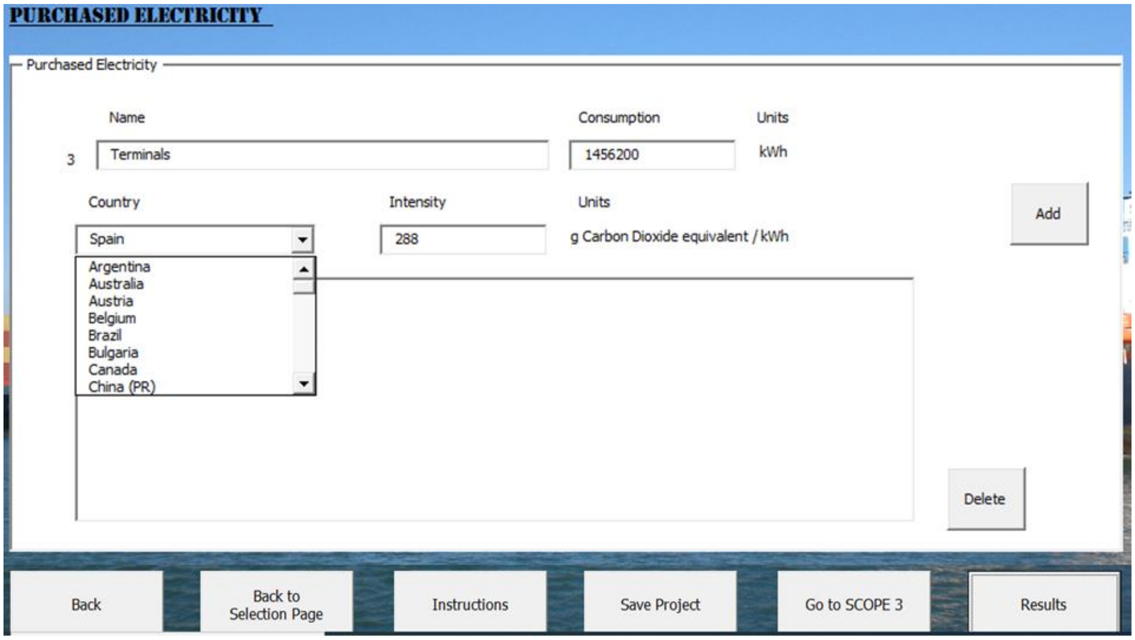



**Figure 4.16: The screen of scope 2 where user can select the country for the electricity emission factor**

- It was suggested to provide an option to add the value of electricity emission factor manually in scope 2 if the port has its own value.

  - This suggestion was accepted and a cell was introduced in the display of countries called "other". If the name of a country is not in the list or if the user is not satisfied with the intensity value provided, by choosing the "other" button, the desired value can be added to the intensity box (✓) as it can be seen in Figure 4.17 (✓).

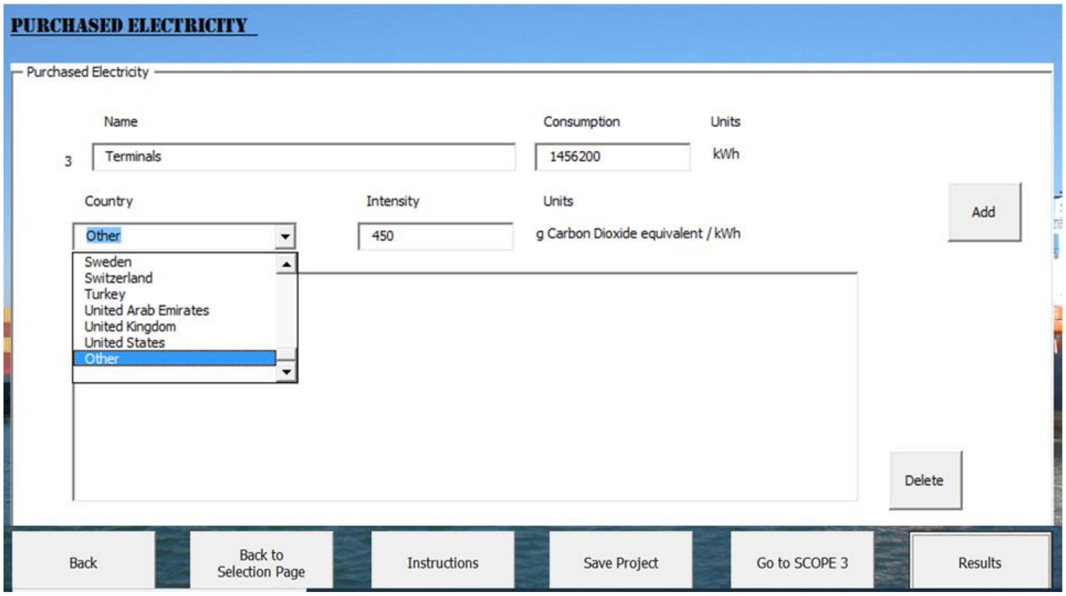



**Figure 4.17: A screen of scope 2 to add the value of electricity emission factor manually in the final version of the tool**

- It was suggested to put the name of countries in alphabetical order.

- This suggestion was accepted and the related modification was done as it can be seen in Figure 4.16 or 4.17 (✓).

### 4.4.3. Scope 3

Comments on Scope 3 are summarized below:

- As it can be seen in Figure 4.18, in the first version of the tool, Scope 3 was divided into two categories of sources: "Mobile" and "Stationary". It was suggested to add two more groups of sources which are "Tenants purchased electricity" and "Employees' Commuting" to this scope.

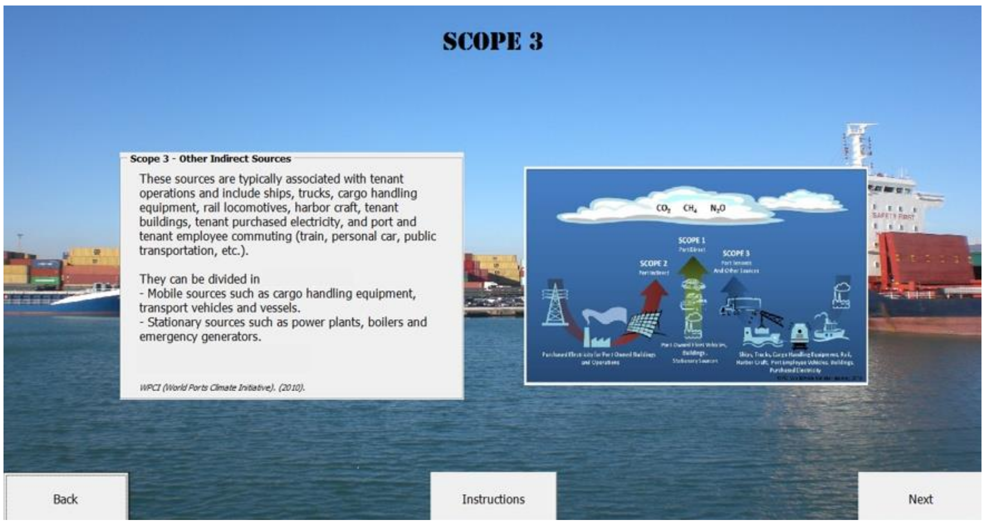



**Figure 4.18: Scope 3 sources in the previous versions of the tool**

- This suggestion was accepted and the two aforementioned groups were added to scope 3 as it can be seen in Figure 4.19, highlighted in red colour (✓).

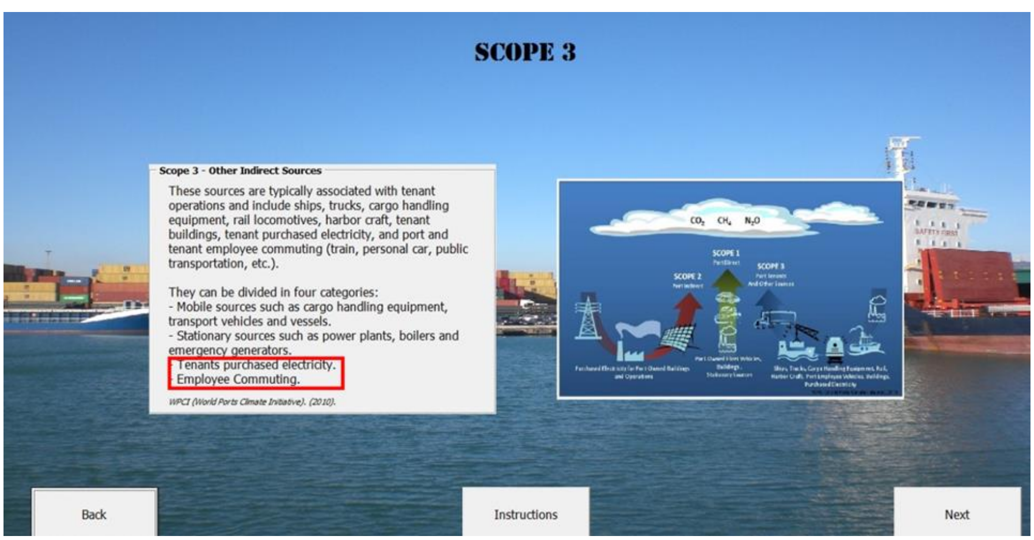



**Figure 4.19: Scope 3 sources in the previous versions of the tool**

- It was suggested to divide the commuting of the port authority employees' from the rest of employees' commuting in the port and include the emissions of the first ones in scope 1 and the second ones in scope 3.
  - This suggestion was rejected. The emission from employees' commuting is an indirect emission and cannot be in the scope 1 (direct emissions) (x).
- It was suggested to include emissions from the whole life cycle of fuel production (i.e. from crude extraction until its use, including the refinement process) in the calculation system.
  - This suggestion was rejected. This was considered to be out of the scope of the tool. It would complicate the data gathering for the port, when it is already quite complex (x).
- It was commented by some reviewers that it is very difficult to get data from tenants for the mobile sources inside the port area. An example of this could be gathering data for the emissions of trucks or ships inside the port area. If tenants provide data, probably it would be for the whole route of the truck or ship. So they suggested to specify very clearly in the tool the emissions required.
  - The research team agreed that this should be explained in detail in the tool in order not to create confusion and incorrect calculations. Tenants should only provide data inside the port area. An explanation about this was added in this section of the tool in the form of a note highlighted in red, as it can be seen in Figure 4.20 (✓).

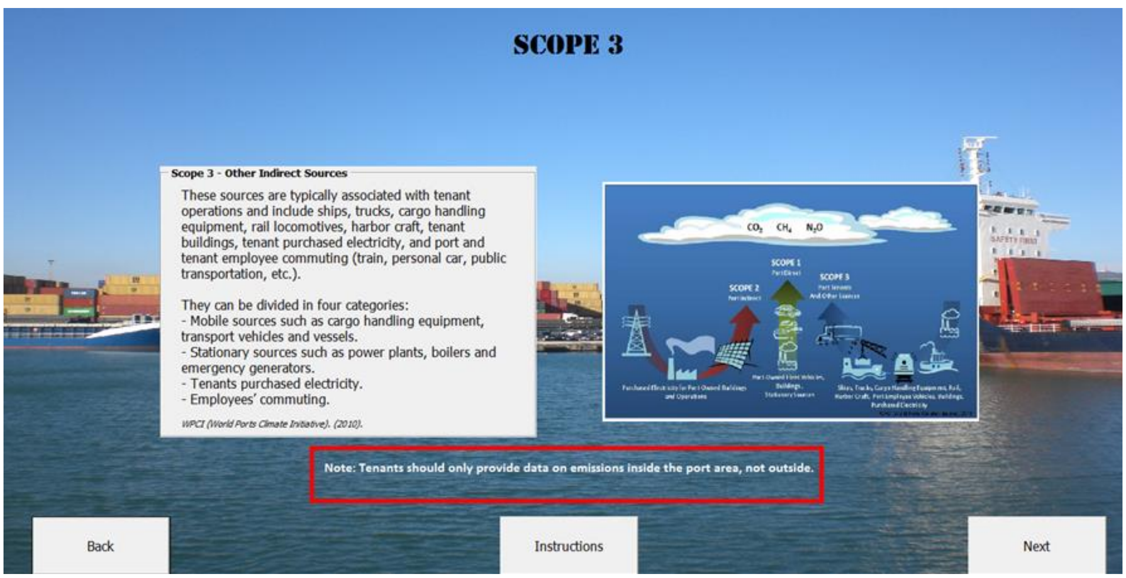


**Figure 4.20: Scope 3 definition slide in the final version of the tool**

## 4.5. Results

The feedback related the results' section can be found below:

- Initially, the emission results were only presented by scope as it can be seen in Figure 4.21. It was suggested to include also the results not only by scope but also by the total amount of $CO_2$eq emissions, by TEU and by total cargo (Carbon Footprint).

# Port Name

Port Address
Country
Capacity 12500 Units

**SCOPE 1:** 362863.9339 CO2e tonnes

*Mobile Sources*

| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Cargo | 147.1740557 | 0% |
| Trucks | 14.48954749 | 0% |
| Rail | 1367.945179 | 0% |
| Harbor Craft | 279480.2523 | 99% |
| OGV | 0 | 0% |
| Construction Equipment | 1322.730222 | 0% |
| Total | 282332.5913 | 100% |

*Stationary Sources*

| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Power Plants | 71216.145 | 88% |
| Boilers | 9304.547687 | 12% |
| Generators | 10.6499522 | 0% |
| Other Facilities | 0 | 0% |
| Total | 80531.34264 | 100% |

**SCOPE 2:** 93838.1 CO2e tonnes

*Purchased Electricity*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Electricity | 93838.1 |

**SCOPE 3:** 1.44063E+11 CO2e tonnes

*Mobile Sources*

| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Cargo | 2611411.628 | 0% |
| Trucks | 486015511.3 | 0% |
| Rail | 4679710.705 | 0% |
| Harbor Craft | 1.43367E+11 | 100% |
| OGV | 3476440.234 | 0% |
| Construction Equipment | 5975.481586 | 0% |
| Total | 1.43864E+11 | 100% |

*Stationary Sources*

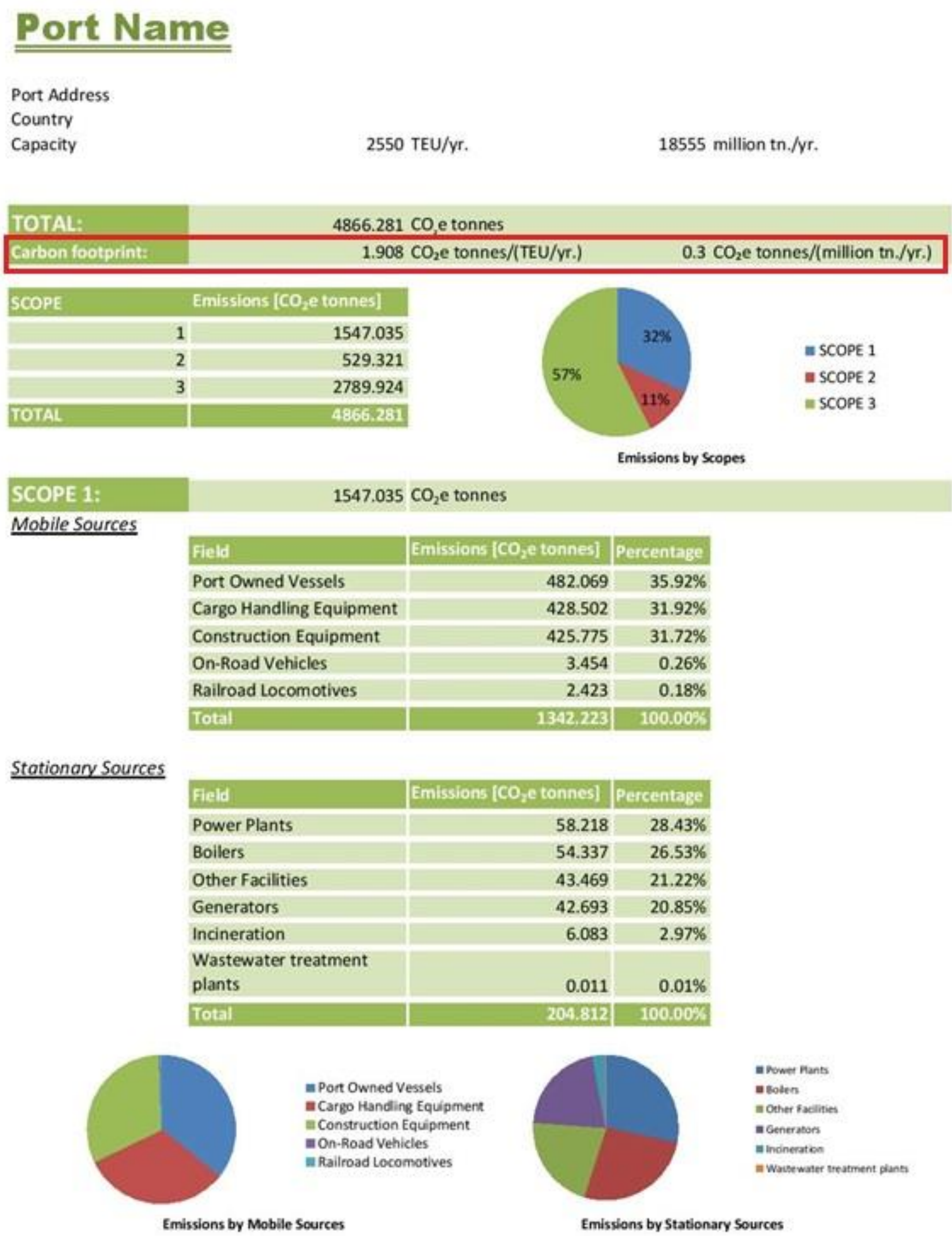
| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Power Plants | 7303927.831 | 4% |
| Boilers | 14295791.25 | 7% |
| Generators | 177290981 | 89% |
| Other Facilities | 0 | 0% |
| Total | 198890700.1 | 100% |

*Purchased Electricity*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Electricity | 12574.676 |

**Figure 4.21: Results sheet (pdf) in previous versions of the tool**

- This suggestion was accepted and the aforementioned values were added to the result page as in can be seen in Figure 4.22 (✓).



**Port Name**

Port Address
Country
Capacity 2550 TEU/yr. 18555 million tn./yr.

| | | |
|---|---|---|
| TOTAL: | 4866.281 $CO_2e$ tonnes | |
| Carbon footprint: | 1.908 $CO_2e$ tonnes/(TEU/yr.) | 0.3 $CO_2e$ tonnes/(million tn./yr.) |

| SCOPE | Emissions [$CO_2e$ tonnes] |
|---|---|
| 1 | 1547.035 |
| 2 | 529.321 |
| 3 | 2789.924 |
| TOTAL | 4866.281 |



| | |
|---|---|
| SCOPE 1: | 1547.035 $CO_2e$ tonnes |

*Mobile Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Port Owned Vessels | 482.069 | 35.92% |
| Cargo Handling Equipment | 428.502 | 31.92% |
| Construction Equipment | 425.775 | 31.72% |
| On-Road Vehicles | 3.454 | 0.26% |
| Railroad Locomotives | 2.423 | 0.18% |
| Total | 1342.223 | 100.00% |

*Stationary Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Power Plants | 58.218 | 28.43% |
| Boilers | 54.337 | 26.53% |
| Other Facilities | 43.469 | 21.22% |
| Generators | 42.693 | 20.85% |
| Incineration | 6.083 | 2.97% |
| Wastewater treatment plants | 0.011 | 0.01% |
| Total | 204.812 | 100.00% |



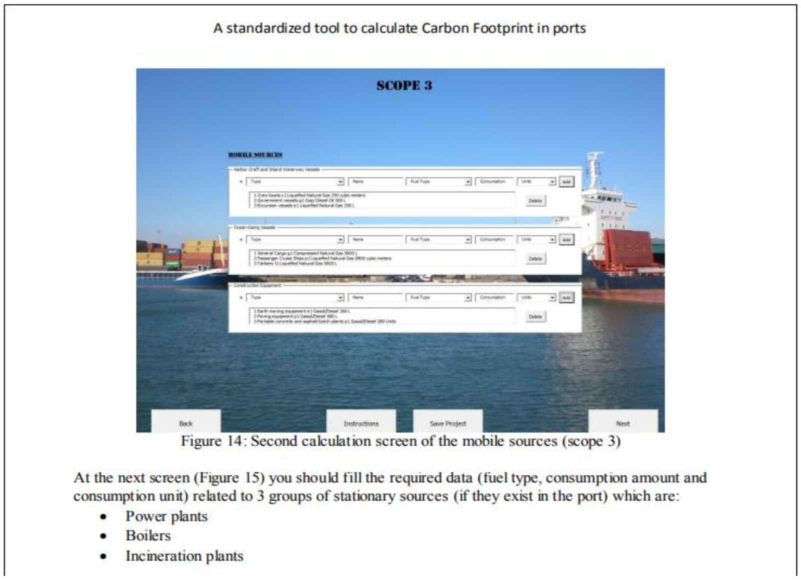
**Figure 4.22: Results sheet (pdf) in the final version of the tool**

- Initially the results where only presented in Tables (Figure 4.21) and it was suggested to have a graphical description of the data.
    - This suggestion was accepted and below each table of emissions, a pie chart was included as it can be seen in Figures 4.22 (✓).
- It was suggested to write the title of the graphs in the results sheet (pdf).
    - This suggestion was accepted and titles of the graphs were added to the results sheet, as it can be observed in Figure 4.22 (✓).

## 4.6. Guidelines

There were also comments regarding the guidelines, which are presented below:

- In the previous versions of the guidelines, for each slide a full screen of the tool was used to explain the section. This was considered to be very small and difficult to read as it can be seen in Figure 4.23. It was suggested to focus on the content of the slides more than in the format.



A standardized tool to calculate Carbon Footprint in ports



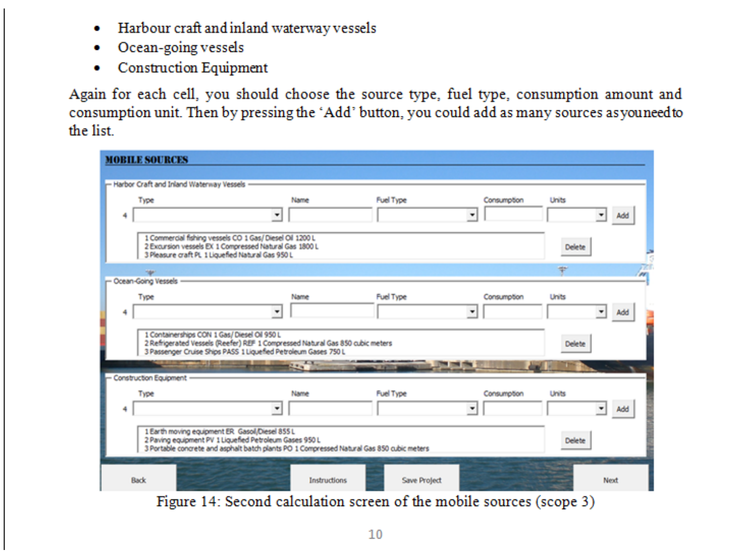
Figure 14: Second calculation screen of the mobile sources (scope 3)

At the next screen (Figure 15) you should fill the required data (fuel type, consumption amount and consumption unit) related to 3 groups of stationary sources (if they exist in the port) which are:

- Power plants
- Boilers
- Incineration plants

**Figure 4.23: A sample with the full screen of the tool in the previous versions of the guidelines**

- This suggestion was accepted and the slides were changed with new ones where the information is more readable and clearer. This is shown in Figure 4.24 (✓).



- Harbour craft and inland waterway vessels
- Ocean-going vessels
- Construction Equipment

Again for each cell, you should choose the source type, fuel type, consumption amount and consumption unit. Then by pressing the 'Add' button, you could add as many sources as you need to the list.



Figure 14: Second calculation screen of the mobile sources (scope 3)

10

**Figure 4.24: A sample with the data of the tool in the final version of the guidelines**

- Originally, as it can be seen in Figure 4.25, the cells of the slides presented in the guidelines were empty, without data. It was suggested to change these slides that were not including any example on how to fill in the cells by slides with filled cells (with example data), in order to have a better understanding of the tool.

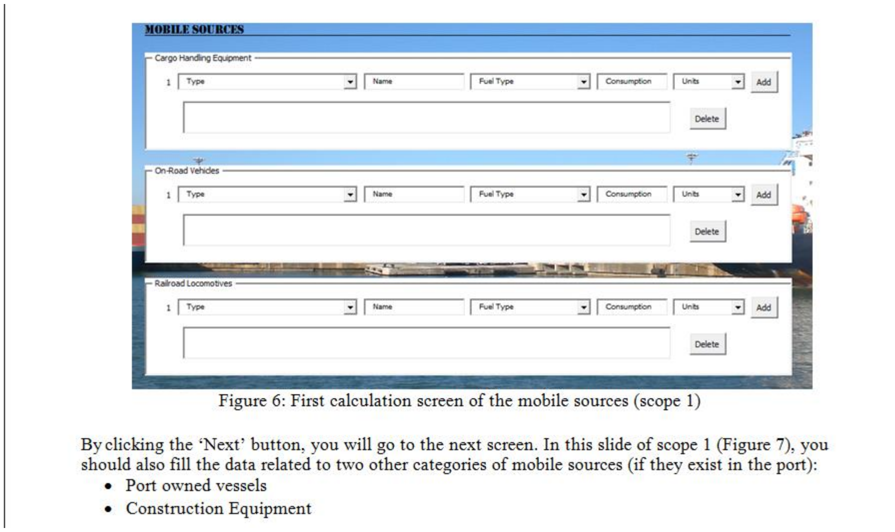



Figure 6: First calculation screen of the mobile sources (scope 1)

By clicking the 'Next' button, you will go to the next screen. In this slide of scope 1 (Figure 7), you should also fill the data related to two other categories of mobile sources (if they exist in the port):

- Port owned vessels
- Construction Equipment

**Figure 4.25: A sample screen without filled cells in the previous versions of the guidelines**

- The suggestion was accepted and the modification was done as it can be seen in Figure 4.26. Examples were included in the slides presented in the guidelines (✓).

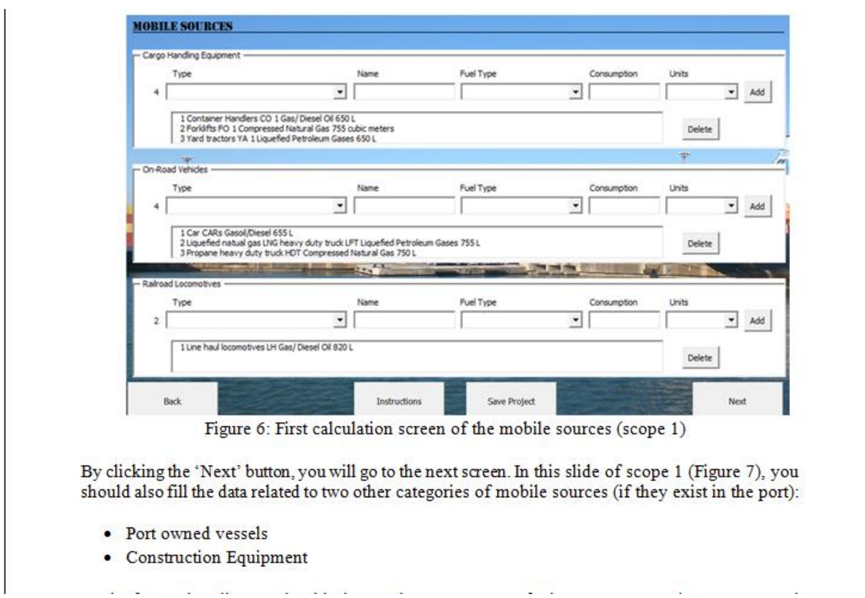



Figure 6: First calculation screen of the mobile sources (scope 1)

By clicking the 'Next' button, you will go to the next screen. In this slide of scope 1 (Figure 7), you should also fill the data related to two other categories of mobile sources (if they exist in the port):

- Port owned vessels
- Construction Equipment

**Figure 4.26: A sample screen with filled cells in the final version of the guidelines**

- It was suggested to divide the guidelines in different sections by numbering them. This will help the reader to go through them.

    - The suggestion was accepted and the modification was done. Now the guidelines are divided in 7 sections to help the reader understand better them (✓).

- It was suggested not to use the name of a specific port as an example of the results section in the guidelines as it was initially done as showed in Figure 4.27. In particular, if the data is not real, as it is the case.

## Barcelona

Port Address
Country
Capacity 12500 Units

| SCOPE 1: | 362863.9339 | CO2e tonnes |
|---|---|---|

*Mobile Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Cargo | 147.1740557 | 0% |
| Trucks | 14.48954749 | 0% |
| Rail | 1367.945179 | 0% |
| Harbor Craft | 279480.2523 | 99% |
| OGV | 0 | 0% |
| Construction Equipment | 1322.730222 | 0% |
| Total | 282332.5913 | 100% |

*Stationary Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Power Plants | 71216.145 | 88% |
| Boilers | 9304.547687 | 12% |
| Generators | 10.6499522 | 0% |
| Other Facilities | 0 | 0% |
| Total | 80531.34264 | 100% |

| SCOPE 2: | 93838.1 | CO2e tonnes |
|---|---|---|

*Purchased Electricity*

| Field | Emissions [$CO_2e$ tonnes] |
|---|---|
| Electricity | 93838.1 |

| SCOPE 3: | 1.44063E+11 | CO2e tonnes |
|---|---|---|

*Mobile Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Cargo | 2611411.628 | 0% |
| Trucks | 486015511.3 | 0% |
| Rail | 4679710.705 | 0% |
| Harbor Craft | 1.43367E+11 | 100% |
| OGV | 3476440.234 | 0% |
| Construction Equipment | 5975.481586 | 0% |
| Total | 1.43864E+11 | 100% |

*Stationary Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Power Plants | 7303927.831 | 4% |
| Boilers | 14295791.25 | 7% |
| Generators | 177290981 | 89% |
| Other Facilities | 0 | 0% |
| Total | 198890700.1 | 100% |

*Purchased Electricity*

| Field | Emissions [$CO_2e$ tonnes] |
|---|---|
| Electricity | 12574.676 |

**Figure 4.27: Results sheet (pdf) in previous versions of the tool**

- This suggestion was accepted and the ports' name was removed as it can be seen in Figure 4.22 (✓).

## 4.7. General comments

The general comments to the tool are presented below:

- It was suggested to translate some keywords to Catalan or Spanish for the users of these areas.
    - This suggestion was accepted and the translation was sent by email to the users that requested it (✓).
- Leisure and fishing ports commented that they could not answer all the questions of the tool. This complicated the fact of using the tool for them.
    - The research team suggested to them to skip the parts that are not applicable to them and proceed with the rest of the tool. The user is not obliged to answer all the questions or fill in all the boxes. In fact, a note 1 mentioning this has been added to the tool, it can be seen in Figure 4.6. This makes the user more comfortable to continue using the tool and it shows the fact that the tool can be adapted to any port (✓).
- It was suggested that this tool could be more useful for ports that have not tried to calculate their Carbon Footprint than for those that they have already done it. It was questioned the need of this tool if the port has already its own method.
    - It is true that this tool can be very useful for small ports that are starting with the calculation of its Carbon Footprint. However, more experienced ports can also benefit from the tool since it provides a standard method which allows comparison between different ports. The fact of providing the results divided by total cargo or TEUs helps to conduct this comparison. In addition, it is a very complete tool that includes all the emission sources, scopes and requirements for the guidelines that in some of the existing methods are missing (×).
- An expert suggested that the emission factors used by the tool seem to be quite different from the ones he used (×).
    - Concerning the emissions factors, the tool uses the standard values. Each individual port may have its own values that are probably more specific and detailed. However, it is complicated to create a standard tool where each port has to add its specific values. Some of them could do so, but others not. Therefore, it was decided to use the standard ones for scope 1 and 3, but for scope 2, a part of providing the list of the electricity emission factors for each country and additional box was added to allow the user to introduce his/her particular value if necessary, as it can be seen in Figure 4.17.

## 4.8. Summary of the tool's modifications

Table 4.2 presents a summary of the feedback obtained from the aforementioned reviewers for each section. It also includes a column indicating whether an action has taken concerning the comment because it has been accepted (√) or not because it has been rejected (×).

**Table 4.2: Feedback obtained and actions taken**

| Reviewers' feedback | | Action taken |
|---|---|---|
| Introduction slide | Summarizing the description present in this slide in the first version of the tool | ✓ |
| | Changing the background photo of the tool from a particular port website to one that belonged to the authors to avoid copyright issues | ✓ |
| Steps' description | Highlighting the fact that the information is confidential | ✓ |
| General port Data | Adding a box to introduce the total cargo to the tool in this slide | ✓ |
| | Clarifying the option to proceed with the tool without completing all sections, if they are not applicable to a specific port or data are not available | ✓ |
| | Explaining that the boundaries of the tool are the port area | ✓ |
| Scopes | Ensuring the possibility to go from one scope to another without following a consecutive order and without no need to fill in the three of them | ✓ |
| | Removing the scopes' definitions (by putting the mouse on them) from the scopes' introduction slide | ✓ |
| | Providing an option to see the title of the cells again (such as Fuel type, Consumption and etc.), after inserting related data in the cell | ✓ |
| | Erasing the name of the cells and put them on top of them to avoid their disappearance when moving inside the tool | ✓ |
| | Providing an option to the ports to be able to decide what to put in each scope | × |
| Scope 1 | Adding "electricity" as a fuel type in scope 1 and 3 for the on road vehicles, as some of them may use electricity | × |
| | Adding of "Biogasoline" and "Biodiesels" as a fuel type for the on road vehicles | ✓ |
| | Excluding of the locomotives from the mobile sources list, as many ports do not have it | × |
| | Adding the emissions from other industrial waste treatment plants to the stationary emission sources | × |
| Scope 2 | Adding an option to select the electricity intensity according to the mix of energy of each country with updated data in scope 2 | ✓ |
| | Providing an option to add the value of electricity emission factor manually in scope 2, if the port has its own value | ✓ |
| | Modifying the name of countries based on alphabetic order | ✓ |
| Scope 3 | Adding two more groups of emission sources to scope three, which are "Tenants purchased electricity" and "Employees' Commuting" | ✓ |
| | Separating the port authority employees' commuting from the rest of employees' commuting in the port. Inclusion of the emissions of the first ones in scope 1 and the second ones is scope 3 | × |
| | Including emissions from the whole life cycle of the fuel production (i.e. from crude extraction until its use, including the refinement process) | × |
| | Clarifying that tenants should only provide data inside the port area | ✓ |
| Results | Presenting the results by total amount of $CO_2$e emissions, but also by TEU, by total cargo and by scope | ✓ |
| | Presenting the results not only through Tables but also as graphics | ✓ |
| | Adding the title of the graphs to the result sheet (pdf) | ✓ |
| Guidelines | Changing the slides presented in the guidelines focusing more on the content of the slides than in the format | ✓ |
| | Changing the slides present in the guidelines that were not including any example on how to fill them (with no data) by slides with filled cells (with example data) in order to have a better understanding of the tool | ✓ |
| | Removing the name of a specific port as an example in the result sheet | ✓ |
| | Dividing different sections of the guidelines by numbering them to facilitate their understanding | ✓ |
| General Comments | Translating some keywords to Catalan or Spanish | ✓ |
| | Skipping the parts that are not applicable to the leisure and fisher ports and be able to proceed with the tool | ✓ |
| | Justifying the usefulness of this tool for both small ports that are starting with the calculation of Carbon Footprint and also more experienced ports | ✓ |
| | Using individual values for the emission factors required by the tool | × |

To conclude, the updated version of the tool was developed based on the amendments which are presented and justified above. The final screenshots of the tool are presented in chapter 3 and in the user guidelines in appendix 5.

# Chapter 5: Case studies

In this chapter, the new tool is being validated with some case studies. In first place, a case study with public data from the Port of Oslo (Norway) is used to test the tool (Port of Oslo, 2008). In second place, a case study with data from Ports de la Generalitat (Catalonia, Spain) is presented (OCCC, 2019). In both cases, the results obtained by the Port of Oslo (using ISO14064-1) and by Ports de la Generalitat (using the OCCC tool-Catalan Office for Climate Change) are compared with the ones calculated by the tool developed in this thesis.

It is important to note, that in the tools used in the previous case studies, all the scopes and all the emission sources recommended by the World Port Climate Initiative Guidelines (WPCI, 2010), the IPCC guidelines (IPCC, 2006 and 2019b) and the GHG protocol (WRI and WBSCD, 2004) were not taken into account. For example, emissions from ocean going vessels, cargo handling equipment and wastewater treatment plant are not considered in any of the tools. On the contrary, the new tool, designed specifically for ports, includes all the aspects recommend by these port guidelines. In order to test the whole sources of each scope, a case study model port has been created using literature information and port expertise. This port is called Bandare-Bid port. The characteristics of this port are presented in the third section of this chapter. The emissions of this pre-settled port are then calculated using the new tool. These results are then compared with two additional tools to validate the results. Among the different tools that were reviewed in Chapter 3, two of them have been selected to make this comparison. These are the OCCC tool and the tool of the Ecological Transition Ministry (MITECO) of the Spanish government, since their guidelines are clear and easy to follow and they are freely available. These tools were mentioned in Chapters 3 but its calculation methodology is explained in detail in the second and third section of this chapter. Therefore, both tools have been used to calculate the emissions of this last case study. Then, the obtained results have been compared with those achieved with the tool developed in this thesis. The results of this comparison are presented at the end of this chapter. Finally, some conclusions are drawn.

## 5.1. Case Study 1: Port of Oslo

The Port of Oslo (Norway) was founded in the east of the Aker River in about 1050 AD. The city was burnt due to a great fire in 1624 and after that a new town (Christiania) was built under the walls of the Akershus fortress. During the 1800s, the town grew to absorb many nearby towns. By 1850, it had replaced the Port of Bergen as the biggest and most powerful city in Norway. In 1925, Christiania was returned to its original name of Oslo. The Port of Oslo grew quickly after the Second World War, incorporating more and more towns. Now, Port of Oslo is operated by the municipality of Oslo.

The port has approximately 100 employees with a head office at Vippetangen, and other offices located on Sjursøya. The port includes containers, dry bulk terminals and liquid bulk terminals and handles a diverse range of cargo and container traffic, including consumer goods, motor vehicles, grain, oil, salt and cement for the construction industry. The port facilitates efficient and environmentally friendly operations to support maritime transport, monitor traffic in the municipality's waters, and manage the port's properties and facilities in an economical and environmentally sound manner. Port of Oslo is certified in ISO 14001 for its management and operations since 2001 and it aims to become one of the world's first emissions-free ports (Port of Oslo, 2020). The Norwegian power production sector is predominantly based on hydropower, however, suppliers use a mix of locally produced power and imported power (Port of Oslo, 2008). Figure 5.1 shows the Satellite view of Port of Oslo.

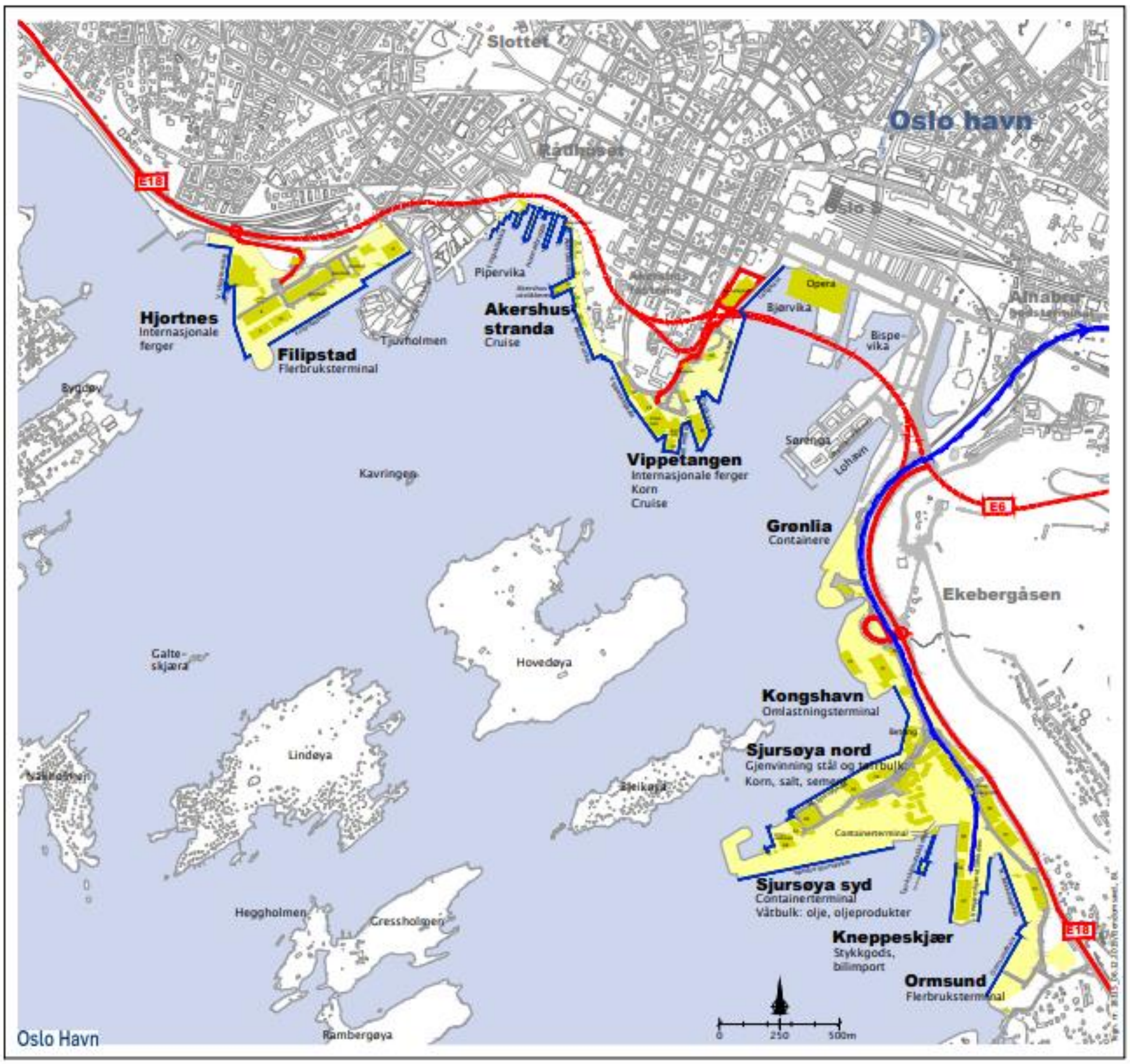



**Figure 5.1: Satellite view of Port of Oslo (Port of Oslo website, 2020)**

### 5.1.1. Data source

The data used for this case study belongs to the calculation of the Carbon Footprint that the Port of Oslo conducted in 2007 and published in 2008 (Port of Oslo, 2008). Table 5.1 shows the data used to calculate$CO_2$ emissions. The calculation was developed based on the ISO14064-1 standard (ISO, 2006)(explained in section 1.3.3) which derives from GHG Protocol (WRI and WBSCD, 2004)(explained in section 1.3.2). The definitions of emission scopes used by the Port of Oslo are described in section 2.1.3.

**Table 5.1: The data used to calculate $CO_2$ emissions (Port of Oslo, 2008)**

| Emission Source | | Fuel Type | Consumption Amount | Unit |
|---|---|---|---|---|
| Scope 1 | Company owned cars | Diesel | 128068 | Litre |
| | | Motor Gasoline | 43570 | Litre |
| | Operational Vessels Owned by the port | Diesel | 37451 | Litre |
| | Portable Worksite Generators | Diesel | 21921 | Litre |
| Scope 2 | Cranes | Electricity | 613072 | kWh |
| | Lightning | Electricity | 3258242 | kWh |
| | Buildings | Electricity | 5226359 | kWh |
| | Lighthouse | Electricity | 26669 | kWh |
| | Others | Electricity | 130834 | kWh |
| Scope 3 | Cars | Gasoline | 44886 | Litre |
| | Cars | Diesel | 8560 | Litre |

### 5.1.2. Carbon footprint calculation done with the ISO 14064 method

As it can be seen in Figure 5.2, in the case of the Port of Oslo, the largest emission source is scope 1 (44.1%), followed by scope 2 (34.4%) and finally by scope 3 (21.4%).

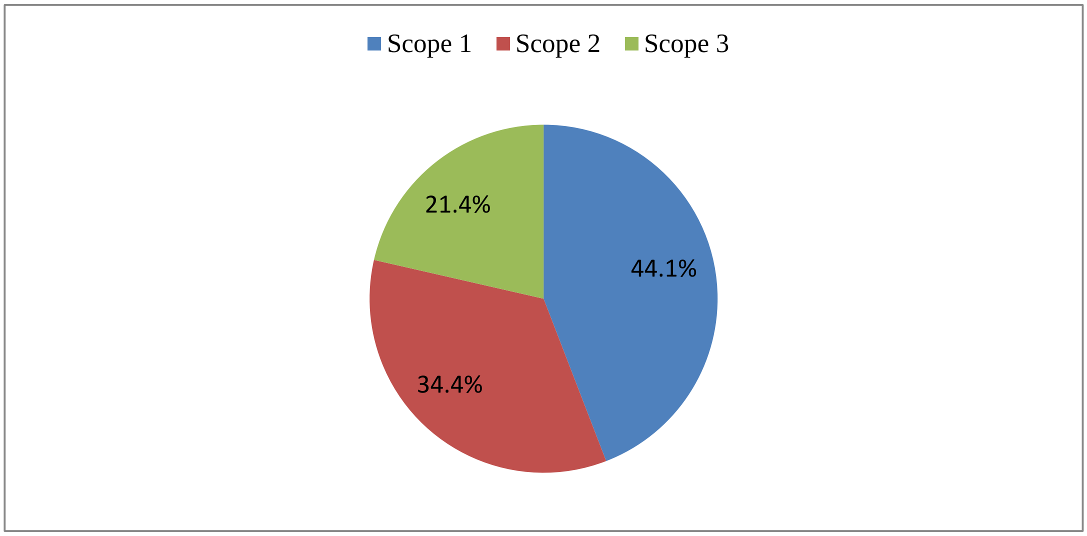



**Figure 5.2: $CO_2$ emissions (%) for the Port of Oslo by scopes (Port of Oslo, 2008)**

The results show that the total estimated $CO_2$ emissions from the Port of Oslo activities are 1345 t $CO_2$eq, as presented in Table 5.2. The relatively low outcome, to a large extent, is due to the fact that the Port of Oslo is being mainly driven by electricity based on hydropower, which is the major source of energy in Norway (Port of Oslo, 2008). Table 5.2 also shows the $CO_2$ emissions for the port of Oslo by emission sources for each scope. Within scope 1, more than half of the emissions belong to diesel usage by company owned cars followed by port owned vessels (diesel).

Within Scope 2, the highest percentage belong to the emissions from electricity usage by port buildings (56.3%) followed by emissions from electricity usage for harbor lightening (35.2%).

In the port of Oslo, in scope 3 only the emissions from Employees' commuting are calculated and the rest of the emissions of this scope are not taken into account. Employees' commuting is the lower contribution to the total amount of the Carbon Footprint (21.4%).

**Table 5.2: $CO_2$ emissions for the Port of Oslo by scopes and emission sources (Port of Oslo, 2008)**

| Scope | Source description | $CO_2$eq (tonnes) | Percentages (%) |
|---|---|---|---|
| Scope 1 | Fuel usage (diesel) by company owned cars in the Port of Oslo | 337 | 56.7 |
| | Fuel usage (petrol) by company owned cars (Port of Oslo) | 101 | 17 |
| | Fuel (diesel) usage by operational vessels owned by the Port of Oslo | 98 | 16.5 |
| | Fuel (diesel) usage by all operational machines owned by the Port of Oslo | 58 | 9.7 |
| | **Total emissions of scope 1** | **594** | **44.1** |
| Scope 2 | Electricity usage by cranes owned by the Port of Oslo | 31 | 6.7 |
| | Electricity usage for the purpose of harbor lightning by the Port of Oslo | 163 | 35.2 |
| | Electricity usage for buildings owned and used by the Port of Oslo (e.g. heating, lightning, intake of power for ships, electricity car, etc.) | 261 | 56.3 |
| | Electricity usage by lighthouse owned by the Port of Oslo | 1 | 0.2 |
| | Electricity usage from other sources in the Port of Oslo | 7 | 1.5 |
| | **Total emissions of scope 2** | **463** | **34.4** |
| Scope 3 | Employees' commuting | 288 | 100 |
| | **Total emissions of scope 3** | **288** | **21.4** |
| **Total** | | **1345** | **100** |

### 5.1.3. Carbon Footprint calculation carried out with the new tool

In this section, the same input data as the one of the Port of Oslo (2008) is used to validate the new tool. As it can be seen in Figure 5.3, the total estimated $CO_2$ emissions from the Port of Oslo activities calculated by the new tool are 1293 t $CO_2$eq. In addition, scope 1 is the largest emission source (47%), followed by Scope 2 with 36% of the total emissions. Scope 3 emits only 17% of total emissions.

Within scope 1, 73.59% of emissions belong to on-road vehicles, 16.66% of emissions are for port owned vessels and 9.75% is for construction equipment.

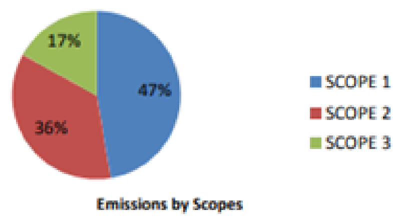
## Port of Oslo

Akershusstranda, 19, 0102, Oslo
Norway

| | | |
|---|---|---|
| Capacity | 196.252 TEU/yr. | 337.2 million tn./yr. |

| | | |
|---|---|---|
| **TOTAL:** | 1293.584 $CO_2e$ tonnes | |
| Carbon footprint: | 6.591 $CO_2e$ tonnes/(TEU/yr.) | 3.8 $CO_2e$ tonnes/(million tn./yr.) |

| SCOPE | Emissions [$CO_2e$ tonnes] |
|---|---|
| 1 | 610.931 |
| 2 | 462.759 |
| 3 | 219.895 |
| TOTAL | 1293.584 |




| | |
|---|---|
| **SCOPE 1:** | 610.931 $CO_2e$ tonnes |

*Mobile Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| On-Road Vehicles | 449.572 | 73.59% |
| Port Owned Vessels | 101.783 | 16.66% |
| Construction Equipment | 59.576 | 9.75% |
| Railroad Locomotives | 0.000 | 0.00% |
| Cargo Handling Equipment | 0.000 | 0.00% |
| Total | 610.931 | 100.00% |

| | |
|---|---|
| **SCOPE 2:** | 462.759 $CO_2e$ tonnes |

*Purchased Electricity*

| Field | Emissions [$CO_2e$ tonnes] |
|---|---|
| Electricity | 462.759 |

| | |
|---|---|
| **SCOPE 3:** | 219.895 $CO_2e$ tonnes |

*Employees' commuting*

| Field | Emissions [$CO_2e$ tonnes] |
|---|---|
| Employees' commuting | 219.895 |

**Figure 5.3: $CO_2$ emissions for the Port of Oslo by the new tool**

### 5.1.4. Comparison of the results

Table 5.3 shows the comparison of the results obtained for the calculation of the Carbon Footprint using the two methods. As it can be seen in this table, the existing results of the port of Oslo are almost the same as the results of the new tool: 1345 $CO_2$eq tonnes (Port of Oslo tool) in front of 1294 $CO_2$eq tonnes (new tool).

The total emissions of the scope 1 calculated by the port of Oslo are 594 $CO_2$eq and by the new tool are 611$CO_2$eq. In this scope, using the port of Oslo method, 73.7% (56.7+17) of the emissions belong to the On-road vehicles (Table 5.2). With the new tool, these emissions are 73.6% (Figure 5.3), being practically the same. 16.5% of emissions belong to port own vessels when using the Port of Oslo method (Table 5.2) and with the new tool, 16.7% of the emissions belong to this source (Figure 5.3). Emissions from construction equipment calculated by both methods are 9.7%.

The reasons for the minor differences in scope 1 are due to the usage of different calculation methods. The Oslo Port is using the ISO14064 method whereas the new tool uses IPCC guidelines, GHG protocol and WPCI guidelines, more specific for ports. In addition, each method uses its own emission factors which vary depending on different elements such as type of industry, location and type of fuel. In particular, the new tool uses the ones of IPCC (IPCC, 2006 and 2019).

The total emissions of the scope 2 calculated by the port of Oslo and by the new tool are 463 $CO_2$eq (Table 5.3).

Concerning scope 3, emissions of the employees' commuting calculated by the port of Oslo are 288 $CO_2$eq whereas by the new tool are 220 $CO_2$eq. This difference can be explained by the different calculation method used by the Port of Oslo and the new tool for this scope. In the port of Oslo study, the emissions are calculated based on two methods: fuel consumption and travel distance. In the new tool, according to the availability of data, the user must choose one of the following three methods: fuel-based method, distance-based method and average data method (section 3.4.1). In this case, the calculation has been done using the fuel-based method since to calculate the emissions based on the travel distance, the number of working days is needed and this information has not been provided by the port of Oslo.

**Table 5.3: Comparison of the Carbon Footprint results with the two methods**

| Scopes | Port of Oslo 2008 ($CO_2$eq tonnes) | Results of the new tool($CO_2$eq tonnes) |
|---|---|---|
| 1 | 594 | 611 |
| 2 | 463 | 463 |
| 3 | 288 | 220 |
| **Total** | 1345 | 1294 |

Overall, as it has been explained and presented in table 5.3, the results are quite similar. This shows that the new tool is almost in line with the one used by the Port of Oslo.

## 5.2. Case study 2: Ports de la Generalitat

Ports de la Generalitat represents a group of 26 ports located in the Catalan Coast of Spain. This organization was founded in 1998 and belongs to the Department of Territory and Sustainability of the Generalitat de Catalunya. It directs and manages fishing, sports and commercial ports and also regulates the use of commercial, cultural, sports, recreational facilities linked to the ports.

Ports de la Generalitat is aware of the environmental impacts of its port activities. It has been certified with an Environmental Management System according to the European EMAS Regulation (EC Regulation 1221/2009 and EU Regulation 2017/1505) and the UNE-EN-ISO 14001: 2015 Standard. The verification of the System has been performed since 2009.

Figure 5.4 shows the location of the Ports de la Generalitat. 8 of these ports are located in Girona, 6 of them in Barcelona and 12 of them in Tarragona. It is organized in three port areas (Port de la Generalitat, 2020):

- North Area: Girona (from the border with France to La Tordera)
- Center Area: Barcelona (from La Tordera to the municipality of Cubelles with Cunit)
- South Area: Tarragona (from the municipality of Cunit to the SéniaRiver).


**Figure 5.4: The location of the Ports de la Generalitat (Ports de la Generalitat, 2020)**

## 5.2.1. Data source

The data used for this case study (Table 5.4) belongs to the calculation of the Carbon Footprint that the Ports de la Generalitat conducted in 2018 (Ports de la Generalitat, 2018). The boundaries include the 26 ports along the Catalonia coast. The north Area includes 7 offices, the center area 1 office and the south area 4 offices. In addition, the north area has 3 vehicles, the center area has 2 vehicles and the south area has 5 vehicles.

Since 2012 they started to calculate GHG emissions every year using the tool developed by the Catalan Office for Climate Change (OCCC). This methodology is explained in detail in the next section.

**Table 5.4: The data used to calculate $CO_2$ emissions (Ports de la Generalitat, 2018)**

| Emission Source | | Fuel Type | Consumption Amount | Unit |
|---|---|---|---|---|
| Scope 1 | Cars (10 vehicles) | Diesel | 13568.84 | Litre |
| | | Motor Gasoline | 1403.22 | Litre |
| Scope 2 | Offices (12 offices) | Electricity | 120811 | kWh |
| | Ports | Electricity | 780931 | kWh |

### 5.2.2. Introducing the Catalan Office for Climate Change (OCCC) tool

As it is mentioned in section 1.3.5, in 2008 the Catalan Office for Climate Change developed an excel based tool to calculate $CO_2$ emissions. The latest version of this tool with its guideline was published in 2019. The purpose of this guideline is to facilitate the estimation of GHG emissions (OCCC, 2019).

The calculation tool of the OCCC has been developed based on the GHG Protocol (WRI and WBSCD, 2004; section 1.3.2)and the latest version of ISO 14064 standard (ISO, 2006; section 1.3.3). In this tool, emissions are categorized into 3 scopes (OCCC, 2019):

- Scope 1 (Direct emissions): They include direct emissions that come from sources owned or controlled by the entity generating the activity.
- Scope 2 (Indirect emissions): These comprise the emissions derived from electricity consumption, and heat, steam and cooling.
- Scope 3 (Other indirect emissions): They include all other indirect emissions. Scope 3 emissions are a consequence of the entity's activities, though they come from sources that are not owned or controlled by the entity.

The OCCC tool consists of 20 excel sheets. Five sheets belong to scope 1, two sheets are for scope 2, nine sheets are for scope 3 and the rest of the sheets present a summary, an explanation and emission factors.

Figure 5.5 presents the first sheet of the tool. Here some data are required such as the name of the organization, the emission calculation period or the number of employees (white cells on the left side of the figure). If the user wants to compare the current results with the ones of the previous year, he/she can introduce the former results in the white cells on the right side of the sheet.

The result of the emissions based on the different scopes and sources, together with the total emissions are presented in the grey cells. After that, there is a set of sheets dedicated to each scope. Since the complete explanation of the tool is too broad, a summary for each scope is presented below.

**Scope 1**

Emissions from scope 1 that come from sources owned or controlled by the entity's activities are calculated in 5 sheets of this tool. These sources are:

- Fossil fuel consumption by different sources

In order to calculate emissions from fossil fuel consumption, the user should enter the data (amount of the fuel and the unit) based on the fuel type.

- Road transport

The user can calculate emissions from road transportation using different alternative methods based on the fuel consumption, fuel expedition and distance travelled. It should be mentioned that the electricity consumption (Kwh) of the electric vehicles must only be entered once, either on the electricity sheet (scope 2) or the road transport sheet (scope 1).

- Rail transport

In order to calculate emissions from rail transport, the user should provide data like total distance travelled and the number of passengers for each means of transport.

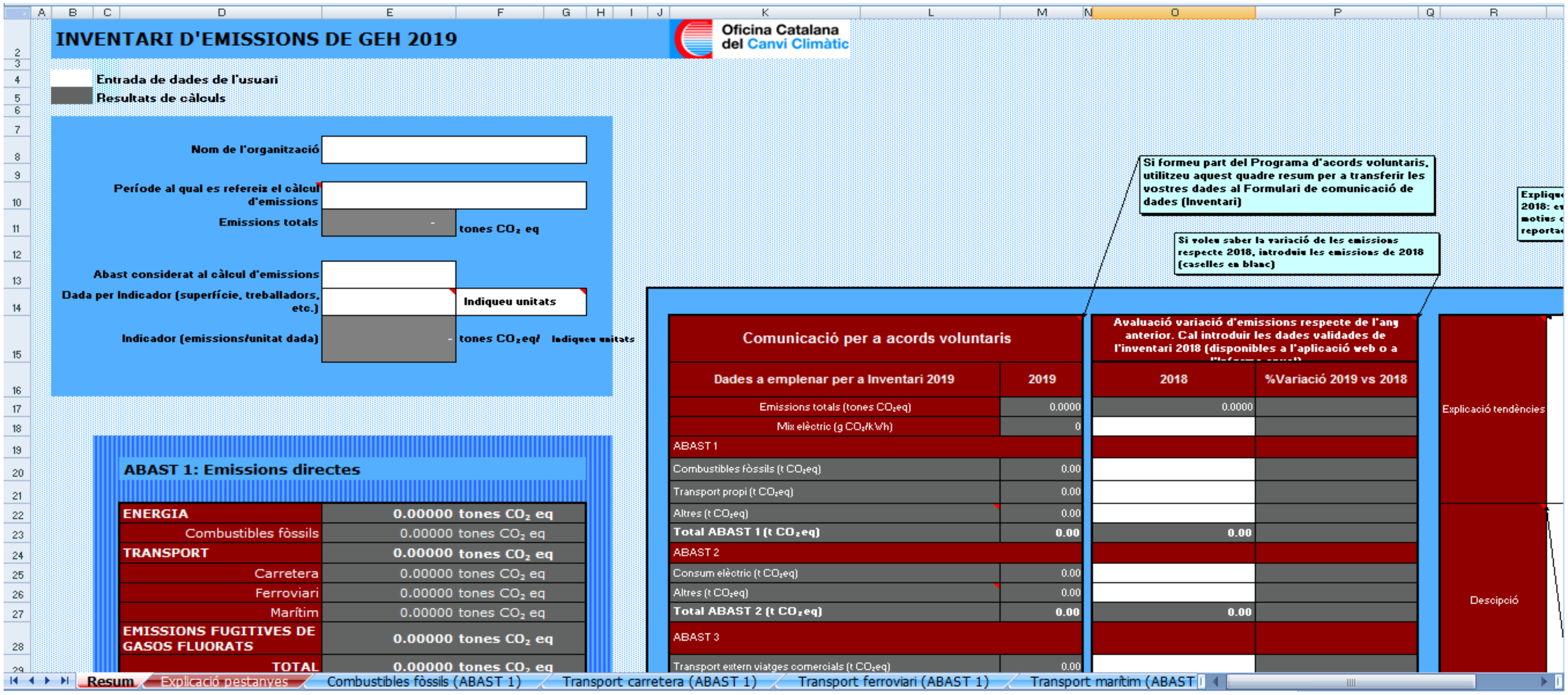



**Figure 5.5: The first sheet of the OCCC tool**

- Sea transport

Sea transport emissions are calculated based on fuel consumption or distance travelled. In order to calculate emissions from passenger or freight transport by fuel based method, the user should insert the amount of the consumed fuel in the corresponding sheet.

- Fugitive emissions

To calculate fugitive emissions, the user should enter the amount of fluorinated gas (kg) in the white cell.

**Scope 2**

The user can calculate the emissions from electricity consumption depending on specific circumstances:

1. Electricity consumption from the grid without a GoO certificate[40]
2. If the electricity consumption from the grid is from renewable sources with a GoO certificate, the $CO_2$ emission factor is 0.
3. Electricity self-consumed from an installation owned by the company indicates only self-consumed kWh and the $CO_2$ emission factor is 0.
4. If the electricity consumption from a facility is not connected to the grid and not owned by the company, the user should enter the $CO_2$ emission factor manually according to the type of facility from which electricity is consumed.

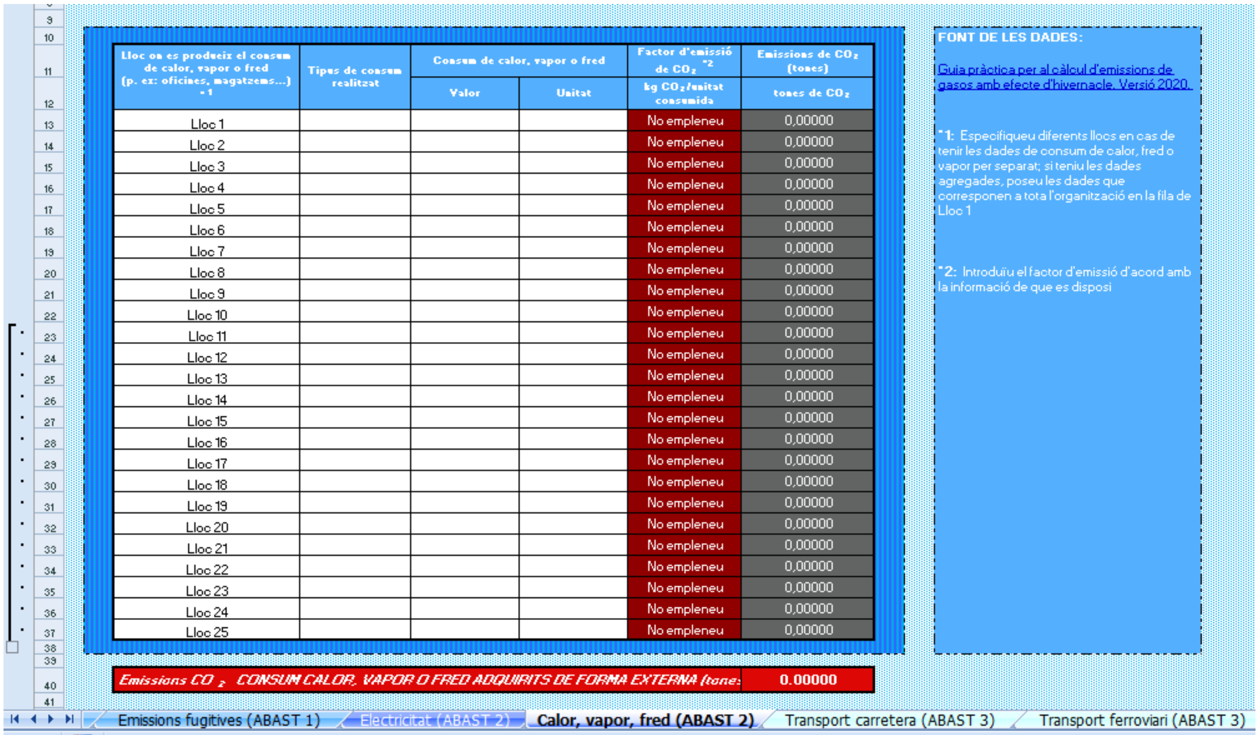
Then, the user should enter the general grid or a Mix from a specific trading company. The user should indicate if he/ she uses own trading company's mix or the general mix of the grid without GoO. In the event the user uses the trading company's mix, he/she should enter the $CO_2$ emission factor in accordance with the data available at:

- Practical Guide for Calculating Greenhouse Gas Emissions. Version: 2019 (OCCC, 2019)
- The web site of the National Commission on Markets and Competition (CNMC, 2020)

Finally, the user should enter the amount of electricity consumption in kWh.

Figure 5.6 shows the calculation sheet for emissions derived from electricity consumption to produce heat, steam and cooling. As it can be seen, the carmine cells are for default data such as emission factors, the grey cells present calculation results and the red cell show the final results of the sheet.

[40]A Guarantee of Origin (GoO) is similar to a green certificate. The GoO proves that power has been produced from a specific source.



| Lloc on es produeix el consum de calor, vapor o fred (p. ex: oficines, magatzems...) *1 | Tipus de consum realitzat | Consum de calor, vapor o fred | | Factor d'emissió de $CO_2$ *2 | Emissions de $CO_2$ (tones) |
|---|---|---|---|---|---|
| | | Valor | Unitat | kg $CO_2$/unitat consumida | tones de $CO_2$ |
| Lloc 1 | | | | No empleneu | 0,00000 |
| Lloc 2 | | | | No empleneu | 0,00000 |
| Lloc 3 | | | | No empleneu | 0,00000 |
| Lloc 4 | | | | No empleneu | 0,00000 |
| Lloc 5 | | | | No empleneu | 0,00000 |
| Lloc 6 | | | | No empleneu | 0,00000 |
| Lloc 7 | | | | No empleneu | 0,00000 |
| Lloc 8 | | | | No empleneu | 0,00000 |
| Lloc 9 | | | | No empleneu | 0,00000 |
| Lloc 10 | | | | No empleneu | 0,00000 |
| Lloc 11 | | | | No empleneu | 0,00000 |
| Lloc 12 | | | | No empleneu | 0,00000 |
| Lloc 13 | | | | No empleneu | 0,00000 |
| Lloc 14 | | | | No empleneu | 0,00000 |
| Lloc 15 | | | | No empleneu | 0,00000 |
| Lloc 16 | | | | No empleneu | 0,00000 |
| Lloc 17 | | | | No empleneu | 0,00000 |
| Lloc 18 | | | | No empleneu | 0,00000 |
| Lloc 19 | | | | No empleneu | 0,00000 |
| Lloc 20 | | | | No empleneu | 0,00000 |
| Lloc 21 | | | | No empleneu | 0,00000 |
| Lloc 22 | | | | No empleneu | 0,00000 |
| Lloc 23 | | | | No empleneu | 0,00000 |
| Lloc 24 | | | | No empleneu | 0,00000 |
| Lloc 25 | | | | No empleneu | 0,00000 |
| Emissions $CO_2$ CONSUM CALOR, VAPOR O FRED ADQUIRITS DE FORMA EXTERNA (tone: | | | | | 0.00000 |



**Figure 5.6: The second sheet of scope 2 of the OCCC tool**

### Scope 3

Scope 3 emissions (indirect emissions) are a consequence of the entity's activities, although they come from sources that are not owned or controlled by the entity. These sources are calculated in 8 sheets of the OCCC tool. These sources are:

- Road transport

The user can calculate emissions from the journey made by the staff of an organization when they travel from home to work and from work to home. In addition, it also includes emissions from the journey made for distribution of goods and services purpose, using different alternative methods based on the fuel consumption, fuel expedition and distance travelled. The user can calculate the emissions from urban buses by entering the distance.

- Rail transport

The user can calculate emissions for different means of train transports by entering rout, total distance travelled (km) and the number of passengers for commercial journeys, distribution journeys and staffs' journeys from home to work and from work to home.

- Sea transport

The user can calculate emissions from commercial journeys, distribution journeys and freight transport based on fuel consumption or distance travelled. The user can follow the same way as sea transport in scope 1.

- Air transport

The emissions are estimated using the ICAO (International Civil Aviation Organization) Carbon Emissions Calculator (ICAO, 2016). The user can calculate the emissions by entering the type of ticket, type of journey, number of passengers, number of stops, city of origin, city of destination, flight distance (km) and fuel consumption (kg).

- Fugitive emissions

The fugitive emissions calculation is similar to scope1.

- Waste

In order to calculate emissions from waste, the user should enter the amount of generated different types of waste in the related cells. Waste emissions include emissions generated from a product that ends up as waste and it is left inside bins until its final treatment. This includes direct and indirect emissions from the entire management process: collection and transport, transfer stations, pretreatment plants, and final waste treatment and disposal plants.

- Water

The user can calculate emissions from water consumption by entering the amount of consumed water ($m^3$).

- Electricity

The method of electricity consumption emissions of tenants is the same as scope 1.

- Fossil fuel consumption

The calculation of emissions from fossil fuel consumption is also the same as scope 1.

### 5.2.3. Results of Ports de la Generalitat using OCCC

This section presents the emissions obtained after the application of the OCCC methodology to the Ports de la Generalitat case study for the three scopes. It should be mentioned that in this tool, for scope 1, only the emissions from transportation are taking into account. Emissions from port own vessels, construction equipment and cargo handling equipment are not included whereas they are in the new tool. In addition, for scope 3, only the emissions from water consumption are calculated. This is not common in any of the standards.

As it can be seen in Table 5.5, the total amount of emissions in scope 1, scope 2 and scope 3 are 36.8, 315.6 and 10.4 tonnes $CO_2$eq, respectively. The total estimated $CO_2$ emissions from the Ports de la Generalitat including scope 3 are 362.8 t $CO_2$eq. The higher percentage of emissions corresponds to electricity consumption (86.9%).

**Table 5.5: The result of the GHG emission in Ports de la Generalitat in 2018 (tonnes $CO_2$eq) (Ports de la Generalitat, 2018)**

| **Emission sources** | **2018** | **Percentages (%)** |
|---|---|---|
| Scope 1 (Transportation) | 36.8 | 10.2 |
| Scope 2 (Electricity consumption) | 315.6 | 86.9 |
| Scope 3 (Water consumption) | 10.4 | 2.9 |
| **TOTAL tonnes $CO_2$eq** | **362.8** | **100** |

### 5.2.4. Carbon Footprint calculation carried out with the new tool

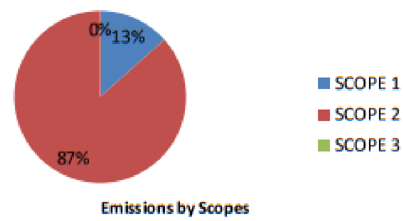
In this section, the same input data as the one of the Ports de la Generalitat (2018) was used to validate the new tool. As it can be seen in Figure 5.7, the total estimated $CO_2$ emissions from the Ports de la Generalitat activities calculated by the new tool are 299.8 t $CO_2$eq. As with the previous tool, scope 2 is the largest emission source (87%), followed by Scope 1 with 13% of the total emissions. In the previous calculation using the OCCC tool, Ports de la Generalitat included in scope 3 only the emissions from water consumption. These emissions are not included in any other international guidelines, therefore the tool presented in this thesis does not take into account these emissions. On the contrary, international standards consider the emissions from commuting and tenants in scope 3. Since the new tool follows these standards and there was not information on the commuting or tenants' emissions, there is no value for Scope 3 emissions.

# Ports de la Generalitat

Spain

| TOTAL: Carbon footprint: | 299.848 $CO_2e$ tonnes |
|---|---|

| SCOPE | Emissions [$CO_2e$ tonnes] |
|---|---|
| 1 | 40.146 |
| 2 | 259.702 |
| 3 | 0.000 |
| TOTAL | 299.848 |



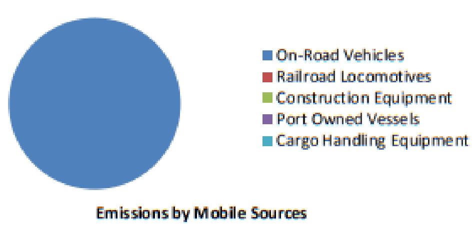

| SCOPE 1: | 40.146 $CO_2e$ tonnes |
|---|---|

*Mobile Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| On-Road Vehicles | 40.146 | 100.00% |
| Railroad Locomotives | 0.000 | 0.00% |
| Construction Equipment | 0.000 | 0.00% |
| Port Owned Vessels | 0.000 | 0.00% |
| Cargo Handling Equipment | 0.000 | 0.00% |
| Total | 40.146 | 100.00% |

*Stationary Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Incineration | 0.000 | |
| Generators | 0.000 | |
| Boilers | 0.000 | |
| Other Facilities | 0.000 | |
| Power Plants | 0.000 | |
| Wastewater treatment plants | 0.000 | |
| Total | 0.000 | 0.00% |



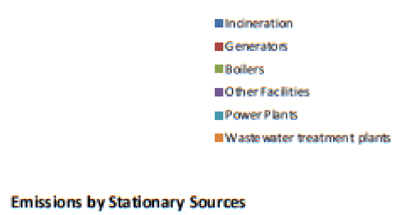




**Figure 5.7: $CO_2$ emissions for the Ports de la Generalitat by the new tool**

## 5.2.5. Comparison of the results

Table 5.6 shows the comparison of the results obtained for the calculation of the Carbon Footprint using the two methods. As it can be seen, the existing results are almost the same as the results of the new tool: 352.4 $CO_2$eq tonnes without scope 3 emissions (OCCC tool) in front of 299.8 $CO_2$eq tonnes (new tool). This shows that the new tool is almost in line with the one used by the OCCC tool. The reasons for the minor differences are due to the usage of different calculation methods (more specific for ports in the case of the new tool) and different emission factors. As it mentioned before, the emission factors are different because each method uses its own emission factors and they vary according to different elements such as type of industry, location and type of fuel.

**Table 5.6: Comparison of the Carbon Footprint results with the two methods (CO2eq tonnes)**

| Scopes | Ports de la Generalitat (OCCC tool) | Results of the new tool |
|---|---|---|
| 1 | 36.8 | 40.2 |
| 2 | 315.6 | 259.7 |
| 3 | 10.4 | - |
| **Total** | **362.8** | **299.8** |

## 5.3. Case study model

The purpose of this case study model is to be able to test the full capacity of the tool, this means all the emission sources included in the WPCI, and the IPCC guidelines and GHG Protocol. Finding a real port that has all these emission sources is complicated. In addition, this port has to share its data for this study. Confidentiality issues and the Covid-19 situation have not helped to achieve this. After a deep research in literature (e.g. Chang et al., 2013, Olukanni & Esu, 2018, Akerman & Hojer, 2006, Misra et al 2017 and López-Aparicioet al., 2017) and getting in contact with several ports, it has been seen that finding this port was practically impossible. For this reason, as mentioned at the beginning of this section, it has been necessary to create a case study model to validate all the sources recommended by guidelines for ports in the three scopes of the new tool. The information used to create the case study has been extracted from the data gathered in the Appendix 6 and from consultation with port experts. This port is called Bandare-Bid port and it is presented below.

### 5.3.1. Introducing the Bandare-Bid port

The capacity of the new port is about 20,5 milion tonnes and 791,666 TEU per year. The cruise and ferry terminal has around 520,120 passengers annually. It is assumed, this port is located in Iran. The port is home to 5 terminals including one container terminal, one fishing terminal, one dry bulk terminal, one liquid bulk cargoes terminal and a cruise terminal. This port has an organic chemical industry, a wastewater treatment plant, a waste incineration plant and a power plant which are managed by tenants. The total number of employees is 145. The different parts of this port are presented in Figure 5.8.

As it mentioned in chapter 3, emission sources in ports are divided into four main groups: Mobile sources, Stationary sources, Purchased electricity and Employees' commuting. In the next section, the amounts of consumed fuel in the different sources are presented. They are categorized based on the scopes which are:

**Scope 1 (Port Authority):** It includes the main offices of the port authority, a restaurant, some mobile and stationary sources such as cargo handling equipment, construction equipment, port owned on-road vehicles and port Owned Vessels.

**Scope 2 (Purchased Electricity):** It includes the electricity consumption in the different sources of the port authority.

**Scope 3 (Tenants):** It includes different mobile and stationary sources in the container terminal, the fishing terminal, the dry bulk terminal, the liquid bulk cargo terminal, the cruise terminal, the power plant, the waste incineration plant, the electricity consumption from tenants and the employee's commuting.

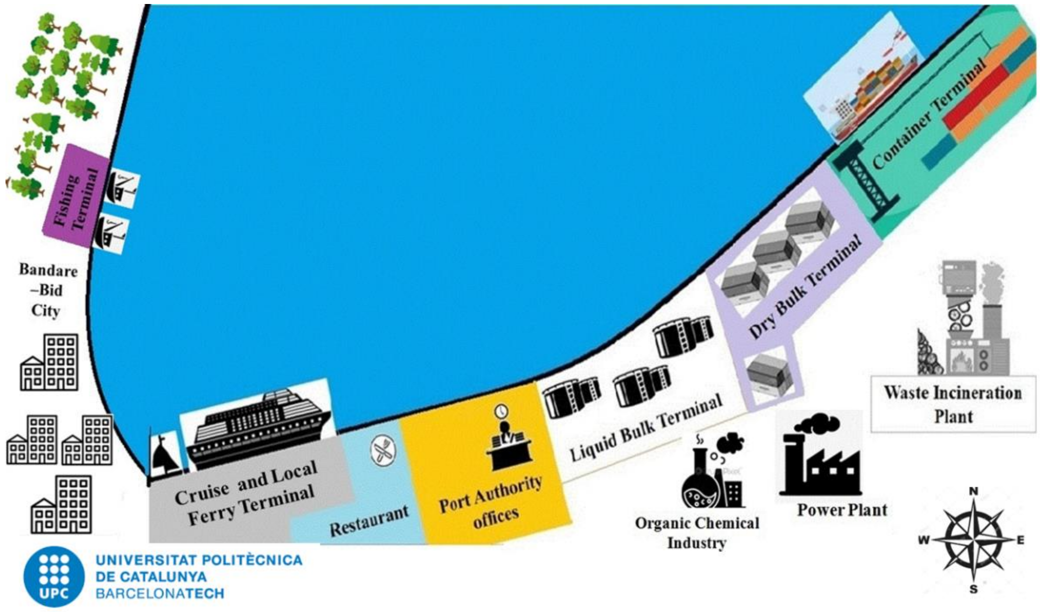



**Figure 5.8: Different parts of the Bandare-Bid Port**

- **Scope 1**

The sources of this scope are directly under the control and operation of the port authority. These sources are divided into two main groups: Mobile sources and Stationary sources. The amounts of consumed fuel in the different sources of the port authority are presented in Table 5.7. As it can be seen in this table, the mobile sources include cargo handling equipment, on-road vehicles, port owned vessels and construction equipment. The stationary sources include boilers and generators.

**Table 5.7: Fuel consumption in different sources of the port authority (Scope1)**

| Sources | | Name | Number | Fuel type | Consumption | Unit |
|---|---|---|---|---|---|---|
| Mobile Sources | Cargo handling equipment | Crane | 3 | Diesel | 19,800 | L/yr |
| | | Yard Tractor | 2 | Diesel | 12,807 | L/yr |
| | | Forklift | 1 | Diesel | 8,250 | L/yr |
| | On-Road vehicles | Vehicles (cars) | 8 | Biodiesel | 8,800 | kg/yr |
| | | Vehicles (cars) | 11 | Gasoline | 6,947 | L/yr |
| | | Diesel heavy truck | 3 | Diesel | 53,663 | L/yr |
| | Port Owned Vessels | Assist Tugboats * | 1100call | Diesel | 1,320,700 | L/yr |
| | | Cleaning boats | 620 call | Diesel | 830,200 | L/yr |
| | | Others(e.g. ,work boats**, Towboats and Push boats***) | 825call | Diesel | 990,600 | L/yr |
| | Construction equipment | Earth moving Equipment | 2 | Diesel | 18,200 | L/yr |
| | | Dredger | 3 | Diesel | 8,708 | L/yr |
| | | Portable generator | 3 | Diesel | 8,202 | L/yr |
| Stationary Sources | Boilers | | 2 | Petroleum cock | 25,480 | Kg/yr |
| | Generators | | 2 | Petroleum cock | 21,805 | Kg/yr |

***Assist Tugboats assist OGVs during maneuvering and docking

** Work boats carry workers to offshore locations

*****Towboats and Push boats –move barges and other floating objects

- **Scope 2**

As mentioned in chapter 3, scope 2 includes Purchased electricity which is consumed in the routine operation of the port authority. Table 5.8 presents the amounts of electricity consumption by different sources of the port. It should be mentioned that since the port is assumed to be located in Iran, the average $CO_2$ specific emission factor in Iran has been used, which is 571.29 g/kWh (Noorpoor and Nazari, 2015). This amount should be entered manually in the new tool.

**Table 5.8: The amounts of the electricity consumption by different sources of the port**

| Name | Consumption | Unit |
|---|---|---|
| 3 Cranes owned by port | 115,102 | kWh/yr |
| Heating | 101,284 | kWh/yr |
| Cooling | 85,052 | kWh/yr |
| Property electricity | 35,468 | kWh/yr |
| Construction equipment (2 Earth moving Equipment and 3 dredger) | 22,207 | kWh/yr |
| Public lighting on roads and terraces | 135,125 | kWh/yr |
| Offices and Restaurant | 185,254 | kWh/yr |
| Lighthouses and maritime signaling | 50,750 | kWh/yr |
| Other (telecommunications systems, weather stations, cameras, etc.) | 102,196 | kWh/yr |

- **Scope 3**

These sources are associated with tenant operations and include ships, trucks, cargo handling equipment, rail locomotives, harbor craft, tenant buildings, tenant purchased electricity, and the commuting of port authority employees and tenant-employees' commuting.

The tenants of the Bandare-Bid port are a container terminal, a fishing terminal, a dry bulk terminal, a liquid bulk terminal and a cruise terminal. In addition, a power plant and a waste incineration plant are under the control of tenants. It should be also mentioned that the emissions produced by the Ocean-Going vessels while they are at berth and in the port are calculated in this scope.

### Tenant 1- Container Terminal

The capacity of terminal 1 is 791,666 TEUs. When the ship arrives, the cargo is then taken from the warehouse to the quay and then lifted on board by the cranes. Once on board each item must be stowed. Before any loading takes place, any signs of the previous cargo are removed. The discharge of the ship is the reverse of the loading operation. The cargos of this terminal mostly include paper reels, wooden boxes and electrical devices. It should be mentioned that in this terminal, there is a railroad locomotive that transfers 2,400,000tonnes of goods annually to the hinterland. In addition, in this terminal, there are 155 calls per year for containerships and they carry 587, 354 TEU of cargo per year and 51,750 tonnes of goods are transferred by trucks. Table 5.9 shows the amounts of consumed fuel in different sources of this terminal.

**Table 5.9: Fuel consumption in different sources of container terminal 1 (Scope 3)**

| Sources | | Name | Number | Fuel type | Consumption | Unit |
|---|---|---|---|---|---|---|
| Mobile Sources | Cargo handling equipment | Container Handler | 3 | Diesel | 5,860 | L/yr |
| | | Crane | 3 | Diesel | 7,650 | L/yr |
| | | Tractor | 3 | Diesel | 5,560 | L/yr |
| | | Forklift | 2 | Diesel | 3,150 | L/yr |
| | On-Road vehicles | Vehicles (Cars) | 12 | Gasoline | 6,245 | L/yr |
| | | Heavy truck | 6 | Diesel | 32,663 | L/yr |
| | Rail road Locomotives 100 km* | | 1 | Diesel | 185,487 | L/yr |
| | Ocean going vessels | Containership | 155 calls | Diesel | 210,300 | L/Yr |
| | Construction equipment | Earth moving equipment | 3 | Diesel | 6,120 | L/yr |
| | | Portable generator | 3 | Diesel | 7,320 | L/yr |
| Stationary Sources | Generators | | 2 | Petroleum cock | 12,805 | Kg/yr |
| Purchased electricity | | | | Electricity | 365,100 | kWh/yr |

*There is one railway and it transfers 2,400,000 tonnes of the cargo to the next city which is in 100 km.

## Tenant 2- Fishing Terminal

The capacity of this fishing terminal is 2,650 tonnes. Of this amount, 1,200 tonnes of fishes are transported by refrigerated trucks and 1,450 tonnes are carried by refrigerated cargo vessels. Table 5.10 shows the amounts of consumed fuel in different sources of this terminal.

**Table 5.10: Fuel consumption in different sources of Fishing Terminal (Scope 3)**

| Sources | | Name | Number | Fuel type | Consumption | Unit |
|---|---|---|---|---|---|---|
| Mobile Sources | Cargo handling equipment | Container handler | 3 | Diesel | 5,100 | L/yr |
| | | Crane | 3 | Diesel | 8,695 | L/yr |
| | | Forklift | 3 | Diesel | 5,095 | L/yr |
| | On-Road vehicles | Vehicles | 10 | Gasoline | 4,230 | L/yr |
| | | Trucks | 5 | Diesel | 21,936 | L/yr |
| | Harbor Craft | Commercial Fishing Vessels | 65 calls | Diesel | 90,500 | L/Yr |
| | | Local Ferries | 25 calls | Diesel | 31,500 | L/Yr |
| | Ocean going vessels | Refrigerated Cargo Vessel | 145 calls | Diesel | 201,880 | L/Yr |
| | Construction Equipment | Portable generator | 4 | Diesel | 12,540 | L/yr |
| Stationary Sources | Generators | | 2 | Petroleum cock | 10,805 | Kg/yr |
| Purchased electricity | | | | Electricity | 165,100 | kWh/yr |

## Tenant 3- Dry bulk terminal

This dry bulk terminal is used as a buffer between an incoming and outgoing flow of bulk solids materials mainly iron, cement, tin, steel, and grains in its cargo holds. The capacity of this terminal is 9,250,000 tonnes. In this terminal dry bulks are being loaded and unloaded. Then they are transferred by trucks (72,450 tonnes) and by dry bulk container ships (9,177,550 tonnes) to their destinations. The amounts of consumed fuel in different sources of this terminal are presented in Table 5.11.

**Table 5.11: Fuel consumption in different sources of dry bulk terminal (Scope 3)**

| Sources | | Name | Number | Fuel type | Consumption | Unit |
|---|---|---|---|---|---|---|
| Mobile Sources | Cargo handling equipment | Dry bulk handler | 3 | Diesel | 5,750 | L/yr |
| | | Crane | 2 | Diesel | 7,100 | L/yr |
| | | Tractor | 3 | Diesel | 4,950 | L/yr |
| | | Forklift | 2 | Diesel | 2,750 | L/yr |
| | | Sweeper | 2 | Diesel | 980 | L/yr |
| | On-Road vehicles | Vehicles (Cars) | 12 | Gasoline | 5,200 | L/yr |
| | | Heavy truck | 7 | Diesel | 23,500 | L/yr |
| | Ocean going vessels | Dry Bulk Carrier | 250 calls | Diesel | 318,200 | L/Yr |
| | Construction Equipment | Portable generator | 2 | Diesel | 7,200 | L/yr |
| Stationary Sources | Generators | | 2 | Petroleum cock | 14,050 | Kg/yr |
| Purchased electricity | | | | Electricity | 325,000 | kWh/yr |

## Tenant 4- Liquid bulk terminal

The capacity of the liquid bulk terminal is 4,300,000 tonnes. Vegetable oils, fish oils and dairy products (e.g. milk, liquid yogurt) are the bulk liquids of this terminal. It should be mentioned, 3,060,000 tonnes of these liquid bulks are carried by Cargo ships, 1,226,200 tonnes are carried by the Refrigerated ships and 13,800 tonnes are carried by the trucks. The amounts of consumed fuel in different sources of this terminal are presented in Table 5.12.

**Table 5.12: Fuel consumption in different sources of liquid bulk terminal (Scope 3)**

| Sources | | Name | Number | Fuel type | Consumption | Unit |
|---|---|---|---|---|---|---|
| Mobile Sources | Cargo handling equipment | Container Handler | 2 | Diesel | 2,100 | L/yr |
| | | Crane | 1 | Diesel | 3,100 | L/yr |
| | | Tractor | 1 | Diesel | 2,500 | L/yr |
| | | Forklift | 1 | Diesel | 1,250 | L/yr |
| | On-Road vehicles | Vehicles (Cars) | 6 | Gasoline | 2,100 | L/yr |
| | | Heavy truck | 2 | Diesel | 10,550 | L/yr |
| | Ocean going vessels | General Cargo Ship | 85 calls | Diesel | 115,350 | L/Yr |
| | | Refrigerated Vessel | 30 calls | LPG | 25,250 | Kg/Yr |
| | Construction equipment | Earth moving equipment | 1 | Diesel | 4,200 | L/yr |
| | | Portable generator | 1 | Diesel | 3,700 | L/yr |
| Stationary Sources | Generators | | 1 | Petroleum cock | 9,400 | Kg/yr |
| Purchased electricity | | | | Electricity | 153,000 | kWh/yr |

## Tenant 5- Cruise terminal

The cruise terminal handles around 100 calls with 400,120 passengers. In addition, this terminal has 600 calls with about120,000 passengers for the local ferries annually. Table 5.13 presents the amounts of consumed fuel in different sources of this terminal.

**Table 5.13: Fuel consumption in different sources of Cruise terminal (Scope 3)**

| Sources | | Name | Number | Fuel type | Consumption | Unit |
|---|---|---|---|---|---|---|
| Mobile Sources | Cargo handling equipment | Container Handler | 1 | Diesel | 1,100 | L/yr |
| | | Forklift | 1 | Diesel | 880 | L/yr |
| | On-Road vehicles | Vehicles (Cars) | 3 | Gasoline | 850 | L/yr |
| | | Heavy truck | 2 | Diesel | 920 | L/yr |
| | Harbor crafts | Local Ferries | 600 calls | Diesel | 805,500 | L/Yr |
| | Ocean going vessels | General Cargo Ship | 100 calls | Diesel | 140,220 | L/Yr |
| | | Passenger ship | 100 calls | Diesel | 180,700 | L/Yr |
| | Construction equipment | Portable generator | 3 | Diesel | 7,400 | L/yr |
| Stationary Sources | Generators | | 2 | Petroleum cock | 8,950 | Kg/yr |
| Purchased electricity | | | | Electricity | 210,000 | kWh/yr |

### Tenant 6- Power plant

This Power plant generates electricity by burning petroleum coke. It works daily and provides the electricity supply for the tenants. The installed capacity of the power plants is 120 Mwh and it consumes 395000 Kg of petroleum coke annually.

### Tenant 7- Organic Chemical Industry

An Organic chemical industry is located in the port. The industrial organic chemical sector produces organic chemicals (those containing carbon) used as either chemical intermediates or end-products. Generally, it produces raw materials and intermediates, as well as a wide variety of finished products for industry, business and individual consumers (EPA, 1995).

The industry which is located in the Bandare-Bid port produces about 860 tonnes per year of Plastics Materials, Soaps, Cleaners, Toilet Goods, Gum and Wood Chemicals.

The fuel used by this industry is natural gas. This industry consumes 15,000 $m^3$ of natural gas per year and produces 40 tonnes of waste which is burnt in the incineration plant located in the port. This industry consumes 330,700 kWh/yr electricity.

### Tenant 8- Wastewater treatment plant

In order to validate the new tool, in the Bandare-Bid port, there is a wastewater treatment plant that belongs to the aforementioned organic chemical industry. In this plant, an anaerobic treatment method is used.

The assessment of the potential production of $CH_4$ from industrial wastewater streams is based on the concentration of degradable organic matter in the wastewater, the volume of wastewater, and the propensity of the industrial sector to treat their wastewater in anaerobic systems (IPCC, 2019).

Based on the IPCC guidelines (IPCC, 2006 and 2019), the default value for removal of the organic component from wastewater as sludge in anaerobic wastewater treatment plants without separate primary treatment is 1.16 and the default for $CH_4$ recovery is zero.

### Tenant 9- Waste incineration plant

There is a waste incinerator plant in the port area that belongs to the organic chemical industry which is located in the port area.About40 tonnes per year of residues are burnt in this site coming from the waste generated in the Organic chemical industry. The produced energy is used as an energy input to the incineration process.

It is considered that the type of incinerator is a continuous stoker which is a combustion system that consists of a series of stepped fire grates. They move back and forth to facilitate efficient contact between the waste and air, ensuring stable combustion of the waste despite its non-uniform properties.

### Port waste

A part from the waste generated in the Organic chemical industry that is incinerated, other residues are produced in this port. These are presented in Table 5.14. This distinction is necessary for the OCCC tool calculation that takes into account all type of residues, not for the one developed in this thesis.

**Table 5.14: Amounts of the waste based on the different categories**

| Categories | Amount (Tonnes/yr) |
|---|---|
| Paper | 115 |
| Glass | 185 |
| Light weight packages | 95 |
| Organic wastes | 205 |
| Organic chemical industry's waste | 40 |
| Others | 135 |

### Purchased Electricity

Table 5.15 presents the amounts of electricity consumption generated by different sources of the tenants. As in mentioned in scope 2, the average $CO_2$ specific emission factor used for this study is the one for Iran, 571.29 g/kWh (Noorpoor and Nazari, 2015).

**Table 5.15: The amounts of the electricity consumption by different sources of the port**

| Name | Consumption | Unit |
|---|---|---|
| Container Terminal | 365,100 | kWh/yr |
| Fishing Terminal | 165,100 | kWh/yr |
| Dry Bulk Terminal | 325,000 | kWh/yr |
| Liquid Bulk Terminal | 153,000 | kWh/yr |
| Cruise Terminal | 210,000 | kWh/yr |
| Organic chemical industry | 330,700 | kWh/yr |

### Employees' Commuting

As mentioned in Chapter 3, employees' commuting is one of the main sources of GHG emissions in scope 3. This category includes emissions from the transportation of employees between their homes and their worksites, and business travels. Table 5.16 shows fuel consumption for commuting employees and business travels in Bandare-Bid port.

**Table 5.16: Fuel consumption for commuting employees and business travels**

| Name | Number of passengers | Distance (km) | Fuel Type | Consumption (L/Yr) |
|---|---|---|---|---|
| Train | 16 | 75,000 | Gasoline | 4,500 |
| Metro | 33 | 52,600 | Diesel | 3,450 |
| Bus | 19 | 30,300 | Diesel | 2,150 |
| Personal car | 8 | 40,800 | Diesel | 2,150 |
| Local ferry | 4 | 15,500 | Diesel | 930 |
| Walking or Bicycle | 6 | 1,250 | - | - |
| Domestic business travel by plane | 8 | 10,200 | Gasoline | 2,620 |
| Short-haul business travel by plane | 6 | 50,400 | Gasoline | 4,816 |
| Long-haul business travel by plane | 6 | 60,500 | Gasoline | 5,220 |
| Business travel by taxi | 16 | 45,800 | Gasoline | 2,748 |
| Business travel in non-company owned vehicles | 23 | 26,200 | Gasoline | 1,572 |

As commented at the beginning of this chapter, the emission from this case study will be calculated using the new tool, the OCCC tool (explained in section 5.2.2) and the MITECO tool. The methodology of the latter tool will be explained in detail in the next subsection.

### 5.3.2. The Ecological Transition Ministry (MITECO) of the Spanish government tool

As it is explained in section 1.3.4, since 2007 the Ecological Transition Ministry (MITECO) of the Spanish government developed an excel based tool and guidelines to calculate the Carbon Footprint. The last version of these guidelines was published in 2019 and they aim to calculate emissions of scope 1 and scope 2 (MITECO, 2019).

- Scope 1: Emissions from Fossil fuels consumption and Emissions from fluorinated gases (air conditioning equipment and cooling)
- Scope 2: Emissions from Electricity consumption

As it can be seen in figure 5.9, the emissions of the aforementioned scopes are calculated in 10 sheets.

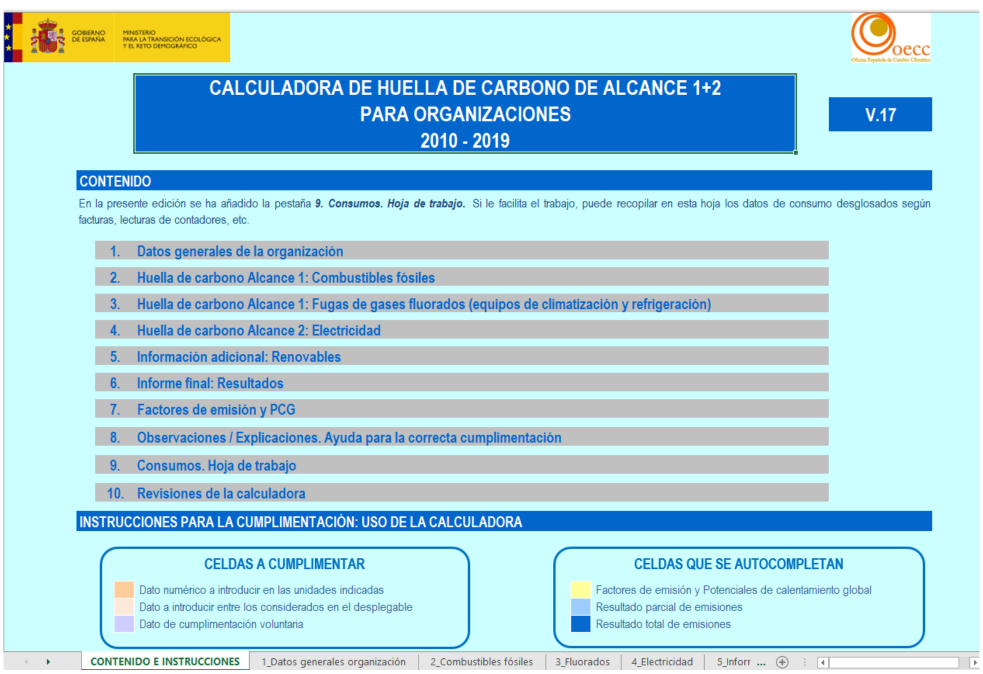



**Figure 5.9: The introduction sheet of the MITECO tool**

In the first sheet, general data of the organization such as name, type of organization and different years of calculation should be introduced. The next sheets are described below:

- Fossil fuel consumption in stationary sources and mobile sources

In this sheet (Figure 5.10), the user can calculate emissions from fossil fuel consumption in stationary sources and mobile sources (Scope 1). In order to calculate emissions from stationary sources, the user should choose the type of fuel for each source and he/she should enter the amount of consumed fuel. In order to calculate emissions from mobile sources the user has two options, he/she can calculate emissions based on fuel consumption or based on a movement in km.

As it can be seen in Figure 5.10, three kinds of cells can be filled by the user: orange cells with numerical data (such as the amount of consumed fuel), pink cells with data chosen from a provided list in the same cell and light purple cells with voluntary data introduced by the user. Yellow cells are for emission factors. As it can be seen, there are two columns for the emission factors. In the first one, emission factors are introduced automatically by the tool, they are obtained from the different editions of the National Emissions Inventory of Spain (from the 1990-2006 edition to the 1990-2017 edition) and in the IPCC guidelines for national inventories of greenhouse gases of 2006 (IPCC, 2006). In the second column, the user can insert its own emission factors, if they are different from those provided automatically. Blue cells present the results.

- Fugitive emissions

The user should enter the amount of fluorinated gas (kg).

- Purchased electricity

Emissions from purchased electricity in buildings and emissions from electric or hybrid vehicles can be calculated by this tool. The user should specify the buildings and the annual amount of electricity consumption in kWh. In addition, emissions can be calculated by entering the annual amount of electricity consumption.

- Renewable energies facilities

If the organization has any kind of renewable energies facilities for sale or for self-consumption, the user can calculate related emissions by choosing the type of renewable energy or the type of biomass and by entering the amount consumption in the related cells.

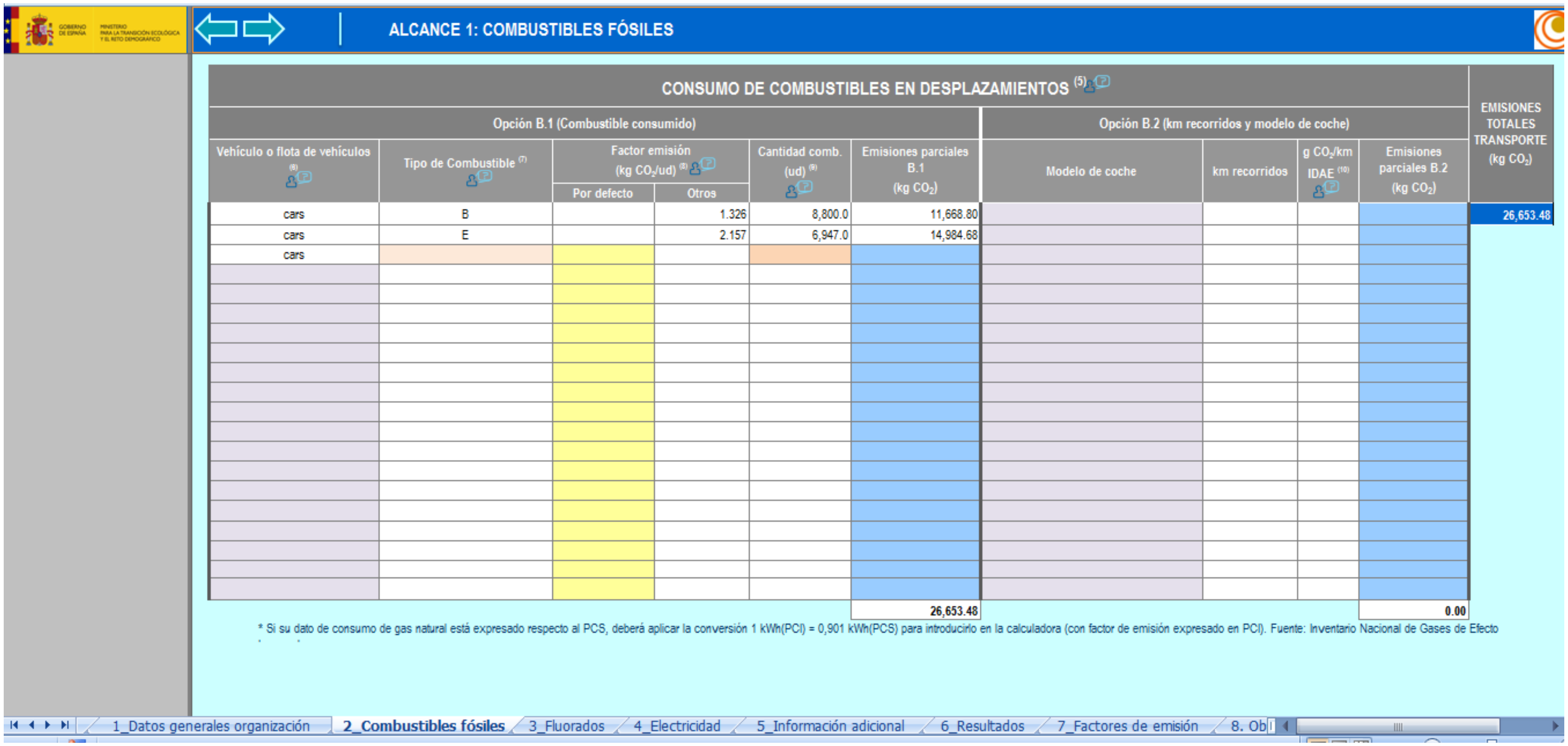



**Figure 5.10: The sheet of the MITECO tool for calculating emissions from fossil fuel consumption**

Finally, the results are presented in a last slide where the total amount of emissions, the amount of emissions in each scope and the amount of emissions for each year are summarized (Figure 5.11).

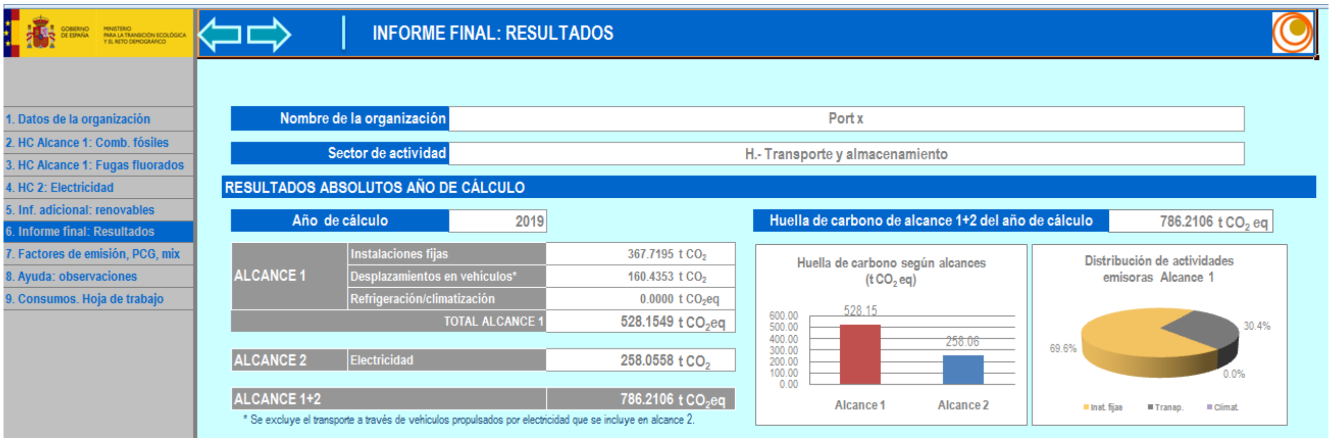


**Figure 5.11: The result sheet of the MITECO tool**

### 5.3.3. Carbon Footprint calculation for Bandare-Bid port

In this section, GHG emissions of the Bandare-Bid port are calculated by the new tool, the OCCC tool and the MITECO tool. The results are presented below.

#### 5.3.3.1. Carbon Footprint calculation of the case study carried out with the new tool

In this section, the data of the case study is used to validate the new tool. As it can be seen in Figure 5.12, the total $CO_2$ emissions from the case study's activities calculated by the new tool are 20710.551 t $CO_2$eq. As explained in section 3.4.1, the Carbon footprint of this port is calculated in two ways by the new tool dividing the emissions by TEU per year or by million tonnes per year: 0.026$CO_2$eq t / (TEU/Yr) and 1010.3 $CO_2$eq t /(million t/ Yr).

As it can be observed in Figure 5.1, scope 3 is the largest emission source with 1161.547 $CO_2$eq t (54% of the total), followed closely by scope 1 with 44% and scope 2 with 2%.

Within the emissions of mobile sources of scope 3, 46.69% of them belong to ocean-going vessels, harbor crafts (local ferries and fishing vessels) emit 36.44% of these emissions. Railroad locomotives, on-road vehicles, cargo handling equipment and construction equipment emit around 17% of the total of this category. Concerning stationary sources, the power plantgenerates38.16% these emissions, followed by the wastewater treatment plant (29.44%) and other facilities (organic chemical industry) (24.94%). Generators and incineration add a total of 7.46% of the emissions for this subcategory.

For the mobile sources of scope 1, practically all the emissions belong to port owned vessels (95.68%), being minority the emissions from on-road vehicles, cargo handling equipment and construction equipment. Among stationary sources, boilers emit 53.89% and generators emit 46.11% of the GHG of this subcategory. Scope 2 emits only 475.564 $CO_2$eq t.

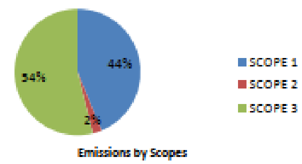
## Bandare Bid

Iran

| | | |
|---|---|---|
| Capacity | 791666 TEU/yr. | 20.5 million tn./yr. |

| | | |
|---|---|---|
| TOTAL: | 20710.551 $CO_2e$ tonnes | |
| Carbon footprint: | 0.026 $CO_2e$ tonnes/(TEU/yr.) | 1010.3 $CO_2e$ tonnes/(million tn./yr.) |

| SCOPE | Emissions [$CO_2e$ tonnes] |
|---|---|
| 1 | 9073.440 |
| 2 | 475.564 |
| 3 | 11161.547 |
| TOTAL | 20710.551 |



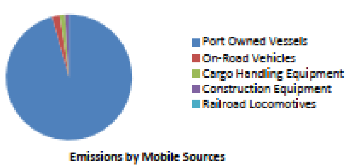

**SCOPE 1:** 9073.440 $CO_2e$ tonnes

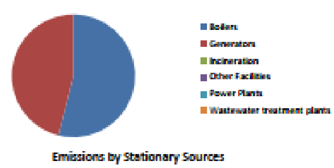
*Mobile Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Port Owned Vessels | 8537.863 | 95.68% |
| On-Road Vehicles | 178.909 | 2.00% |
| Cargo Handling Equipment | 111.040 | 1.24% |
| Construction Equipment | 95.421 | 1.07% |
| Railroad Locomotives | 0.000 | 0.00% |
| Total | 8923.232 | 100.00% |

*Stationary Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Boilers | 80.941 | 53.89% |
| Generators | 69.267 | 46.11% |
| Incineration | 0.000 | 0.00% |
| Other Facilities | 0.000 | 0.00% |
| Power Plants | 0.000 | 0.00% |
| Wastewater treatment plants | 0.000 | 0.00% |
| Total | 150.208 | 100.00% |




**SCOPE 2:** 475.564 $CO_2e$ tonnes

*Purchased Electricity*

| Field | Emissions [$CO_2e$ tonnes] |
|---|---|
| Electricity | 475.564 |

**SCOPE 3:** 11161.547 $CO_2e$ tonnes

*Mobile Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| OGV | 3229.352 | 46.69% |
| Harbor Craft | 2520.728 | 36.44% |
| Railroad Locomotives | 548.011 | 7.92% |
| On-Road Vehicles | 286.822 | 4.15% |
| Cargo Handling Equipment | 199.946 | 2.89% |
| Construction Equipment | 131.757 | 1.90% |
| Total | 6916.616 | 100.00% |

*Stationary Sources*

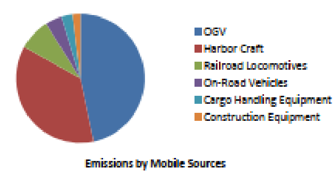
| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Power Plants | 1254.776 | 38.16% |
| Wastewater treatment plants | 968.010 | 29.44% |
| Other Facilities | 819.971 | 24.94% |
| Generators | 177.924 | 5.41% |
| Incineration | 67.284 | 2.05% |
| Boilers | 0.000 | 0.00% |
| Total | 3287.964 | 100.00% |

*Purchased Electricity*

| Field | Emissions [$CO_2e$ tonnes] |
|---|---|
| Electricity | 884.871 |

*Employees' commuting*

| Field | Emissions [$CO_2e$ tonnes] |
|---|---|
| Employees' commuting | 72.096 |



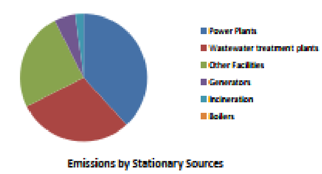




**Figure 5.12: $CO_2$ emissions for the Case study by the new tool**

#### 5.3.3.2. Carbon Footprint calculation of the case study carried out with the OCCC tool

The results of the GHG emissions carried out with the OCCC tool are presented below. As it can be seen in Figure 5.13, scope 3 is responsible of half of the emissions, followed closely by scope 1 (47.43%). Scope 2 has a minor percentage of emissions (2.47%).

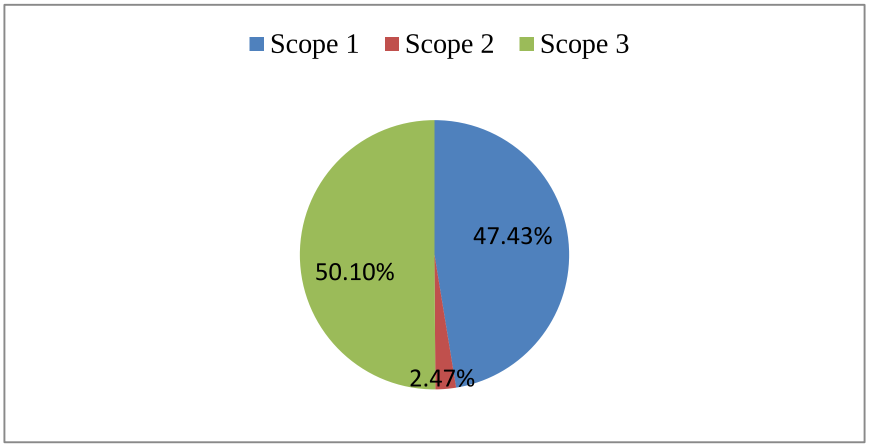



**Figure 5.13: Results of the GHG emissions (%) carried out with the OCCC**

As it can be seen in Table 5.17, the total $CO_2$ emissions from the case study's activities calculated by the OCCC tool are 19188.09 t $CO_2$eq.

Within scope 1, most of the emissions belong to sea transport. Fossil fuel consumption and road transport represent only 6% of these emissions. Scope 2 emits 475.546 t $CO_2$eq.

In scope 3, sea transport occupies the first position with 60%of the emissions, followed by fossil fuel consumption (18.84%) and electricity consumption (9.20%).

**Table 5.17: Results of the GHG emissions carried out with the OCCC tool**

| Scope | Sources | Emissions (Tonnes $CO_2$eq) | Percentage (%) |
|---|---|---|---|
| 1 | Fossil fuel consumption | 367.682 | 4.04% |
| | Road transport | 169.798 | 1.86% |
| | Sea transport | 8,560.90 | 94.09% |
| | **Total emissions of Scope 1** | **9,098.380 (47.43%)** | **100** |
| 2 | Electricity consumption (Scope 2) | 475.564 | - |
| | **Total emission of Scope 2** | **475.564 (2.47%)** | **100** |
| 3 | Fossil fuel consumption | 1,811.470 | 18.84% |
| | Road transport | 263.510 | 2.74% |
| | Rail transport | 558.000 | 5.80% |
| | Sea transport | 5,747.82 | 59.78% |
| | Waste | 184.870 | 1.92% |
| | Electricity | 884.871 | 9.20% |
| | Employees commuting | 163.605 | 1.70% |
| | **Total emission of Scope 3** | **9,614.146 (50.10%)** | **100%** |
| **Total** | | **19,188.090** | **-** |

#### 5.3.3.3. Carbon Footprint calculation of the case study carried out with the MITECO tool

The results of the GHG emissions carried out with the MITECO tool are presented below. As it can be seen in Figure 5.14, two thirds of the total emissions belong to scope 1 and the rest to scope 2. Emissions of scope 3 are not included in this tool.

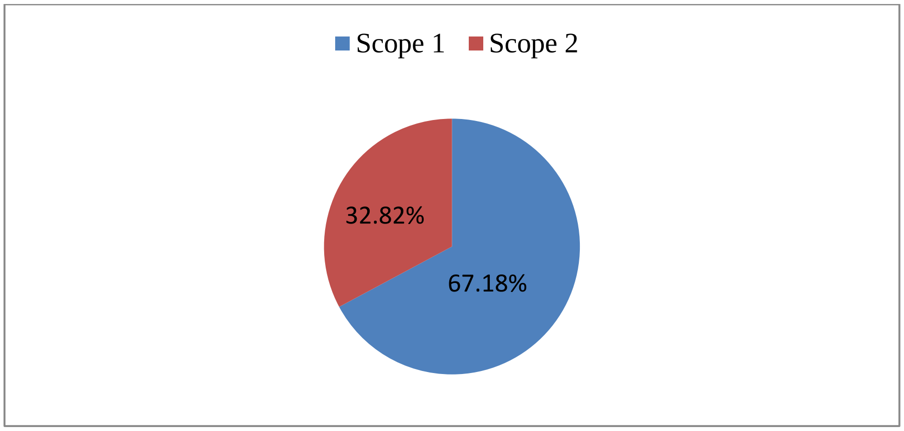



**Figure 5.14: Results of the GHG emissions (%) carried out with the MITECO tool**

The total $CO_2$ emissions from the case study's activities calculated by this tool are 786.206 t $CO_2$eq as presented in Table 5.18. Scope 1 emits 528.151 t $CO_2$eq. Practically one third of these emissions of belong to road transport, followed by cargo handling equipment (22.18%), construction equipment (19.06%), boilers (15.28%) and generators (13.08%). It should be mentioned that emissions from port owned vessels are not considered in this tool. Scope 2 emits 258.055 t $CO_2$eq.

**Table 5.18: Results of the GHG emissions carried out with the MITECO tool**

| Scope | Sources | Emissions (Tonnes $CO_2$eq) | Percentage (%) |
|---|---|---|---|
| 1 | Cargo handling equipment | 117.177 | 22.18% |
| | Construction equipment | 100.694 | 19.06% |
| | Boilers | 80.745 | 15.28% |
| | Generators | 69.100 | 13.08% |
| | Road transport | 160.435 | 30.37% |
| | **Scope 1 total emission** | **528.151** | **100** |
| 2 | Electricity consumption (Scope 2) | 258.055 | 32.82% |
| **Total** | | **786.206** | **100** |

#### 5.3.3.4. Comparing the results

Table 5.19 shows the comparison of the results obtained for the calculation of the Carbon Footprint using the three methods. The comparison shows there are some similarities between the results.

The total emissions obtained with the new tool and the OCCC tool are very similar, 20,710.551 and 19,188.09$CO_2$eq tonnes, respectively. The results from MITECO are quite different mainly because this tool does not include scope 3 in its calculations.

Within scope 1, as it can be seen in table 5.19, the results obtained by the new tool (9,073.440 t $CO_2$eq) and the OCCC tool (9,098.380t $CO_2$eq) are very similar. The results of scope 1 using the MITECO are lower because, as already mentioned, emissions from port owned vessels are not considered in this tool. In the other two tools, these emissions (port owned vessels) represent around 95% of total of scope 1.

The result of scope 2 in the new tool and OCCC tool is exactly the same (475.564 t $CO_2$eq) due to the use of the same emission factor for the electricity (the Iranian one). In these two tools the emission factor is introduced by the user manually whereas in the MITECO tool there is a default amount for Spain which is not possible to modify by the user. For this reason, the results of the MITECO tool are lower since the electricity emission factor in Spain is less than in Iran.

Concerning scope 3, it is important to remember that the emissions of this scope are not taken into account in the MITECO tool, for this reason there is no value in table 5.19.The results obtained by the new tool (11, 161.547 $CO_2$eq) and OCCC tool (9,614.146.7 $CO_2$eq)in scope 3 are very similar. The slight difference is mainly related to the different emissions factors. The OCCC tool is using the emission factors recommended by the ISO 14064 (i.e. GHG protocol) and the new tool is using IPCC values.

**Table 5.19: Comparison of the Carbon Footprint results ($CO_2$eq tonnes)**

| Scopes | New tool | OCCC tool | MITECO tool |
|---|---|---|---|
| 1 | 9073.440 | 9098.380 | 528.151 |
| 2 | 475.564 | 475.564 | 258.055 |
| 3 | 11161.547 | 9614.146 | - |
| **Total** | **20,710.551** | **19,188.090** | **786.206** |

## 5.4. Conclusions

In this chapter, in order to compare the published results of the ports with the results of the new tool, the new tool is validated with public data from the Port of Oslo and Ports de la Generalitat.

The existing results of the port of Oslo are almost the same as the results of the new tool: 1345 $CO_2$eq tonnes (Port of Oslo tool –ISO 14064) in front of 1293.5 $CO_2$eq tonnes (new tool). The total emissions of the scope 1 calculated by the port of Oslo and by the new tool are very similar. The reasons for the minor differences in this scope are due to the usage of different calculation methods. The total emissions of the scope 2 calculated by the both tools are the same. Concerning scope 3, emissions of the employees' commuting calculated by the port of Oslo are slightly higher than the new tool. This difference can be explained by the different calculation method used by the Port of Oslo and the new tool for this scope.

For the case study of Ports de la Generalitat, the comparison of results has been done without including scope 3, since in the OCCC tool (method used by Ports de la Generalitat), emissions derived from water consumption are considered as scope 3 emissions, whereas they are not included neither in the new tool nor in the standard guidelines. Looking at the results for the other two scopes, the published results of the Ports de la Generalitat (without scope 3 emissions) are almost the same as the results of the new tool: 352.4 $CO_2$eq tonnes (OCCC tool) in front of 299.8 $CO_2$eq tonnes (new tool).

These comparisons show that the new tool is almost in line with the ones used by the Port of Oslo and Port de la Generalitat. The reasons for the minor differences are due to the usage of different calculation methods and different emission factors which are more updated.

As it was mentioned at the beginning of this chapter, neither the OCCC tool nor the ISO 14064 method, (the tools used in the previous case studies) are not taking into account all the scopes and all the emission sources recommended by the World Port Climate Initiative (WPCI) guidelines. On the contrary, the new tool, designed specifically for ports, includes all the aspects recommend by these port guidelines. Therefore, to test the whole sources of each scope, a case study model has been created using literature information and port expertise. Finding a real port that had all the emission sources included in the WPCI guidelines would have been very complicated. However, attempts to involve selected ports in the validation process have been done. Unfortunately, confidentiality issues and Covid-19 situation has made it not possible The case study model has been used to validate the new tool developed in this thesis, through the comparison of the results obtained with the OCCC and MITECO tools. The comparison shows there are some similarities and some differences. The total amounts of the emissions calculated by the new tool and the OCCC tools are very similar. The reasons for the minor differences are due to the usage of different calculation methods and different emission factors. However, the total amount of the emissions calculated by the MITECO tool is much lower than the two other tools. This is due to the fact that the MITECO tool does not consider emissions from vessels in scope 1 and does not include scope 3 emissions. The results of scope 1 obtained by the new tool and the OCCC tool are very similar. The results of scope 1 in the MITECO tool are lower because emissions from port owned vessels are not considered in this tool. The result of scope 2 in the new tool and OCCC tool are the same. Scope 2 emissions calculated by the MITECO tool are lower than with the two other tools. The difference, as explained before, is due to different emission factors. Concerning scope 3, the results obtained by the new tool and OCCC tool are very similar. The slight difference is mainly related to the different emissions factors. Emissions of this scope are not taken into account in the MITECO tool.

To conclude, a paper of the results of this chapter was accepted to present at the 17th International Conference on Environmental Science and Technology in Athens in Greece (Azarkamand et al., 2021) (September 2021).

# 6. Conclusions

Climate Change is gaining more importance every day in the maritime sector and particularly in port areas, which contribute with their daily activities to Green House Gases (GHG) emissions. Due to the foreseen increase of the maritime trade and transportation, it is expected that GHG emissions from ports will rise in the future with consequences such as the increase in air and water temperature, and the rise in the sea level. Therefore, it is important for ports to calculate, report and control their Climate Change impacts. An indicator that can be used for this purpose is the Carbon Footprint which measures the potential contribution of human activities, including ports, to Climate Change.

In this thesis, a review on global initiatives undertaken on Climate Change and Carbon Footprint has been conducted. Based on this research, many international organizations have been working to control Climate Change and Carbon Footprint for more than 40 years. For example, in 1979 the first World Climate Conference was held in Geneva, being the first major international meeting on Climate Change. Another important initiative was the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The aim of this convention was to stabilize GHG concentrations in the atmosphere. Besides in 1997 the Kyoto Protocol developed an action to limit GHG emissions by at least 5% below 1990 levels in the commitment period from 2008 to 2012.The most recent and the most important initiative is the Paris Agreement (2015) which recognized Climate Change as an urgent threat and set the mitigation goal of limiting the global temperature increase up to 2 °C and ideally up to 1.5°C.

It should be mentioned that as a consequence of these global initiatives some guidelines to calculate GHG emissions were developed. For example, in 1995 the Intergovernmental Panel on Climate Change (IPCC) published set of guidelines for the National GHG Inventories, which have been updated on a regular basis. In 1998 the GHG Protocol was created and one of its tasks was the creation of the guidance documents to calculate GHG emissions. In addition, the International Organization for Standard (ISO) developed the standard ISO 14064 which contains principles and requirements for designing, developing, managing and reporting organization or company level GHG inventories.

A part from these global initiatives, this thesis has also researched specific initiatives on Climate Change and Carbon Footprint for the Maritime Sector. For example, in 2008 the International Maritime Organization (IMO) published a package for reducing shipping's $CO_2$ and in 2019 PIANC developed Carbon Management packages for Ports and Navigation Infrastructures. More recently in 2020, PIANC Working Group 178 prepared a technical guidance document to help the owners, operators and users of waterborne transport infrastructure to adapt to Climate Change. Last year as well, the European Sea Ports Organisation (ESPO) published its position paper on the European Green Deal in which. ESPO stated that by 2030, $CO_2$ emissions from ships at berth and in ports should be reduced by 50% on average and across all segments of shipping.

Again in this case, some of these initiatives ended up with developing guidelines to calculate GHG emissions. In 2010, the World Ports Climate Initiative (WPCI) which was developed by the International Association of Ports and Harbors (IAPH) published a guidance document which is a resource guide for ports wanting to develop or improve their GHG emissions inventories. In addition, in 2015, the Clean Cargo Working Group (CCWG) also developed tools and methods to calculate the $CO_2$ footprint for a single shipment or a total transportation company.

Both types of guidelines to calculate GHG emissions, general and specific for the maritime sector, were analyzed in depth in order to understand the calculations and the required inputs. From them, those that were considered the most relevant ones are WPCI, IPCC and GHG protocol. It should be mentioned, WPCI is the only existing guideline for calculating Carbon Footprint in ports and IPCC and GHG protocol are the most updated and the most complete reference to calculate GHG emissions. In addition, UNFCCC COP3 held in 1997 in Kyoto, reaffirmed the relevance of the IPCC guidelines for National GHG Inventories calculation.

All the previous research was literature based, and one of the objectives of this thesis was to conduct a practical research on the topic. For this reason, a survey was prepared and presented in the Valencia Greenport Congress on 17th and 18th October 2018. Responses from 55 different port actors that replied the questionnaire were obtained. The results were analyzed and were compared with the annual ESPO environmental report to have a better understanding of the situation of Carbon Footprint in ports. Based on the results of Congress survey, most of the ports believed that Climate Change has an impact on their organization but few of them monitored it and had associated Environmental performance indicators to control it. Half of the ports collected data on Climate Change, and also, more than a half of the cases reported their carbon emissions. Data collection, Measuring and calculating data, and Coordination among stakeholders were the most important challenges in implementing a carbon management program. Most of the respondents considered that GHG emissions from shipping generated in the port area should be included as third-party emission in the Carbon Footprint of the port. Based on the results of this practical research, Climate Change occupied the sixth position among the top 10 environmental priorities in ports. In addition, most of the participants considered that a common, port-sector Carbon Footprint scheme would benefit individual port authorities and the port-sector as a whole. The development of a practicable, user-friendly and easy to use tool with a standardized method for the calculation of Carbon Footprint in ports was highly demanded. The results of this conference were the main motivation to accomplish the main objective of this thesis: to develop a standard tool for the Carbon Footprint calculation in ports.

At this stage, it was believed necessary to research on the existing methodologies on Carbon Footprint used in the maritime sector. Detailed information on the methodologies used by15 ports, 3 port terminals and 4 ships were found and studied in depth. In this regard, the technique used to calculate GHG emissions for each case, the boundaries and scopes set up, and the results obtained were analyzed. A set of conclusions about their main strengths and opportunities for further enhancement was extracted. As main strengths, it could be highlighted the fact that in most of the methodologies, ships' emissions were taken into account and also that more than half of the cases all GHG emissions were calculated. In addition, in more than half of the cases, the calculation was done based on standard methods such as the GHG Protocol, IPCC and ISO 14064. On the other hand, the fact that in most of the studies, all the emission sources (direct and indirect) mentioned in the standard guidelines were not calculated could be an opportunity for further development. Moreover, in most of the cases, emissions from waste operations such as incinerators or wastewater treatment plants were not included in the calculation and scopes were not defined based on the standard methods. Other weaknesses are the fact that in around 70% of the cases, emissions from employees' commuting were not included and in around 60% of the studies, the whole set of scope 3 emissions were not calculated. In addition, in 60% of the researches where a tool was developed, the access to this tool was not possible. In more than half of the cases, the methodology was not fully described and an estimation was used for the calculation and not real data. As a conclusion of this research, it can be stated that in recent years many ports have started to calculate their Carbon Footprint and reported it. However, each port uses its own method and there is no single or unified method to calculate the carbon footprint in ports. Although there exist some strengths in the existing methodologies, there are also several aspects that can be improved.

Bearing in mind all this, a new standardized tool was developed. This new tool tried to overcame all the mentioned weaknesses and it included all the strengths. The development of the tool was done based on the GHG Protocol, IPCC and WPCI guidelines to make the sourcing more complete. As mentioned before, after the research conducted in this thesis, these guidelines were considered to be the most suitable ones for the Carbon footprint calculation. The tool was created using an Excel software and visual basic.

In the new tool, the three scopes and all the direct and indirect emission sources present in the WPCI guidelines were taken into account. Pollutants were chosen also based on the WPCI guidance document. The most common GHGs associated with port-related operations, which are Carbon dioxide ($CO_2$), Methane ($CH_4$) and Nitrous oxide ($N_2O$), were included in this tool. In addition, in this new tool, the most updated emission factors were used. In order to choose formulae, among the different guidelines and methodologies presented, the IPCC guidelines and GHG protocol were selected. After defining the scopes and choosing all the formulae, the tool was developed.

Once the first version of the tool was available, it was firstly tested by a group of students in class. With their comments it was firstly improved. Then, it was sent to 20 experts including environmental port managers, environmental experts and port professionals all around the world. They were contacted through personal visits, telephone calls or via email. The tool was presented to them and suggestions and comments were obtained. Most of them were implemented in the tool through different amendments. For example, a clarification was introduced specifying that the user could proceed with the tool without completing all sections if they were not applicable or data was not available. Other suggestions were to provide an option to add the value of electricity emission factor manually in scope 2 (if the port has its own value), to specify that tenants should only provide data inside the port area or to add "Biogasoline" and "Biodiesels" as a fuel type for the on road vehicles. Those comments that were not implemented were justified accordingly.

Finally, an updated version of the tool was developed and validated with the existing results of the Port of Oslo and Ports de la Generalitat. The results of the port of Oslo were almost the same as the results of the new tool. Scope 1 emissions calculated by both tools had minor differences and they were due to the usage of different calculation methods. The total emissions of scope 2 calculated by the port of Oslo and by the new tool were exactly the same. Concerning scope 3, only emissions from employees' commuting were calculated in this case study and there was a minor difference between the results. This difference can be explained by the different calculation methods. In the port of Oslo study, the emissions were calculated based on the fuel consumption and travel distance. In the new tool, according to the availability of data, the fuel-based method was used.

In the case of Ports de la Generalitat, the existing results were almost the same as the ones of the new tool and the reasons for the minor differences were due to the usage of different calculation methods. In addition, in this case study, in scope 1 only emissions from on-road vehicles were taken into account and in scope 3 only emissions from water consumption were calculated which is not suggested by any standard guidelines.

Since in the previous case studies, all the scopes and all the emission sources recommended by WPCI and IPCC guidelines and GHG Protocol were not taken into account, a case study model was created. For example, ocean going vessels and waste incineration plants emissions were not included in the previous case studies. This case study was developed to test all the functionalities of the tool

This port is called Bandare-Bid port and it is assumed that is located in Iran. It includes 5 terminals including one container terminal, one fishing terminal, one dry bulk terminal, one liquid bulk cargoes terminal and a cruise terminal. In addition, it has an organic chemical industry, a wastewater treatment plant, a waste incineration plant and a power plant which are managed by tenants. The GHG emissions of this port were calculated by the new tool, the Catalan Office for Climate Change (OCCC) tool and Ecological Transition Ministry (MITECO) tool.

The emission values obtained by three tools were compared to validate the results. The total emissions obtained with the new tool and the OCCC tool were very similar. The results from MITECO were quite different because in this tool scope 3 was not taken into account. Concerning scope 1, the results obtained by the new tool and the OCCC tool were very similar and the results of the MITECO were lower because emissions from port owned vessels are not calculated in this tool.

The result of scope 2 in the new tool and OCCC tool was exactly the same due to the use of the Iranian emission factor for the electricity. In the MITECO tool, there is a default amount for Spain and for this reason, the result of the MITECO tool was lower since the electricity emission factor in Spain is less than in Iran. Concerning scope 3, emissions of this scope are excluded from the MITECO tool. The results obtained by the new tool and OCCC tool were very similar. The slight difference is mainly related to the different emissions factors.

To conclude, the aim of the thesis has been accomplished, a standard tool for calculating the greenhouse emissions and Carbon Footprint in ports was created. This tool can be used by all type of port authorities and port tenants around the world. It includes the three scopes and all the possible emission sources that a port terminal may have. This is an important difference with the rest of the tools as well as the fact that is free of use.

The tool provides options to select the scopes that are more suitable and applicable to each port. In addition, it allows for normalizing (standardize to a common ground) the total annual emissions in terms of total tonnes of cargo handled or annual TEUsto be able to compare of the results of different ports standardizing to a common ground.

The tool includes guidelines and a video tutorial which facilitates using the tool and helps the user to fill the tool step by step. The tool, the guidelines and the video can be downloaded from http://eports.cat/carboonfootprint. The user can obtain the results of three scopes and the total GHG emissions and save it as a pdf file.

This tool assists the Ports to monitor the activities that are sources of GHG emissions and helps them to recognize those with more emissions. Then they may develop strategies to reduce emissions, optimize efficiency and provide environmental, financial and social benefits to the entire port community. This will help the port to achieve its sustainable development goals. By calculating the GHG emissions and developing programs and strategies to reduce emissions, ports will be able to act more sustainably.

## References

Air Resources Board of California. California environmental protection agency. (2006). Diesel particular matter exposure assessment study for the ports of Los Angeles and Long Beach. Retrieved from https://pdfs.semanticscholar.org/d801/f3340bb6cbba66d64392d518745b783c62e0.pdf?_ga=2.264227532.1524048418.1568714657-35665948.1568714657 (Accessed 17/09/2019)

Akerman, j. and Hojer, m. (2006). How much transport can the climate stand ?— Sweden on a sustainable path in 2050. Energy Policy, 34, 1944–1957. https://doi.org/10.1016/j.enpol.2005.02.009

Alvarez, S. (2014). Huella de carbon de organizacion y producto con enfoque hibrido: Mejores en el metodo compuesto de las cuentas conTables. Universidad Politecnica de Madrid.Ph.D Thesis.

ASCENT. (2018). California Environmental Quality Act (CEQA) and Climate Action Planning. Retrieved from https://www.sandag.org/uploads/cap/ReCAPTAV.pdf (Accessed 27/09/2019)

Association of European Vehicle Logistics. (2011). Standard Shipping Terms. Retrieved from http://ecgassociation.eu/Portals/0/Documentation/Maritime & Ports/ShippingTerms/Standard Shipping Terms Sept 2011 Version 1.pdf (Accessed 12/10/2019)

Azarkamand, S., Balbaa, A., Wooldridge, Ch., Darbra, R.M. (2020a). Climate Change—Challenges and Response Options for the Port Sector. Sustainability Journal. 2020, 12 (17), 6941; https://doi.org/10.3390/su12176941

Azarkamand, S., Wooldridge, Ch., and R. M. Darbra. (2020b). Review of initiatives and methodologies to reduce CO2 emissions and Climate Change effects in ports. International Journal of Environmental Research and Public Health. doi:10.3390/ijerph17113858

Azarkamand, S., Ferré, G., and R. M. Darbra. (2020c). Calculating the Carbon Footprint in ports by using a standardized tool. Science of the Total Environment (STOTEN 139407).. doi:10.3390/ijerph17113858

Azarkamand, S., Ferré, G., and R. M. Darbra. (2020d). Development of a standardized tool to calculate Carbon Footprint in ports. 8th international conference on Maritime Transport, Barcelona, Spain.

Azarkamand, S., Ferré, G., and R. M. Darbra. (2021). Calculating Carbon Footprint in ports through a new Standard Tool: case study applications. 17th International Conference on Environmental Science and Technology. Athens, Greece, September 2021.

BASS. (2020). Climate Change and the Maritime industry: Moving forward. Retrieved from https://bassnet.no/wp-content/uploads/2020/04/Q1-White-Paper-Climate-Change-the-Maritime-Industry.pdf (Accessed 28/01/2021)

Bazan, G. (1997). Our Ecological Footprint - Reducing Human Impact on the Earth. Reviewed by Gene Bazan. Electronic Green Journal, 1–3. Retrieved from https://escholarship.org/content/qt7730w81q/qt7730w81q.pdf (Accessed 01/07/2019)

Becker, A., Inoue, S., Fischer, M., Schwegler, B., Becker, A., Inoue, S., & Fischer, M. (2011). Climate Change Impacts and Adaptation: A challenge for Global Ports. Clamatic Change. https://doi.org/10.1007/s10584-011-0043-7

BPO. (2019). Collaboration – maritime industry’s path to 2030. Retrieved from http://www.bpoports.com/collaboration-–-maritime-industry’s-path-to-2030.html (Accessed 06/04/2019)

Brinkman, N., Wang, M., Weber, T., & Darlington, T. (2005). Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems, A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions. Retrieved from https://greet.es.anl.gov/files/4mz3q5dw (Accessed 13/09/2019)

Carballo-penela, A., Mateo-mantecón, I., & Doménech, J. L. (2012). From the motorways of the sea to the green corridors ’ Carbon Footprint : The case of a port in Spain. https://doi.org/10.1080/09640568.2011.627422

Carbon Footprint. (2019). Carbon Footprint, Country specific Electricity Factors. 1–10. Retrieved from https://www.carbonfootprint.com/docs/2019_06_emissions_factors_sources_for_2019_electricity.pdf (Accessed 10/02/2020

Carbon Trust. (2017). Carbon Footprinting. Retrieved from https://www.carbontrust.com/resources/carbon-footprinting-guide (Accessed 19.02.2020)

CCWG (Clean Cargo Working Group). (2015). Clean Cargo Working Group Carbon Emissions Accounting Methodology. (June). Retrieved from https://www.bsr.org/reports/BSR_CCWG_Carbon_Emissions_Methodology_2015.pdf (Accessed 08.04.2019)

CCWG (Clean Cargo Working Group). (2020). 2019 Global Container Shipping Trade Lane Emissions Factors. Retrieved from https://static1.squarespace.com/static/5b3f37f489c17230345b5f15/t/5f46109c14efc67813f2bca8/1598427336870/BSR-Clean-Cargo-Emissions-Report-2020.pdf (Accessed 01.02.2021)

Chang, Y., Song, Y., & Roh, Y. (2013). Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon. Transportation Research Part D, 25, 1–4. https://doi.org/10.1016/j.trd.2013.06.008

Chao, Q., & Feng, A. (2018). Scientific basis of Climate Change and its response. Global Energy Interconnection, 1(4), 420–427. https://doi.org/10.14171/j.2096-5117.gei.2018.04.002

Chowhan, S., Hiremath, A. M., & Asolekar, S. R. (2012). Carbon Footprinting of Container Terminal Ports in Mumbai. Retrieved from https://www.researchgate.net/publication/269702576_Carbon_Footprinting_of_Container_Terminal_Ports_in_Mumbai (Accessed 12.09.2019)

Climate Action Tracker. (2020. Paris Agreement turning point Wave of net zero targets reduces warming estimate to 2.1˚C in 2100 All eyes on 2030 targets. Retrieved from https://climateactiontracker.org/documents/829/CAT_2020-12-01_Briefing_GlobalUpdate_Paris5Years_Dec2020.pdf (Accessed 28.01.2021)

Congressional research service. (2019). Vehicle Fuel Economy and Greenhouse Gas Standards : Frequently Asked Questions. Retrieved from https://fas.org/sgp/crs/misc/R45204.pdf (Accessed 10.09.2019)

Cooper, D., & Gustafsson, T. (2004). Methodology for calculating emissions from ships : 2 . Emission factors for 2004 reporting. (5), 1–11. Retrieved from http://www.diva-portal.org/smash/get/diva2:1117169/FULLTEXT01.pdf (Accessed 30.09.2019)

Department of Ecology State of Washington. (2017). Washington State Agency Greenhouse Gas Reporting and Calculator Instructions. Retrieved from https://ecology.wa.gov/DOE/files/0b/0b06814a-e3fc-43b2-858c-ddb3dfa26a3f.pdf (Accessed 18.09.2019)

Dube TradePort. (2016). Carbon Footprint Analysis Report 2015. 27. Retrieved from https://www.dubetradeport.co.za/SiteFiles/101421/DTPC Carbon Footprint Analysis 2015.pdf (Accessed 08.04.2019)

Ecofys. (2006). The gold standard, Voluntary Emission Reductions. Retrieved from https://www.goldstandard.org/sites/default/files/documents/developermanual_gs-ver_v.1.pdf (Accessed 08.04.2019)

El National. (2019). Les deu claus de l'acord de la Cimera del Clima de Madrid. Retrieved from https://www.elnacional.cat/ca/societat/claus-acords-cimera-clima-2019_451737_102.html (Accessed 10/02/2020)

EPA (United States Environmental Protection Agency). (1995). Organic Chemical Industry, Sector Notebook Project Retrieved from https://clu-in.org/download/toolkit/organic.pdf (Accessed 04.02.2021)

EPA (United States Environmental Protection Agency). (1997). Technical Highlights, Emission Factors for Locomotives. 2–6. Retrieved from https://nepis.epa.gov/Exe/ZyPDF.cgi/P1001Z8C.PDF?Dockey=P1001Z8C.PDF (Accessed 09.09.2019)

EPA (United States Environmental Protection Agency). (2018). Greenhouse Gas Inventory Guidance. 3–5. Retrieved from https://www.epa.gov/climateleadership/center-corporate-climate-leadership-greenhouse-gas-inventory-guidance (Accessed 15.10.2019)

EPA (United States Environmental Protection Agency). (2021). Basic Information of Air Emissions Factors and Quantification. Retrieved fromhttps://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification#About%20Emissions%20Factors(Accessed 05.06.2021)

Erik, P. et al. (2021). 10 New Insights in Climate Science 2020 - a Horizon Scan. Global Sustainability. DOI: 10.1017/sus.2021.2

ESPO (European Sea Ports Organisation). (2018). Environmnetal Report 2018 EcoPortsinSights 2018. Retrieved from https://www.espo.be/media/ESPO Environmental Report 2018.pdf (Accessed26.12.2018)

ESPO (European Sea Ports Organisation). (2019). Environmnetal report 2019 EcoPortsinSights 2019. ESPO, 1–23. Retrieved from https://www.espo.be/media/Environmental Report-2019 FINAL.pdf (Accessed 21.10.2019)

ESPO (European Sea Ports Organisation). (2020 a). Environmnetal report 2020 EcoPortsinSights 2020. ESPO. Retrieved from https://www.espo.be/media/Environmental%20Report-WEB-FINAL.pdf (Accessed 16.11.2020)

ESPO (European Sea Ports Organisation). (2020b). ESPO ' s Roadmap to implement the European Green Deal objectives in ports. Retrieved from https://www.espo.be/media/ESPO Green Deal position paper Green Deal-FINAL.pdf (Accessed 20.02.2020)

Forster, P. M., Forster, H. I., Evans, M. J., Gidden, M. J., Jones, C. D., Keller, C. A., Lamboll, R. D., Le Quéré, C. , Rogelj, J., Rosen, D., Schleussner, C.-F., Richardson, T. B., Smith, C. J., & Turnock, S. T. (2020). Current and future global climate impacts resulting from COVID-19. Nature Climate Change, 10, 913–919. https://doi.org/10.1038/s41558-020-0883-0

Gilbert, P., Manchester, T., Starkey, R., & Manchester, T. (2010). Shipping and Climate Change : Scope for unilateral action. Retrieved from http://shippingefficiency.org/sites/shippingefficiency.org/files/Tyndall.pdf (Accessed 05.03.2019)

Greenport. (2019). cooperation on climate action. Retrieved from https://www.greenport.com/news101/europe/cooperation-on-climate-action (Accessed 27.01.2020)

GreenPort., (2019b). Balancing Environmental Challenges with economics demands.Reports on an emissions survey undertaken at GreenPort Congress GreenPort Journal. Issue Summer, p. 15.

GRI (Global Reporting Initiatives). (2013). Sustainability Reporting Guidelines (G4). Retrieved from https://www.globalreporting.org/resourcelibrary/GRIG4-Part2-Implementation-Manual.pdf (Accessed 14.10.2019)

GRI (Global Reporting Initiatives). (2019). A Closer Look at Water and GHG Emissions Disclosure Mapping Reporting Practice to an Investor Perspective. Retrieved from https://www.globalreporting.org/resourcelibrary/A-Closer-Look-At-Water-and-GHG-Emissions-Disclosure.pdf (Accessed 14.10.2019)

Guillem Ferré Domènech. (2020). Desenvolupament d ' una Eina per Calcular les Emissions de Gasos d ' Efecte Hivernacle en Ports Marítims. Universitat Politècnica de Catalunya.

Hero, N. (2014). Wastewater Treatment in Harbors, Thesis to obtain the Master of Science Degree in Civil Engineering, University Tecnico Lisbo, Retrieved from https://fenix.tecnico.ulisboa.pt/downloadFile/395146461780/Extended%20abstract-Neva%20Hero.pdf (Accessed 15.06.2020)

Hooven, C., Hirsch, J., White, M., Daugherty, D., Moran, L., Kim, D., White, M. (2011). Ad Hoc Expert Meeting on Climate Change Impacts and Adaptation : A Challenge for Global Ports Port of San Diego Climate Mitigation and Adaptation Plan By Port of San Diego Climate Mitigation and Adaption Plan. Retrieved from https://unctad.org/sections/wcmu/docs/AHM2011_2_22_Hooven_en.pdf (Accessed 26.04.2019)

IAPH (International Association of Ports and Harbors). (2010). IAPH Tool Box for Port Clean Air Programs. Retrieved from http://iaphtoolbox.wpci.nl/DRAFT IAPH TOOL BOX dea.pdf (Accessed 16.03.2019)

ICAO (International Civil Aviation Organization). 2016. ICAO Carbon Emissions Calculator Methodology ,Version 9. Retrieved fromhttps://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology_ICAO_Carbon_Calculator_v9_2016.pdf (Accessed 08.12.2020)

IMO (International Maritime Organization). (2009). Guidelines for voluntary use of the ship energy efficiency operational indicator (EEOI). Retrieved from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Resolution MEPC.304(72)_E.pdf (Accessed 05.04.2019)

IMO (International Maritime Organization). (2014). Third IMO Greenhouse Gas Study 2014. Retrieved from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Third Greenhouse Gas Study/GHG3 Executive Summary and Report.pdf (Accessed 16.03.2019).

IMO (International Maritime Organization). (2018). Initial IMO strategy on reduction of GHG emissions from ships (IMO). 304(April), 1–11. Retrieved from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Resolution MEPC.304(72)_E.pdf (Accessed 05.04.2019)

IMO (International Maritime Organization). (2019). Air Pollution, Energy Efficiency and Greenhouse Gas Emissions. Retrieved from http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Default.aspx (Accessed 05.04.2019)

IMO (International Maritime Organization). (2021). Reducing greenhouse gas emissions from ships. Retrieved from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx (Accessed 28.01.2021)

International Emissions Trading Association. (2014). The Global Warming Solutions ACT : Assembly Bill 32. 2020(2014), 2020. Retrieved from https://www.ieta.org/resources/Resources/101s/gwsa-assembly-bill-32-sept2014.pdf (Accessed 09.10.2019)

IPCC (Intergovernmental Panel on Climate Change). (2003). Revision of the "Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovermentall Panel On Climate Change National Greenhouse Gas Inventories Programme. Retrieved from https://www.ipcc-nggip.iges.or.jp/meeting/pdfiles/2006GLs_scoping_meeting_report_final.pdf (Accessed 23/10/2019)

IPCC (Intergovernmental Panel on Climate Change). (2006). 2006 IPCC guidelines for National Greenhouse Gas Inventories. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2006gls_all_in.zip (Accessed 18/09/2019)

IPCC (Intergovernmental Panel on Climate Change). (2015a). Climate Change Synthesis Report. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf (Accessed 06.03.2019)

IPCC (Intergovernmental Panel on Climate Change). (2015b). IPCC Factsheet : Timeline – highlights of IPCC history. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/04/FS_timeline.pdf (Accessed 07/06/2019)

IPCC (Intergovernmental Panel on Climate Change). (2019a). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Vegetatio, Vol. 54. Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/2019rf_all_in.zip (Accessed 19/11/2019)

IPCC (Intergovernmental Panel on Climate Change). (2019b). About IPCC. 1–5. Retrieved from https://www.ipcc.ch/about/ (Accessed 14/10/2019)

IPCC (Intergovernmental Panel on Climate Change). (2020). The IPCC and the Sixth Assessment cycle. Retrieved from https://www.ipcc.ch/site/assets/uploads/2020/05/2020-AC6_en.pdf (Accessed 28/01/2021)

IPIECA (International Petroleum Industry Environmental Conservation Association). (2011). Petroleum Industry Guidelines for Reporting Greenhouse Gas Emissions. Retrieved from https://www.api.org/~/media/Files/EHS/climate-change/GHG_industry-guidelines-IPIECA.pdf (Accessed 19/07/2019)

ISO (International Organization for Standard). (2006). ISO 14064-1 first edition, Greenhouse Gases, Part1 specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. 2006. Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:14064:-1:ed-1:v1:en (Accessed 15/07/2019)

ISO (International Organization for Standard). (2018). ISO 14064-1 second edition, Greenhouse Gases, Part1 specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. 2018. Retrieved from https://www.iso.org/obp/ui/#iso:std:iso:14064:-1:ed-2:v1:en (Accessed 15/07/2019)

Joos, F., & Spahni, R. (2007). Rates of change in natural and anthropogenic radioactive forcing over the past 20,000 years. Proceedings of the National Academy of Sciences, 0–5.

Karl, T., Melillo, J. M., & Peterson, T. C. (2009). Global Climate Change impacts in the United States: A state of knowledge report from the U.S. Global change research program. Retrieved from http://www.iooc.us/wp-content/uploads/2010/09/Global-Climate-Change-Impacts-in-the-United-States.pdf (Accessed 22.03.2019)

Koroneos, C. Ã., & Nanaki, E. (2007). Environmental assessment of the Greek transport sector. Energy Policy, 35, 5422–5432. https://doi.org/10.1016/j.enpol.2007.05.005

KPMG (KPMG's Climate Change& Sustainability Services). (2013). GRI's G4 Guidelines: the impact on reporting. 1–7. Retrieved from https://assets.kpmg/content/dam/kpmg/pdf/2013/06/g4-the-impact-on-reporting-v2.pdf (Accessed 15.10.2019)

Laboratorio de ingeniería sostenible. (2004). 9 Years of Carbon Footprint in a Spanish Port. 1–2. Retrieved from http://www.lis.edu.es/uploads/06a2431c_85a6_4952_a7da_f4a90e3309b5.pdf (Accessed 20.11.2018)

López-Aparicio, S., Tønnesen, D., Thanh, T., Neilson, H. (2017). Shipping emissions in a Nordic port: Assessment of mitigation strategies. Transportation Research Part D 53 (2017) 205–216. http://dx.doi.org/10.1016/j.trd.2017.04.021

MED (Europe in Mediterranean). (2011). Methodology Assessment Handbook, CLIMEPORT Project. Program co financed by the European Regional Development Fund. Retrieved from https://www.programmemed.eu/uploads/tx_ausybibliomed/CLIMEPORT_2_Component_3_-_Executive_Report_EN.pdf (Accessed 11.10.2019)

MED (Europe in Mediterranean). (2012a). ABACUS, A port area energy consumption and C02 footprint calculation tool. Retrieved from https://www.programmemed.eu/uploads/tx_ausybibliomed/CLIMEPORT_7_ECO_ABACUS_User_manual_EN.pdf (Accessed 11.10.2019)

MED (Europe in Mediterranean). (2012b). Methodology Assessment Handbook, CLIMEPORT Project. Retrieved from https://www.programmemed.eu/uploads/tx_ausybibliomed/CLIMEPORT_1_Methodology_Assessment_Handbook_EN.pdf (Accessed 08.04.2019)

Misra, A., Panchabikesan, K., Gowrishankar, S. K., Ayyasamy, E., & Ramalingam, V. (2017). GHG emission accounting and mitigation strategies to reduce the Carbon Footprint in conventional port activities – a case of the Port of Chennai. 3004. https://doi.org/10.1080/17583004.2016.1275815

MITECO (Ministerio para la Transición Ecológica). (2019). Calculadora de huella de carbono de una organización. Alcance 1+2. 1–21. Retrieved from https://www.miteco.gob.es/es/cambio-climatico/temas/mitigacion-politicas-y-medidas/calculadoras.aspx (Accessed 17.02.2020)

NACCA (National Association of Clean Air Agencies). (2013). Background and History of EPA Regulation of Greenhouse Gas (GHG) Emissions Under the Clean Air Act & National Association of Clean Air Agencies' Comments on EPA GHG Regulatory and Policy Proposals. Retrieved from http://4cleanair.org/Documents/Background_and_History_ EPA_Regulation_GHGs-Aug2013-post.pdf (Accessed 11.04.2019)

NOAA and ESRL (National Oceanic & Atmospheric Administration and Earth System Research Laboratory). (2019). Trends in atmospheric carbon dioxide. Retrieved from https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html (Accessed 08.04.2019)

Noorpoor, A.R., Nazari Kudahi, s. (20015). $CO_2$ emissions from Iran's power sector and analysis of the influencing factors using the stochastic impacts by regression on population, affluence and technology (STIRPAT) model. Carbon Management. Volume 6, Issue 3-4 https://doi.org/10.1080/17583004.2015.1090317

OCCC (Catalan Office for Climate Change). (2019). Practical guide for calculate Greenhose Gas (GHG) emissions.

0–125. Retrieved from https://canviclimatic.gencat.cat/web/.content/04_ACTUA/Com_calcular_emissions_GEH/guia_de_calcul_de missions_de_co2/190301_Practical-guide-calculating-GHG-emissions_OCCC.pdf (Accessed 05/02/2020)

Olmer, N., Comer, B., Roy, B., Mao, X., & Rutherford, D. A. N. (2017). Greenhouse Gas emissions from global shipping. 2013–2015. Retrieved from https://theicct.org/sites/default/files/publications/Global-shipping-GHG-emissions-2013-2015_ICCT-Report_17102017_vF.pdf (Accessed 10/04/2019)

Olukanni, D. O., & Esu, C. O. (2018). Estimating greenhouse gas emissions from port vessel operations at the Lagos and Tin Can ports of Nigeria. Cogent Engineering, 5(1), 1–9. https://doi.org/10.1080/23311916.2018.1507267

Peters, G. P. (2010). Carbon Footprints and embodied carbon at multiple scales. Current Opinion in Environmental Sustainability, 2(4), 245–250. https://doi.org/10.1016/j.cosust.2010.05.004

PIANC (World Association for Waterborne Transport Infrastructure). (2014). Sustainable Ports'A Guide for Port Authorities. Retrieved from https://sustainableworldports.org/wp-content/uploads/EnviCom-WG-150-FINAL-VERSION.pdf (Accessed 09/04/2019)

PIANC (World Association for Waterborne Transport Infrastructure). (2019a). EnviCom 188: Carbon Management for Port and Navigation Infrastructure. Journal of Chemical Information and Modeling, 53(9), 1689–1699. Retrieved from https://www.pianc.org/publications/envicom/wg188(Accessed 15/10/2019)

PIANC (World Association for Waterborne Transport Infrastructure). (2019b). Navigating a Changing Climate Partnership. Retrieved from https://navclimate.pianc.org/about/navigating-a-changing-climate-partnership (Accessed 12/11/2019)

PIANC (World Association for Waterborne Transport Infrastructure). (2020). Climate Change adaptation planning for ports and inland waterways, EnviCom WG Report n° 178. Retrieved from https://www.pianc.org/uploads/publications/reports/WG-178.pdf (Accessed 10/01/2020)

port of Barcelona. (2013). Climate strategy. 53(9), 1689–1699. Retrieved from http://www.portdebarcelona.cat/en/web/el-port/113 (Accessed 12/19/2019)

Port of Gothenburg. (2018). Sustainability Report of Gothenburg Port Authority 2018 Sustainable Port. Retrieved from https://www.portofgothenburg.com/FileDownload/?contentReferenceID=14781 (Accessed 11/04/2019)

port of Olympia. (2018). Port of Olympia 2017 GHG Emissions Inventory Report. (March). Retrieved from https://www.portolympia.com/DocumentCenter/View/3109/2017-Port-of-Olympia-GHG-Emissions-Inventory?bidId= (Accessed 26/04/2019)

Port of Oslo. (2008). $CO_2$ Emissions for the calendar year 2008 (Based on the ISO 14064 standard). Retrieved from http://www.renoslofjord.no/sfiles/52/50/5/file/co2-footprint-port-of-oslo-2008-1.pdf (Accessed 05/12/2018)

Port of Oslo website. (2020). Retrieved from https://www.oslohavn.no/en/menu/about-us/om-oslo-havn-kf/. (Accessed 15/11/2020)

Port of Rotterdam. (2017). Port of Rotterdam CO2 neutral. Retrieved from https://www.portofrotterdam.com/sites/default/files/port-of-rotterdam-co2-neutral.pdf (Accessed 06/09/2019)

Port of Rotterdam authority. (2013). CO 2 footprint Port of Rotterdam Authority. Retrieved from https://www.portofrotterdam.com/sites/default/files/downloads/co2_footprint_en_factsheet2017.pdf (Accessed 03/12/2018)

Port of San Diego. (2013). climate action plan. Retrieved from https://pantheonstorage.blob.core.windows.net/environment/Port-of-San-Diego-Climate-Action-Plan.pdf (Accessed 24/07/2019)

port of stockholm. (2017). Annual Report and Sustainability Report 2017. Retrieved from https://www.stockholmshamnar.se/siteassets/trycksaker/ports_of_stockholm_2017.pdf (Accessed 13/09/2019)

Ports de la Generalitat. (2018). DECLARACIÓ AMBIENTAL 2018. Retrieved from http://ports.gencat.cat/wp-content/uploads/2019/07/Declaracio_ambiental_2018_def.pdf (Accessed 06/02/2020)

Ports de la Generalitat website. (2020). Retrieved from https://ports.gencat.cat/presentacio-i-objectius/ (Accessed 15/11/2020)

Ports of Long Beach and Los Angeles. (2016). Clean Air Action Plan Technology Advancement Program. 2015 Annual Report. (November 2016). Retrieved from http://www.cleanairactionplan.org/wp-content/uploads/2016/11/CAAP-2017-Draft-Discussion-Document-FINAL.pdf (Accessed 08/04/2019)

POST. (2006). Carbon Footprint of electricity generation. (268). Retrieved from https://www.parliament.uk/documents/post/postpn268.pdf (Accessed 25/03/2019)

Puerto de Ferrol. (2017). Autoridad Portuaria de Ferrol San Cibrao. Memoria Anual 2016. Retrieved from https://www.apfsc.com/wp-content/uploads/2017/07/desempeno-ambiental_2016.pdf (Accessed 03/05/2020)

Puig, M. (2016). Methodology for the selection and implementation of environmental aspects and performance indicators in ports by Methodology for the selection and implementation of environmental aspects and by. Barcelona: Universitat Politècnica de Catalunya.

Quéré, C. Le, Andrew, R. M., Canadell, J. G., Sitch, S., Korsbakken, J. I., Peters, G. P., … Barbero, L. (2016). Global Carbon Budget. Earth System Science Data, 605–649. https://doi.org/10.5194/essd-8-605-2016

Sánchez-Arcilla, A., Mösso, C., Sierra, J.P., Mestres, M., Harzallah, A., Senouci, M., Raey, M. (2011). Climatic Drivers of Potential Hazards in Mediterranean Coasts. Environmental Change. Retrieved from https://doi.org/10.1007/s10113-010-0193-6(Accessed 06.04.2019)

Schmied, M. and Knörr, W. (2012). Calculating GHG emissions for freight forwarding and logistics services in accordance with EN 16258 – Terms , Methods , Examples – Calculating GHG emissions for freight forwarding and logistics services. 1–63. Retrieved from https://www.clecat.org/media/CLECAT_Guide_on_Calculating_GHG_emissions_for_freight_forwarding_and_logistics_services.pdf (Accessed 22.10.2019)

Scott H, McEvoy D, Chhetri P, Basic F, M. J. (2013). Climate Change adaptation guidelines for ports. https://doi.org/978-1-921609-83-1

Sprinz and Luterbacher. (1996). International Relations and Global Climate Change. Climate Policy. Retrieved from https://www.pik-potsdam.de/research/publications/pikreports/.files/pr21.pdf (Accessed 18.01.2019)

Starcrest Consulting group. (2019). San Pedro Bay Ports 1990 Greenhouse Gas Emissions Baseline Report. Retrieved from http://www.cleanairactionplan.org/documents/1990-greenhouse-gas-emissions-baseline-report.pdf/ (Accessed 09/08/2019)

Starcrest counsulting group. (2019). San Pedro Bay Ports Emissions Inventory Methodology Report. Retrieved from https://kentico.portoflosangeles.org/getmedia/3559520c-b85d-45ad-ad68-9947c34b980d/WV_FINAL_SPBP_Emissions_Inventory-_Methodology_4-25-19_scg (Accessed 09/08/2019)

The city of San Diego. (2015). Climate Action Plan. Retrieved from https://www.sandiego.gov/sites/default/files/final_december_2015_cap.pdf (Accessed 24/07/2019)

Tsai, Y. T., Liang, C. J., Huang, K. H., Hung, K. H., Jheng, C. W., & Liang, J. J. (2018). Self-management of greenhouse gas and air pollutant emissions in Taichung Port, Taiwan. Transportation Research Part D: Transport and Environment, 63(2015), 576–587. https://doi.org/10.1016/j.trd.2018.07.001

Tucher and Stirbu. (2018). Giurgiulesti International Free Port Report on Carbon Footprint 2017. (May). Retrieved from http://gifp.md/en/wp-content/files_mf/1529738875CarbonFootprintReport2018.pdf (Accessed 20/12/2018)

UNFCCC(United Nations Framework Convention on Climate Change). (1992). United Nations Framework Convention. Unfcc, 62220, 25. Retrieved from https://unfccc.int/resource/docs/convkp/conveng.pdf (Accessed 26/12/2018)

UNFCCC (United Nations Framework Convention on Climate Change). (2021). Glasgow Climate Change Conference (COP 26). Retrieved from https://unfccc.int/process-and-meetings/conferences/glasgow-climate-change-conference (Accessed 28/01/2021)

United Nations. (2015). Paris Agreement. Adoption of the Paris Agreement. Proposal by the President., 21932(December), 32. Retrieved from https://unfccc.int/sites/default/files/english_paris_agreement.pdf. (Accessed 26/12/2018)

UNFCCC (United Nations Framework Convention on Climate Change). (1998). Kyoto Protocol To the United Nations Framework Kyoto Protocol To the United Nations Framework. Review of European Community and International Environmental Law, 7, 214–217. Retrieved from https://unfccc.int/resource/docs/convkp/kpeng.pdf. (Accessed 26/12/2018)

United Nations Institute for Training and Research. (2015). Resource Guide for Advanced Learning on the Scientific Fundamentals of Climate Change. Retrieved from https://www.uncclearn.org/sites/default/files/guide_scientific_fundamentals.pdf (Accessed 01/04/2019)

Van Duin, J. H. R., & Geerlings, H. (2011). Estimating CO2 footprints of container terminal port-operations. International Journal of Sustainable Development and Planning, 6(4), 459–473. https://doi.org/10.2495/SDP-V6-N4-459-473

Wackernagel, M., Monfreda, C., Moran, D., Wermer, P., Goldfinger, S., Deumling, D., & Murray, M. (2005). National Footprint and Biocapacity Accounts 2005 : The underlying calculation method. 21(2004), 231–246. Retrieved from https://pdfs.semanticscholar.org/91bb/1ea1caaf0236ff724920656bbd7204dd2e4a.pdf (Accessed 08/04/2019)

Wiedmann, T., & Minx, J. (2008). A Definition of ‘ Carbon Footprint .’ Ecological Economics Research Trends, 1–11. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.467.6821&rep=rep1&type=pdf (Accessed 8/04/2019)

Williamson, T., Hulskotte, J., German, R., Kirsten, M. (2017). Port of London Emissions Inventory 2016 Report to Port of London Authority and Transport for London. (November). Retrieved from https://www.pla.co.uk/assets/finalplaportwideinventoryoutputsreportv10.2publication.pdf (Accessed 12/01/2019)

Winnes, H., Styhre, L., & Fridell, E. (2015). Research in Transportation Business & Management Reducing GHG emissions from ships in port areas. Research in Transportation Business & Management, 17, 73–82. https://doi.org/10.1016/j.rtbm.2015.10.008

worldportsource website. (2020). Retrieved from http://www.worldportsource.com/ports/maps/NOR_Port_of_Oslo_627.php (Accessed 15/11/2020)

WPCI (World Ports Climate Initiative). (2010). Carbon Footprinting for Ports, Guidance document. Retrieved from http://wpci.iaphworldports.org/data/docs/carbonfootprinting/PV_DRAFT_WPCI_Carbon_Footprinting_Guidance_Doc-June-30-2010_scg.pdf (Accessed 15/11/2018)

WPSP (World Ports Sustainability Program). (2018). World Ports Sustainability Program Chapter. Retrieved from https://sustainableworldports.org/wp-content/uploads/wpsp-declaration.pdf (Accessed 05/04/2019)

WPSP (World Ports Sustainability Program). (2020). World Ports Sustainability Report. Retrieved from https://sustainableworldports.org/wp-content/uploads/WORLD-PORTS-SUSTAINABILITY-REPORT-2020.pdf (Accessed 16/05/2020)

WRI and WBSCD (World Resources Institute and World Business Council for Sustainable Development). (2004). GHG protocol. Retrieved from https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf (Accessed 20/03/2019)

WRI and WBSCD (World Resources Institute and World Business Council for Sustainable Development). (2013). Technical Guidance for Calculate Scope 3 Emissions. (Scope 3), 1–182. Retrieved from https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf (Accessed 07/02/2020)

Wright, P. (2013). Impacts of Climate Change on ports and shipping. MCCIP Science Review 2013, 263–270. Retrieved from https://doi.org/10.14465/2013.arc28.263-270(Accessed 20/03/2019)

Yang, Y. C. (2017). Operating strategies of $CO_2$ reduction for a container terminal based on Carbon Footprint perspective. Journal of Cleaner Production, 141, 472–480. https://doi.org/10.1016/j.jclepro.2016.09.132

# Appendixes

## List of Appendixes:

# Appendix 1: Sample Questionnaire

**Greenport Congress, Valencia 2018 - Session 3 - YOU CAN'T MANAGE WHAT YOU CAN'T MEASURE**

**DELEGATE INPUT**

**Delegate's name** (Optional)**…………………………………Email (Optional)…………………………………………………**

**Organisation** (Optional)**………………………………………Job description**…………………………………………………

**NOTE:** All data and information received will be treated in strict confidence and reported anonymously. Your views and recommendations will be incorporated into the Summary Report to be produced as a conference deliverable. It would be helpful in the analysis to be aware of your job description, and should you be interested in follow-up research opportunities it would be most helpful to be able to contact you. Thank you for your cooperation.

In this Survey, the word **organisation*** refers to any of the following: Port Authority, Terminal Operator, Shipping Company, Maritime Logistics Support, or other port-related entity.

**1. What are the Top-5 priority Environmental priority issues/aspects in your Organisation*?**

| Priority | Issue/Aspect | Monitored? YES, or NO | Environmental Performance Indicator(s) selected? YES, or N0 |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

**2. Climate Change**

| | Issue | Yes, or No | Details/Example |
|---|---|---|---|
| a) | Is Climate Change impacting your organisation*? *(In terms of operations, functions, construction projects etc)* | | |
| b) | Has your organisation* prepared risk assessment specifically related to Climate Change? *(Detailed? Basic? Contingency? EIA?).* | | |
| c) | Is your organisation* collaborating with other, third-party, organisations on the issue of Climate Change? | | |
| d) | Is your organisation* collecting data/information on Climate Change? | | |
| e) | Is your organisation* using, or is it aware of, PIANC WG 178 Guidelines/Tool kit? | | |

### 3. Carbon Footprint Management

a) Does your organisation report on Carbon emissions? YES, or NO *(please circle)*

b) What are the main drivers to implement Carbon Management? – please prioritise in the following Table where 1= highest priority, 5 = lowest

| Drivers | Priority (allocate 1 -5) |
|---|---|
| • Compliance with emerging regulations | |
| • Stakeholder pressure to reduce environmental impacts | |
| • Leadership role in Carbon management practices | |
| • Potential to influence practice and regulation through innovation and investment | |
| • Opportunity to reduce and offset emissions from infrastructure development | |

c) Which stakeholders are the key players for development of a Carbon management programme in your organisation?

d) In your opinion, what are the major challenges and problems of developing and implementing a Carbon management program? What are your recommended best options?

**b**

**Carbon Footprint Scheme**

a) Do you consider that ports have a role to play in reducing Greenhouse Gas Emissions (GHG) from shipping? YES, or NO *(Please circle)*
b) Do you consider GHG emissions from shipping generated in the port area should be included as third-party emissions in Carbon Footprint of the port? YES, or NO *(Please circle).*
c) Do you consider that a common, port-sector Carbon Footprint Scheme would benefit individual Port Authorities and the Port-Sector as a whole? YES, or NO *(Please circle).*

On behalf of GreenPort Congress, thank you for your cooperation in contributing your experience, opinions and recommendations. The results will be analysed by independent academics with initial results being reported direct to the GreenPort Congress on Day 2, and a more detailed report communicated by GreenPort website and Journal in due course. As stated at beginning of this input template, full confidentiality of data origin will be observed.

# Appendix 2: Table of Strengths and Weaknesses

**Table1: The strengths of the existing methodologies (Percentages)**

| Case Study | | Inclusion of vessels ‘emissions | Consideration of all the GHG emissions | Using standard methods |
|---|---|---|---|---|
| Ports | The port of Gijón (Spain) | | | * |
| | The Ports of Long Beach and Los Angeles (USA) | | | |
| | The port of Oslo (Norway) | | | |
| | CLIMEPORT (Europe) | | | |
| | The port of San Diego (USA) | | | |
| | The Port of Rotterdam (Netherlands) | | | |
| | The port of Stockholm (Sweden) | | | |
| | The Port of Gothenburg (Sweden) | | | |
| | The Port of Barcelona (Spain) | | | |
| | Ports de la Generalitat (Spain) | | | |
| | The Port of Chennai (India) | | | |
| | The Port Authority of Ferrol–San Cibrao (Spain) | | | |
| | Giurgiulesti International free port (Moldavia) | | | |
| | Taichung Port (Taiwan) | | | |
| | The Port of Olympia (USA) | | | |
| Terminals | Mumbai- India | | | |
| | The Netherlands | | | |
| | Taiwan | | | |
| Ships | Korea | | | |
| | Gothenburg | | | |
| | England | | | |
| | Nigeria | | | |
| **Total** | | **72.7** | **63.6** | **59.1** |

***The grey cells in the table mean that the port has the strength and the white cells mean that the port does not have it.**

**Table2: The weaknesses of the existing methodologies (Percentages)**

| Case Study | | No inclusion of all the emission sources | No inclusion of the waste emissions | No inclusion of Employees' commuting | No classification of scopes based on the standards | Using estimates for the calculation and not real data | Exclusion of some of the recognized scopes or parts of them | No inclusion of scope 3 in the calculation | No access to the tool | Not present well description of the method |
|---|---|---|---|---|---|---|---|---|---|---|
| Ports | The port of Gijón (Spain) | * | | | | | | | | |
| | The Ports of Long Beach and Los Angeles (USA) | | | | | N.I.** | | | N.A. | |
| | The port of Oslo (Norway) | | | | | | | | | |
| | CLIMEPORT (Europe) | | | | | | | | | |
| | The port of San Diego (USA) | | | | | | | | | |
| | The Port of Rotterdam (Netherlands) | | | | | | | | | |
| | The port of Stockholm (Sweden) | | | | | | | | N.A | |
| | The Port of Gothenburg (Sweden) | | | | | | | | | |
| | The Port of Barcelona (Spain) | | | | | N.I. | | | | |
| | Ports de la Generalitat (Spain) | | | | | | | | Access to the tool | |
| | The Port of Chennai (India) | | | | | | | | N.A | |
| | The Port Authority of Ferrol–San Cibrao (Spain) | | | | | | | | Access to the tool | |
| | Giurgiulesti International free port (Moldavia) | | | | | Real data | | | N.A | |
| | Taichung Port (Taiwan) | | | | | | | | | |
| | The Port of Olympia (USA) | | | | | N.I. | | | | |
| Terminals | Mumbai- India | | | | | | | | | |
| | The Netherlands | | | | | | | | | |
| | Taiwan | | | | | | | | | |
| Ships | Korea | | | | | | | | N.A | |
| | Gothenburg | N.A*** | N.A. | N.A. | N.A. | N.I. | N.A. | N.A. | | |
| | England | | | | | | | | | |
| | Nigeria | | | | | | | | | |
| **Total** | | **94.4** | **77.7** | **72.2** | **72.2** | **66.6** | **66.6** | **61.1** | **60** | **59.1** |

*The grey cells in the table mean that the port has the weakness and the white cells mean that the port does not have it.
** There is No Information.
***Weaknesses are Not Applicable on the related cells.

# Appendix3: Fuel properties

Tables below are extracted from Greenhouse Protocol. (Emission Factors from Cross-Sector Tools, https://ghgprotocol.org/calculation-tools, march 2017).

## Table 1. CO2 emission factors by Fuel

| Fuel | | heating Value | $CO_2$ emission factors for fuel consumption data that have been supplied on different measurement bases | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Energy basis | Mass basis | Fuel density information[1] Of liquids (kg/litre fuel) | Of gases ($kg/m^3$ of fuel) | Liquid basis | Gas basis |
| | | TJ/Gg | kg/TJ | kg/tonne | | | kg/ litre | $kg/m^3$ |
| Oil products | Crude oil | 42,3 | 73300 | 3100,59 | 0,8 | | 2,480472 | |
| | Orimulsion | 27,5 | 77000 | 2117,5 | | | | |
| | Natural Gas Liquids | 44,2 | 64200 | 2837,64 | | | | |
| | Motor gasoline | 44,3 | 69300 | 3069,99 | 0,74 | | 2,2717926 | |
| | Aviation gasoline | 44,3 | 70000 | 3101 | 0,71 | | 2,20171 | |
| | Jet gasoline | 44,3 | 70000 | 3101 | 0,71 | | 2,20171 | |
| | Jet kerosene | 44,1 | 71500 | 3153,15 | 0,79 | | 2,4909885 | |
| | Other kerosene | 43,8 | 71900 | 3149,22 | 0,8 | | 2,519376 | |
| | Shale oil | 38,1 | 73300 | 2792,73 | 1 | | 2,79273 | |
| | Gas/Diesel oil | 43 | 74100 | 3186,3 | 0,84 | | 2,676492 | |
| | Residual fuel oil | 40,4 | 77400 | 3126,96 | 0,94 | | 2,9393424 | |
| | Liquified Petroleum Gases | 47,3 | 63100 | 2984,63 | 0,54 | | 1,6117002 | |
| | Ethane | 46,4 | 61600 | 2858,24 | | 1,3 | | 3,715712 |
| | Naphtha | 44,5 | 73300 | 3261,85 | 0,77 | | 2,5116245 | |
| | Bitumen | 40,2 | 80700 | 3244,14 | | | | |
| | Lubricants | 40,2 | 73300 | 2946,66 | 1 | | 2,94666 | |
| | Petroleum coke | 32,5 | 97500 | 3168,75 | | | | |
| | Refinery feedstocks | 43 | 73300 | 3151,9 | | | | |
| | Refinery gas | 49,5 | 57600 | 2851,2 | | | | |
| | Paraffin waxes | 40,2 | 73300 | 2946,66 | | | | |
| | White Spirit/SBP | 40,2 | 73300 | 2946,66 | | | | |
| | Other petroleum products | 40,2 | 73300 | 2946,66 | | | | |
| Coal products | Anthracite | 26,7 | 98300 | 2624,61 | | | | |
| | Coking coal | 28,2 | 94600 | 2667,72 | | | | |
| | Other bituminous coal | 25,8 | 94600 | 2440,68 | | | | |
| | Sub bituminous coal | 18,9 | 96100 | 1816,29 | | | | |
| | Lignite | 11,9 | 101000 | 1201,9 | | | | |
| | Oil shale and tar sands | 8,9 | 107000 | 952,3 | | | | |
| | Brown coal briquettes | 20,7 | 97500 | 2018,25 | | | | |
| | Patent fuel | 20,7 | 97500 | 2018,25 | | | | |
| | Coke oven coke | 28,2 | 107000 | 3017,4 | | | | |
| | Lignite coke | 28,2 | 107000 | 3017,4 | | | | |
| | Gas coke | 28,2 | 107000 | 3017,4 | | | | |
| | Coal tar | 28 | 80700 | 2259,6 | | | | |
| | Gas works gas | 38,7 | 44400 | 1718,28 | | | | |
| | Coke oven gas | 38,7 | 44400 | 1718,28 | | | | |
| | Blast furnace gas | 2,47 | 260000 | 642,2 | | | | |
| | Oxygen steel furnace gas | 7,06 | 182000 | 1284,92 | | | | |
| Natural gas | Natural gas | 48 | 56100 | 2692,8 | | 0,7 | | 1,88496 |
| Other wastes | Municipal waste (Non biomass f | 10 | 91700 | 917 | | | | |
| | Industrial wastes | NA | 143000 | NA | | | | |
| | Waste oils | 40,2 | 73300 | 2946,66 | | | | |
| Biomass | Wood or Wood waste | 15,6 | 112000 | 1747,2 | | | | |
| | Sulphite lyes (Black liqour) | 11,8 | 95300 | 1124,54 | | | | |
| | Other primary solid biomass fue | 11,6 | 100000 | 1160 | | | | |
| | Charcoal | 29,5 | 112000 | 3304 | | | | |
| | Biogasoline | 27 | 70800 | 1911,6 | | | | |
| | Biodiesels | 27 | 70800 | 1911,6 | | | | |
| | Other liquid biofuels | 27,4 | 79600 | 2181,04 | | | | |
| | Landfill gas | 50,4 | 54600 | 2751,84 | | 0,9 | | 2,476656 |
| | Sludge gas | 50,4 | 54600 | 2751,84 | | | | |
| | Other biogas | 50,4 | 54600 | 2751,84 | | | | |
| | Municipal wastes (Biomass frac | 11,6 | 100000 | 1160 | | | | |
| | Peat | 9,76 | 106000 | 1034,56 | | | | |

These emission factors are 'cross-sector'; that is, they can be used by reporting entities from any sector, such as the manufacturing, energy or institutional in

Notes: 1, Fuel density data come from GHG Protocol's tool for stationary combustion

## Table 2. CH4 emission factors by Fuel

| Fuel | | Lower heating Value | $CH_4$ emission factors for fuel consumption data that have been supplied on different measurement bases | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Energy basis | Mass basis | Fuel density information[1] | | Liquid basis | Gas basis |
| | | | | | Of liquids (kg/litre fuel) | Of gases ($kg/m^3$ of fuel) | | |
| | | TJ/Gg | kg/TJ | kg/tonne | | | kg/ litre | $kg/m^3$ |
| Oil products | Crude oil | 42,3 | 10 | 0,423 | 0,8 | | 0,0003384 | |
| | Orimulsion | 27,5 | 10 | 0,275 | | | | |
| | Natural Gas Liquids | 44,2 | 10 | 0,442 | | | | |
| | Motor gasoline | 44,3 | 10 | 0,443 | 0,74 | | 0,00032782 | |
| | Aviation gasoline | 44,3 | 10 | 0,443 | 0,71 | | 0,00031453 | |
| | Jet gasoline | 44,3 | 10 | 0,443 | 0,71 | | 0,00031453 | |
| | Jet kerosene | 44,1 | 10 | 0,441 | 0,79 | | 0,00034839 | |
| | Other kerosene | 43,8 | 10 | 0,438 | 0,8 | | 0,0003504 | |
| | Shale oil | 38,1 | 10 | 0,381 | 1 | | 0,000381 | |
| | Gas/Diesel oil | 43 | 10 | 0,43 | 0,84 | | 0,0003612 | |
| | Residual fuel oil | 40,4 | 10 | 0,404 | 0,94 | | 0,00037976 | |
| | Liquified Petroleum Gases | 47,3 | 5 | 0,2365 | 0,54 | | 0,00012771 | |
| | Ethane | 46,4 | 5 | 0,232 | | 1,3 | | 0,0003016 |
| | Naphtha | 44,5 | 10 | 0,445 | 0,77 | | 0,00034265 | |
| | Bitumen | 40,2 | 10 | 0,402 | | | | |
| | Lubricants | 40,2 | 10 | 0,402 | 1 | | 0,000402 | |
| | Petroleum coke | 32,5 | 10 | 0,325 | | | | |
| | Refinery feedstocks | 43 | 10 | 0,43 | | | | |
| | Refinery gas | 49,5 | 5 | 0,2475 | | | | |
| | Paraffin waxes | 40,2 | 10 | 0,402 | | | | |
| | White Spirit/SBP | 40,2 | 10 | 0,402 | | | | |
| | Other petroleum products | 40,2 | 10 | 0,402 | | | | |
| Coal products | Anthracite | 26,7 | 10 | 0,267 | | | | |
| | Coking coal | 28,2 | 10 | 0,282 | | | | |
| | Other bituminous coal | 25,8 | 10 | 0,258 | | | | |
| | Sub bituminous coal | 18,9 | 10 | 0,189 | | | | |
| | Lignite | 11,9 | 10 | 0,119 | | | | |
| | Oil shale and tar sands | 8,9 | 10 | 0,089 | | | | |
| | Brown coal briquettes | 20,7 | 10 | 0,207 | | | | |
| | Patent fuel | 20,7 | 10 | 0,207 | | | | |
| | Coke oven coke | 28,2 | 10 | 0,282 | | | | |
| | Lignite coke | 28,2 | 10 | 0,282 | | | | |
| | Gas coke | 28,2 | 5 | 0,141 | | | | |
| | Coal tar | 28 | 10 | 0,28 | | | | |
| | Gas works gas | 38,7 | 5 | 0,1935 | | | | |
| | Coke oven gas | 38,7 | 5 | 0,1935 | | | | |
| | Blast furnace gas | 2,47 | 5 | 0,01235 | | | | |
| | Oxygen steel furnace gas | 7,06 | 5 | 0,0353 | | | | |
| Natural gas | Natural gas | 48 | 5 | 0,24 | | 0,7 | | 0,000168 |
| Other wastes | Municipal waste (Non biomass f | 10 | 300 | 3 | | | | |
| | Industrial wastes | NA | 300 | NA | | | | |
| | Waste oils | 40,2 | 300 | 12,06 | | | | |
| Biomass | Wood or Wood waste | 15,6 | 300 | 4,68 | | | | |
| | Sulphite lyes (Black liqour) | 11,8 | 3 | 0,0354 | | | | |
| | Other primary solid biomass fue | 11,6 | 300 | 3,48 | | | | |
| | Charcoal | 29,5 | 200 | 5,9 | | | | |
| | Biogasoline | 27 | 10 | 0,27 | | | | |
| | Biodiesels | 27 | 10 | 0,27 | | | | |
| | Other liquid biofuels | 27,4 | 10 | 0,274 | | | | |
| | Landfill gas | 50,4 | 5 | 0,252 | | 0,9 | | 0,0002268 |
| | Sludge gas | 50,4 | 5 | 0,252 | | | | |
| | Other biogas | 50,4 | 5 | 0,252 | | | | |
| | Municipal wastes (Biomass frac | 11,6 | 300 | 3,48 | | | | |
| | Peat | 9,76 | 10 | 0,0976 | | | | |

These emission factors are specific to 'Institutional' operations as opposed to 'Energy' or 'Manufacturing' operations, which are other categories treated by the IPCC.

Notes: 1, Fuel density data come from GHG Protocol's tool for stationary combustion

## Table 3. N2O emission factors by Fuel

| Fuel | | Lower heating Value TJ/Gg | $N_2O$ emission factors for fuel consumption data that have been supplied on different measurement bases | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Energy basis kg/TJ | Mass basis kg/tonne | Fuel density information[1] Of liquids (kg/litre | Of gases (kg/m | Liquid basis kg/ litre | Gas basis kg/m$^3$ |
| Oil products | Crude oil | 42,3 | 0,6 | 0,02538 | 0,8 | | 0,000020304 | |
| | Orimulsion | 27,5 | 0,6 | 0,0165 | | | | |
| | Natural Gas Liquids | 44,2 | 0,6 | 0,02652 | | | | |
| | Motor gasoline | 44,3 | 0,6 | 0,02658 | 0,74 | | 1,96692E-05 | |
| | Aviation gasoline | 44,3 | 0,6 | 0,02658 | 0,71 | | 1,88718E-05 | |
| | Jet gasoline | 44,3 | 0,6 | 0,02658 | 0,71 | | 1,88718E-05 | |
| | Jet kerosene | 44,1 | 0,6 | 0,02646 | 0,79 | | 2,09034E-05 | |
| | Other kerosene | 43,8 | 0,6 | 0,02628 | 0,8 | | 0,000021024 | |
| | Shale oil | 38,1 | 0,6 | 0,02286 | 1 | | 0,00002286 | |
| | Gas/Diesel oil | 43 | 0,6 | 0,0258 | 0,84 | | 0,000021672 | |
| | Residual fuel oil | 40,4 | 0,6 | 0,02424 | 0,94 | | 2,27856E-05 | |
| | Liquified Petroleum Gases | 47,3 | 0,1 | 0,00473 | 0,54 | | 2,5542E-06 | |
| | Ethane | 46,4 | 0,1 | 0,00464 | | 1,3 | | 0,000006032 |
| | Naphtha | 44,5 | 0,6 | 0,0267 | 0,77 | | 0,000020559 | |
| | Bitumen | 40,2 | 0,6 | 0,02412 | | | | |
| | Lubricants | 40,2 | 0,6 | 0,02412 | 1 | | 0,00002412 | |
| | Petroleum coke | 32,5 | 0,6 | 0,0195 | | | | |
| | Refinery feedstocks | 43 | 0,6 | 0,0258 | | | | |
| | Refinery gas | 49,5 | 0,1 | 0,00495 | | | | |
| | Paraffin waxes | 40,2 | 0,6 | 0,02412 | | | | |
| | White Spirit/SBP | 40,2 | 0,6 | 0,02412 | | | | |
| | Other petroleum products | 40,2 | 0,6 | 0,02412 | | | | |
| Coal products | Anthracite | 26,7 | 1,5 | 0,04005 | | | | |
| | Coking coal | 28,2 | 1,5 | 0,0423 | | | | |
| | Other bituminous coal | 25,8 | 1,5 | 0,0387 | | | | |
| | Sub bituminous coal | 18,9 | 1,5 | 0,02835 | | | | |
| | Lignite | 11,9 | 1,5 | 0,01785 | | | | |
| | Oil shale and tar sands | 8,9 | 1,5 | 0,01335 | | | | |
| | Brown coal briquettes | 20,7 | 1,5 | 0,03105 | | | | |
| | Patent fuel | 20,7 | 1,5 | 0,03105 | | | | |
| | Coke oven coke | 28,2 | 1,5 | 0,0423 | | | | |
| | Lignite coke | 28,2 | 1,5 | 0,0423 | | | | |
| | Gas coke | 28,2 | 0,1 | 0,00282 | | | | |
| | Coal tar | 28 | 1,5 | 0,042 | | | | |
| | Gas works gas | 38,7 | 0,1 | 0,00387 | | | | |
| | Coke oven gas | 38,7 | 0,1 | 0,00387 | | | | |
| | Blast furnace gas | 2,47 | 0,1 | 0,000247 | | | | |
| | Oxygen steel furnace gas | 7,06 | 0,1 | 0,000706 | | | | |
| Natural gas | Natural gas | 48 | 0,1 | 0,0048 | | 0,7 | | 0,00000336 |
| Other wastes | Municipal waste (Non biomass f | 10 | 4 | 0,04 | | | | |
| | Industrial wastes | NA | 4 | NA | | | | |
| | Waste oils | 40,2 | 4 | 0,1608 | | | | |
| Biomass | Wood or Wood waste | 15,6 | 4 | 0,0624 | | | | |
| | Sulphite lyes (Black liqour) | 11,8 | 2 | 0,0236 | | | | |
| | Other primary solid biomass fue | 11,6 | 4 | 0,0464 | | | | |
| | Charcoal | 29,5 | 1 | 0,0295 | | | | |
| | Biogasoline | 27 | 0,6 | 0,0162 | | | | |
| | Biodiesels | 27 | 0,6 | 0,0162 | | | | |
| | Other liquid biofuels | 27,4 | 0,6 | 0,01644 | | | | |
| | Landfill gas | 50,4 | 0,1 | 0,00504 | | 0,9 | | 0,000004536 |
| | Sludge gas | 50,4 | 0,1 | 0,00504 | | | | |
| | Other biogas | 50,4 | 0,1 | 0,00504 | | | | |
| | Municipal wastes (Biomass frac | 11,6 | 4 | 0,0464 | | | | |
| | Peat | 9,76 | 1,4 | 0,013664 | | | | |

These emission factors are specific to 'Institutional' operations as opposed to 'Energy' or 'Manufacturing' operations, which are other categories treated by the IPCC.

Notes: 1, Fuel density data come from GHG Protocol's tool for stationary combustion

# Table 4: Emissions factors due to the Employees' Commuting

## $CO_2$, $CH_4$ and $N_2O$ Emission Factors by Passenger Distance (i.e. Public Transport)

| Vehicle and Type | Region | $CO_2$ | $CO_2$ - Biomass Fuel | $CO_2$ Unit - Numerator | $CO_2$ Unit - Denominator | $CH_4$ | $CH_4$ Unit - Numerator | $CH_4$ Unit - Denominator | $N_2O$ | $N_2O$ Unit - Numerator | $N_2O$ Unit - Denominator |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Air - Domestic | Other | 0,17147 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - Seating Unknown | Other | 0,097 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - Economy Class | Other | 0,09245 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - First/Business Class | Other | 0,13867 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Seating Unknown | Other | 0,11319 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Economy Class | Other | 0,08263 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Economy+ Class | Other | 0,13221 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Business Class | Other | 0,23963 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - First Class | Other | 0,33052 | | Kilogram | Passenger Kilometer | | | | | | |
| Train - Light Rail | Other | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Train - Tram | Other | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Train - Average (Light Rail and Tram) | Other | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Train - National Rail | Other | 0,185 | | Kilogram | Passenger Mile | 0,002 | Gram | Passenger Mile | 0,001 | Gram | Passenger Mile |
| Train - Subway | Other | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Taxi | Other | 0,23 | | Kilogram | Passenger Mile | 0,02 | Gram | Passenger Mile | 0,021 | Gram | Passenger Mile |
| Bus - Local Bus | Other | 0,107 | | Kilogram | Passenger Mile | 0,0006 | Gram | Passenger Mile | 0,0005 | Gram | Passenger Mile |
| Bus - Coach | Other | 0,107 | | Kilogram | Passenger Mile | 0,0006 | Gram | Passenger Mile | 0,0005 | Gram | Passenger Mile |
| Bus - Type Unknown | Other | 0,107 | | Kilogram | Passenger Mile | 0,0006 | Gram | Passenger Mile | 0,0005 | Gram | Passenger Mile |
| Large RoPax Ferry | Other | 0,1152 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Domestic | UK | 0,17147 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - Seating Unknown | UK | 0,097 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - Economy Class | UK | 0,09245 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - First/Business Class | UK | 0,13867 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Seating Unknown | UK | 0,11319 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Economy Class | UK | 0,08263 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Economy+ Class | UK | 0,13221 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Business Class | UK | 0,23963 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - First Class | UK | 0,33052 | | Kilogram | Passenger Kilometer | | | | | | |
| Train - Light Rail | UK | 0,0768 | | Kilogram | Passenger Kilometer | 0,0019 | Gram | Passenger Kilometer | 0,0014 | Gram | Passenger Kilometer |
| Train - Tram | UK | 0,0768 | | Kilogram | Passenger Kilometer | 0,0019 | Gram | Passenger Kilometer | 0,0014 | Gram | Passenger Kilometer |
| Train - Average (Light Rail and Tram) | UK | 0,0768 | | Kilogram | Passenger Kilometer | 0,0019 | Gram | Passenger Kilometer | 0,0014 | Gram | Passenger Kilometer |
| Train - National Rail | UK | 0,0534 | | Kilogram | Passenger Kilometer | 0,0029 | Gram | Passenger Kilometer | 0,0098 | Gram | Passenger Kilometer |
| Train - Subway | UK | 0,07414 | | Kilogram | Passenger Kilometer | 0,0019 | Gram | Passenger Kilometer | 0,0014 | Gram | Passenger Kilometer |
| Taxi | UK | 0,1523 | | Kilogram | Passenger Kilometer | 0,0017 | Gram | Passenger Kilometer | 0,0038 | Gram | Passenger Kilometer |
| Bus - Local Bus | UK | 0,15726 | | Kilogram | Passenger Kilometer | 0,0095 | Gram | Passenger Kilometer | 0,0041 | Gram | Passenger Kilometer |
| Bus - Coach | UK | 0,03 | | Kilogram | Passenger Kilometer | 0,0038 | Gram | Passenger Kilometer | 0,0018 | Gram | Passenger Kilometer |
| Bus - Type Unknown | UK | 0,13394 | | Kilogram | Passenger Kilometer | 0,0076 | Gram | Passenger Kilometer | 0,0033 | Gram | Passenger Kilometer |
| Large RoPax Ferry | UK | 0,11516 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Domestic | US | 0,17147 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - Seating Unknown | US | 0,097 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - Economy Class | US | 0,09245 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Short Haul - First/Business Class | US | 0,13867 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Seating Unknown | US | 0,11319 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Economy Class | US | 0,08263 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Economy+ Class | US | 0,13221 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - Business Class | US | 0,23963 | | Kilogram | Passenger Kilometer | | | | | | |
| Air - Long Haul - First Class | US | 0,33052 | | Kilogram | Passenger Kilometer | | | | | | |
| Train - Light Rail | US | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Train - Tram | US | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Train - Average (Light Rail and Tram) | US | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Train - National Rail | US | 0,185 | | Kilogram | Passenger Mile | 0,002 | Gram | Passenger Mile | 0,001 | Gram | Passenger Mile |
| Train - Subway | US | 0,163 | | Kilogram | Passenger Mile | 0,004 | Gram | Passenger Mile | 0,002 | Gram | Passenger Mile |
| Taxi | US | 0,23 | | Kilogram | Passenger Mile | 0,02 | Gram | Passenger Mile | 0,021 | Gram | Passenger Mile |
| Bus - Local Bus | US | 0,107 | | Kilogram | Passenger Mile | 0,0006 | Gram | Passenger Mile | 0,0005 | Gram | Passenger Mile |
| Bus - Coach | US | 0,107 | | Kilogram | Passenger Mile | 0,0006 | Gram | Passenger Mile | 0,0005 | Gram | Passenger Mile |
| Bus - Type Unknown | US | 0,107 | | Kilogram | Passenger Mile | 0,0006 | Gram | Passenger Mile | 0,0005 | Gram | Passenger Mile |
| Large RoPax Ferry | US | 0,11516 | | Kilogram | Passenger Kilometer | | | | | | |

# Appendix 4: Electricity-specific emission factors

**Table 1: Electricity-specific emission factors for grid electricity (Carbon Footprint, 2019)**

| Grouping | Country | Factor (kgCO₂e per kWh) | Source | Year | Comments |
|---|---|---|---|---|---|
| **Africa** | **South Africa** | **0.9606** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | | | | | |
| **Asia** | **China (PR)** | **0.6236** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **Hong Kong (China)** | **0.8000 or 0.7400** | Hong Kong Electric Company (2018) or CLP Group (2018) **These two companies supply different areas of HK so check which one you need.** | 2018 | Combined generation and T&D factor |
| | **India** | **0.7429** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **Indonesia** | **0.7551** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **Japan** | **0.4916** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **Korea (Republic)** | **0.5170** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | | | | | |
| **Australasia** | **Australia** | Gen = 0.8000<br>T&D = 0.1000 | Australian Government | 2018 | Published in July 2018 |
| | **New Zealand** | Gen = 0.0074<br>T&D = 0.0977 | Ministry for the Environment https://www.mfe.govt.nz/node/18670/ | 2018 (based on 2016 data) | Emission factors published in 2019, based on 2018 national inventory which is based on 2016 data. |
| | | | | | |
| **Middle East** | **Saudi Arabia** | **0.7176** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **Turkey** | **0.5434** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **United Arab Emirates** | **0.4333** | Dubai Electricity & Water Authority (sustainability report 2017) | 2017 | Generation factor only |
| | | | | | |

| Grouping | Country | Factor (kgCO₂e per kWh) | Source | Year | Comments |
|---|---|---|---|---|---|
| **North & Central America** | **Canada** | Gen = 0.1300<br>T&D = 0.0100 | UN Framework Convention on Climate Change | 2019 (based on 2017 data) | **Regional factors are available. See separate table below.** |
| | **Mexico** | **0.4640** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **United States** | **0.4759** | US Env Protection Agency (EPA) eGrid | 2016 | Combined generation and distribution factor. **Regional factors are available. See separate table below.** |
| | | | | | |
| **South America** | **Argentina** | **0.3583** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **Brazil** | **0.0927** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | | | | | |
| **Europe** | **Austria** | **0.1420** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Belgium** | **0.1670** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Bulgaria** | **0.4700** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Croatia** | **0.4170** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Cyprus** | **0.6390** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Czech Republic** | **0.5760** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Denmark** | **0.2090** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Estonia** | **0.8750** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Finland** | **0.1430** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **France** | **0.0470** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Germany** | **0.4690** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Greece** | **0.5670** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Hungary** | **0.3140** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Iceland** | **0.0000** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Ireland** | **0.3930** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Italy** | **0.3270** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Latvia** | **0.3130** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Lithuania** | **0.3620** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Luxembourg** | **0.2010** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Malta** | **0.7610** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Netherlands** | **0.4570** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |

| Grouping | Country | Factor (kgCO₂e per kWh) | Source | Year | Comments |
|---|---|---|---|---|---|
| | **Norway** | **0.0110** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Poland** | **0.8460** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Portugal** | **0.3070** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Romania** | **0.4010** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Russian Federation** | **0.3302** | Climate Transparency (2018 Report) | 2017 | Emissions intensity of the power sector |
| | **Slovakia** | **0.1690** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Slovenia** | **0.3350** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Spain** | **0.2880** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Sweden** | **0.0120** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **Switzerland** | **0.0140** | Association of Issuing Bodies (AIB) | 2018 | Production mix factor |
| | **United Kingdom** | **0.2773** | UK Govt – Defra/BEIS | 2019 (based on 2017 data) | Combined Generation + Transmission & Distribution factor |
| | | | | | |

| State | Grid | Generation Factor (kgCO₂e per kWh) | T&D Factor (kgCO₂e per kWh) | Year |
|---|---|---|---|---|
| ***UNITED STATES*** | | ***0.45548*** | ***0.0213*** | 2016 (published 2018) |
| **Alaska (AK)** | ASCC & ASCC Misc. - Alaska Grid | 0.4218 | 0.0234 | 2016 |
| **Alabama (AL)** | SERC - South | 0.4162 | 0.0196 | 2016 |
| **Arkansas (AR)** | SERC - South | 0.5092 | 0.0239 | 2016 |
| **Arizona (AZ)** | WECC - Southwest | 0.4250 | 0.0188 | 2016 |
| **California (CA)** | WECC- California | 0.2060 | 0.0091 | 2016 |
| **Colorado (CO)** | WECC - Rockies | 0.6704 | 0.0296 | 2016 |
| **Connecticut (CT)** | NPCC - New England | 0.2278 | 0.0107 | 2016 |
| **Washington DC (DC)** | RFC - East | 0.2191 | 0.0103 | 2016 |
| **Delaware (DE)** | RFC - East | 0.4034 | 0.0190 | 2016 |

| State | Grid | Generation Factor (kgCO₂e per kWh) | T&D Factor (kgCO₂e per kWh) | Year |
|---|---|---|---|---|
| ***UNITED STATES*** | | ***0.45548*** | ***0.0213*** | 2016 (published 2018) |
| **Florida (FL)** | FRCC - All | 0.4667 | 0.0219 | 2016 |
| **Georgia (GA)** | SERC - South | 0.4570 | 0.0215 | 2016 |
| **Hawaii (HI)** | HICC - Misc. & Oahu | 0.6953 | 0.0393 | 2016 |
| **Iowa (IA)** | MRO - East | 0.4553 | 0.0214 | 2016 |
| **Idaho (ID)** | WECC - Rockies | 0.0859 | 0.0038 | 2016 |
| **Illinois (IL)** | MRO- East | 0.3701 | 0.0174 | 2016 |
| **Indiana (IN)** | RFC - West | 0.8278 | 0.0389 | 2016 |
| **Kansas (KS)** | SPP- North | 0.5462 | 0.0257 | 2016 |
| **Kentucky (KY)** | SERC - Tennessee Valley | 0.8927 | 0.0419 | 2016 |
| **Louisiana (LA)** | SERC - South | 0.4001 | 0.0188 | 2016 |
| **Massachusetts (MA)** | NPCC - New England | 0.3754 | 0.0176 | 2016 |
| **Maryland (MD)** | RFC - East | 0.4624 | 0.0217 | 2016 |
| **Maine (ME)** | NPCC - New England | 0.1577 | 0.0074 | 2016 |
| **Michigan (MI)** | RFC - Michigan | 0.5017 | 0.0236 | 2016 |
| **Minnesota (MN)** | MRO - East | 0.4628 | 0.0217 | 2016 |
| **Missouri (MO)** | SERC - South | 0.7706 | 0.0362 | 2016 |
| **Mississippi (MS)** | SERC - South | 0.4278 | 0.0201 | 2016 |
| **Montana (MT)** | WECC - Rockies | 0.5716 | 0.0253 | 2016 |
| **North Carolina (NC)** | SERC - Virginia/Carolinas | 0.3958 | 0.0186 | 2016 |
| **North Dakota (ND)** | MRO-West | 0.7597 | 0.0357 | 2016 |
| **Nebraska (NE)** | MRO-West | 0.5855 | 0.0275 | 2016 |
| **New Hampshire (NH)** | NPCC - New England | 0.1437 | 0.0068 | 2016 |
| **New Jersey (NJ)** | RFC - East | 0.2539 | 0.0119 | 2016 |
| **New Mexico (NM)** | WECC - Southwest | 0.7179 | 0.0317 | 2016 |
| **Nevada (NV)** | WECC - Rockies | 0.3500 | 0.0155 | 2016 |
| **New York (NY)** | NPCC - LI, NYC, & Upstate NY | 0.2113 | 0.0099 | 2016 |
| **Ohio (OH)** | RFC - West | 0.6692 | 0.0314 | 2016 |
| **Oklahoma (OK)** | SPP- South | 0.4755 | 0.0223 | 2016 |
| **Oregon (OR)** | WECC - Northwest | 0.1393 | 0.0062 | 2016 |
| **Pennsylvania (PA)** | RFC - West | 0.3901 | 0.0183 | 2016 |
| **Rhode Island (RI)** | NPCC - New England | 0.3954 | 0.0186 | 2016 |
| **South Carolina (SC)** | SERC - Virginia/Carolinas | 0.2870 | 0.0135 | 2016 |

| State | Grid | Generation Factor ($kgCO_2e$ per kWh) | T&D Factor ($kgCO_2e$ per kWh) | Year |
|---|---|---|---|---|
| ***UNITED STATES*** | | ***0.45548*** | ***0.0213*** | 2016 (published 2018) |
| **South Dakota (SD)** | MRO-West | 0.2343 | 0.0110 | 2016 |
| **Tennessee (TN)** | SERC - Tennessee Valley | 0.4529 | 0.0213 | 2016 |
| **Texas (TX)** | ERCOT - All | 0.4784 | 0.0246 | 2016 |
| **Utah (UT)** | WECC - Rockies | 0.7432 | 0.0329 | 2016 |
| **Virginia (VA)** | SERC - Virginia/Carolinas | 0.3715 | 0.0175 | 2016 |
| **Vermont (VT)** | NPCC - New England | 0.0303 | 0.0014 | 2016 |
| **Washington (WA)** | WECC - Northwest | 0.0852 | 0.0038 | 2016 |
| **Wisconsin (WI)** | MRO - East | 0.6334 | 0.0298 | 2016 |
| **West Virginia (WV)** | SERC - Virginia/Carolinas | 0.9029 | 0.0424 | 2016 |
| **Wyoming (WY)** | WECC - Rockies | 0.9258 | 0.0409 | 2016 |

| State | Generation Factor ($kgCO_2e$ per kWh) | T&D Factor ($kgCO_2e$ per kWh) | Year |
|---|---|---|---|
| ***Canada*** | ***0.13*** | ***0.01*** | *2017 (published 2019)* |
| **Alberta (AB)** | **0.75** | **0.05** | 2017 (published 2019) |
| **British Columbia (BC)** | **0.0093** | **0.0004** | 2017 (published 2019) |
| **Manitoba (MT)** | **0.0019** | **0.0002** | 2017 (published 2019) |
| **New Brunswick (NB)** | **0.31** | **0.02** | 2017 (published 2019) |
| **Newfoundland and Labrador (NL)** | **0.04** | **Negligible** | 2017 (published 2019) |
| **Nova Scotia (NS)** | **0.67** | **0.05** | 2017 (published 2019) |
| **Northwest Territories (NT)** | **0.18** | **Negligible** | 2017 (published 2019) |
| **Nunavut (NU)** | **0.75** | **0.04** | 2017 (published 2019) |
| **Ontario (ON)** | **0.017** | **0.003** | 2017 (published 2019) |
| **Prince Edward Island (PE)** | **0.014** | **Unknow use 'New Brunswick'** | 2017 (published 2019) |
| **Quebec (QC)** | **0.0013** | **0.0002** | 2017 (published 2019) |
| **Saskatchewan (SK)** | **0.66** | **0.05** | 2017 (published 2019) |
| **Yukon Territory (YT)** | **0.05** | **0.007** | 2017 (published 2019) |

| State | Generation Factor ($kgCO_2e$ per kWh) | T&D Factor ($kgCO_2e$ per kWh) | Year |
|---|---|---|---|
| ***AUSTRALIA*** | ***0.80*** | *0.10* | *2016/17 (published in 2018)* |
| **Australian Capital Territory** | **0.82** | 0.10 | 2016/17 (published in 2018) |
| **New South Wales** | **0.82** | 0.10 | 2016/17 (published in 2018) |
| **Northern Territory** | **0.64** | 0.09 | 2016/17 (published in 2018) |
| **Queensland** | **0.80** | 0.13 | 2016/17 (published in 2018) |
| **South Australia** | **0.51** | 0.10 | 2016/17 (published in 2018) |
| **Tasmania** | **0.19** | 0.03 | 2016/17 (published in 2018) |
| **Victoria** | **1.07** | 0.10 | 2016/17 (published in 2018) |
| **Western Australia** | **0.70** | 0.05 | 2016/17 (published in 2018) |

## Appendix 5: Tool's User Guidelines

USER GUIDELINES

# A standardized tool to calculate Carbon Footprint in ports


UNIVERSITAT POLITÈCNICA DE CATALUNYA

## 1. Introduction

One of the significant environmental threats in recent years in ports is carbon dioxide emissions generated by different activities in these areas which lead to Climate Change. In a survey conducted by the European Sea Port Organization (ESPO) in 2019, Climate Change occupies the 3rd position in the ranking of ten environmental priorities in ports (ESPO, 2019). This shows that the topic of Climate Change in the maritime industry is getting more critical every day.

In order to calculate, control and reduce $CO_2$ emissions, an indicator was developed: the Carbon Footprint. This concept is defined as the total amount of Greenhouse Gases emissions that are emitted directly and indirectly by an activity.

In the recent years, many ports have started to calculate their Carbon Footprint and report it. However, generally each Authority or Operator uses its own method which makes the comparison of results very difficult and there is no single or unified method to calculate Carbon Footprint in ports.

Therefore, the development of a practicable, user-friendly and free available tool with a standardized method for the calculation of Carbon Footprint in ports is needed and it has been demanded by the port sector (e.g. Greenport conference, 2018). In this regard, a standardized tool has been developed. This tool is specifically designed so that port authorities can calculate their Carbon Footprint and report it accordingly.

The tool provides options to select the scopes and boundaries that are more suitable and applicable to each port. In addition, the tool allows normalizing (standardize to a common ground) the total annual emissions in terms of total tons of cargo handled or annual TEUs. This is basically done to allow a comparison of the results of different ports on the same ground.

All the emission sources gathered in the standard guidelines (i.e. IPCC, GHG protocol and WPCI) are taken into account in this tool. The sources of GHG emissions in ports are divided into four categories:

- Mobile sources such as cargo handling equipment, transport vehicles, vessels and construction equipment
- Stationary sources such as power plants, boilers, emergency generators, incineration plants and wastewater treatment plant
- Purchased electricity includes buildings, lighting, reefer power demand, electrified cargo handling equipment, other terminal electrical demands, etc.
- Employees' commuting includes emissions from the transportation of employees between their homes and their worksites

According to the World Ports Climate Initiative (WPCI, 2010), the GHG inventory is categorized into three emission scopes:

- Scope 1: Port Direct Sources. These emission sources include all the emissions generated by all port authority related buildings, equipment, vehicles, etc.
- Scope 2: Port Indirect Sources. These sources include port purchased electricity for port administration owned buildings and operations.
- Scope 3: Other Indirect Sources. These sources are typically associated with tenant operations and the commuting of port and tenant employees.

## 2. How to start calculation?

The development of the tool has been done by using Excel software and visual basic. The completion of this excel based tool is expected to be around 20 minutes (if data are available) and it is divided into three steps:

- Step1: General data such as the port's name, the country and the port total cargo are required.
- Step 2: The port should select the different scopes to be included in the calculation and the required data should be filled in order to get the final result.
- Step 3: By pressing the result button, a report is produced with the total $CO_2$ equivalent emissions and also with emissions by capacity (carbon footprint) and by scope. This document can be saved as a pdf file.

It is important to mention that Universitat Politècnica de Catalunya (the tool developer) does not have access to any provided data. The tool is totally confidential. This document will guide you through all the tool steps.

The first screen of the tool presents a brief explanation about Climate Change and the different emissions scopes considered in the standard guidelines (Figure 1).

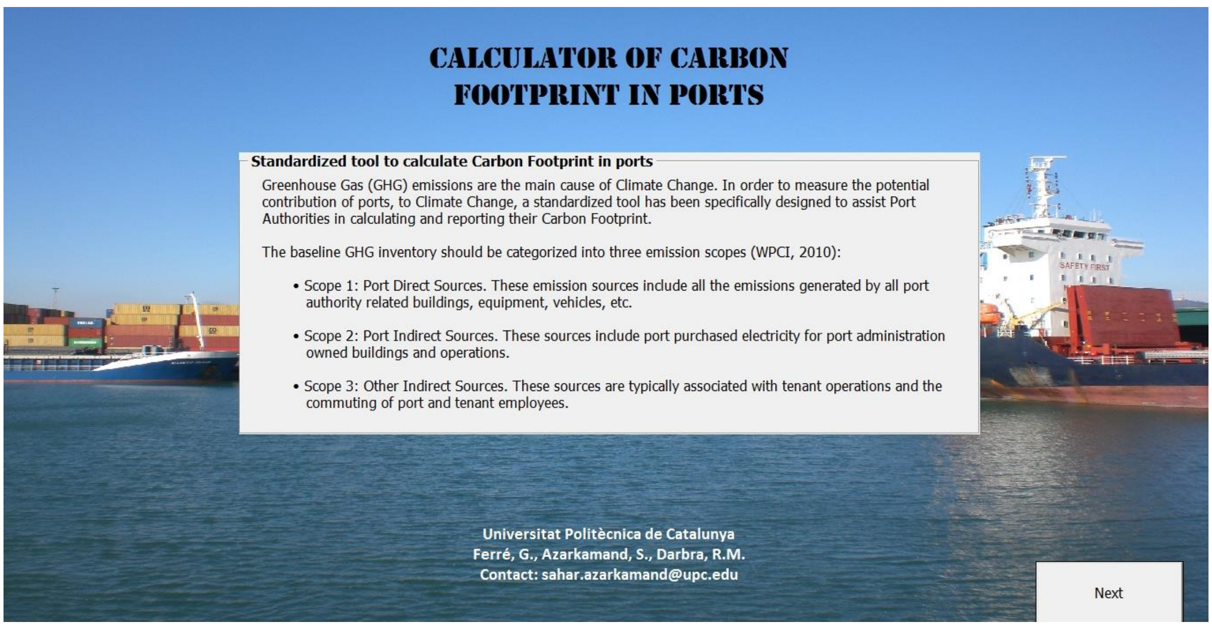



**Figure 1: Introductory screen**

If you press the "next" button of this screen you will continue to the next stage, which includes a description of the different steps of the tool (Figure 2). By clicking on the "Instructions" button, you will be directed to these Guidelines (pdf document). In addition, if you press the "Video tutorial" box you will be able to get the instructions through a video. When you are ready, you can click the "Start calculation" button to proceed with the tool and calculate the GHG emissions of your port.

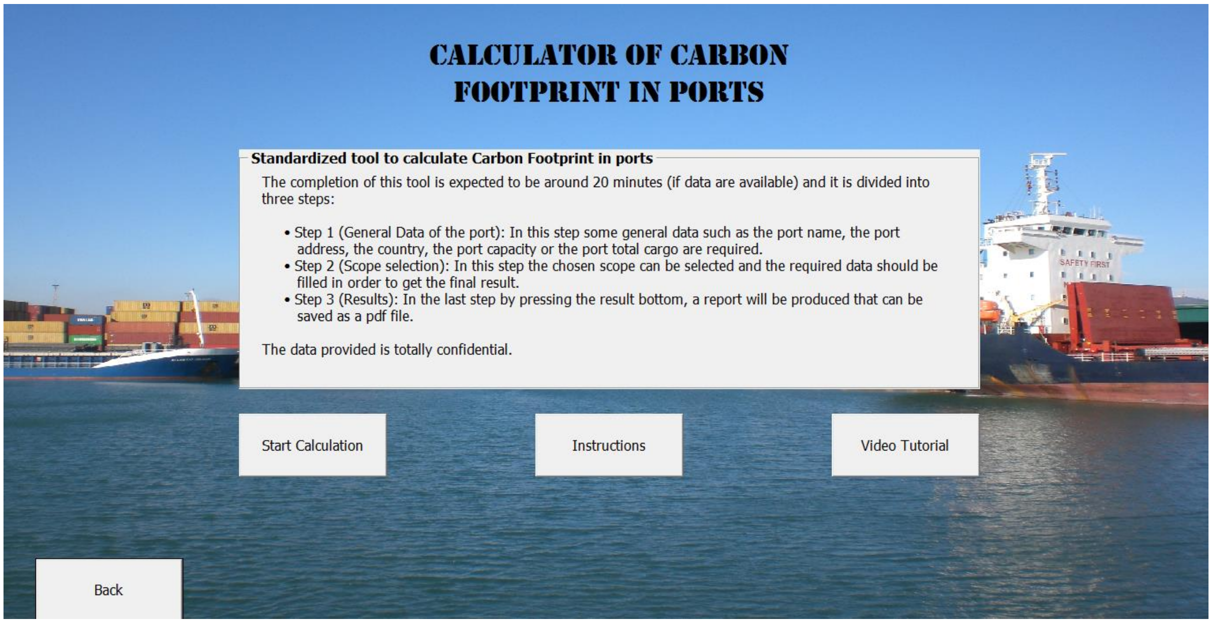



**Figure 2: Steps of the tool**

The first step of the tool includes the completion of the port general data as it can be seen in Figure 3. Here, you should insert some specific information of your port before calculating the emissions. These general data, which are optional, are:

- Port name
- Port address
- Country
- Capacity (TEU/ Year) or Total Cargo (Million tonnes/ Year)

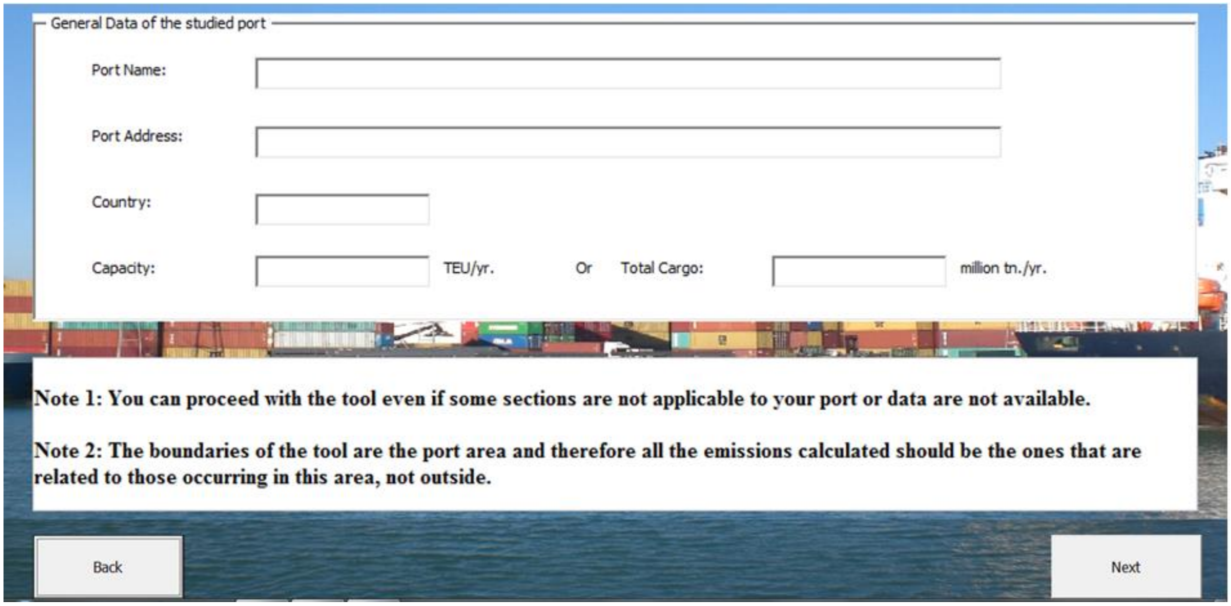



**Figure 3: General data of the port**

As it is explained in the note 1 present in Figure 3, if data are not available for some of the sources or if any of the issues or activities are not applicable to your port, it is not necessary to fill in the boxes. The program will work in any case and you can continue filling in the rest of the tool.

In addition, as mentioned in note 2, the boundaries of the tool are the port area and therefore all the emissions calculated should be the ones that are related to those occurring in this area, not outside. For example, the emissions from trucks and vehicles are taken into account while they move inside the port area (except employees' commuting), not those outside. The same happens with ships' emissions

To proceed to the next step of the tool, you should click on the 'Next' button. Once you have done that you will find a new screen where you should select the scope you want to start with (Figure 4).

In order to have a realistic overview of the Carbon footprint of your port, it is recommended to calculate all three scopes emissions.

It should be mentioned that you could save the project at each stage by clicking on the 'Save Project' button. In addition, you can clear all data by clicking on the 'Clean Project' button.

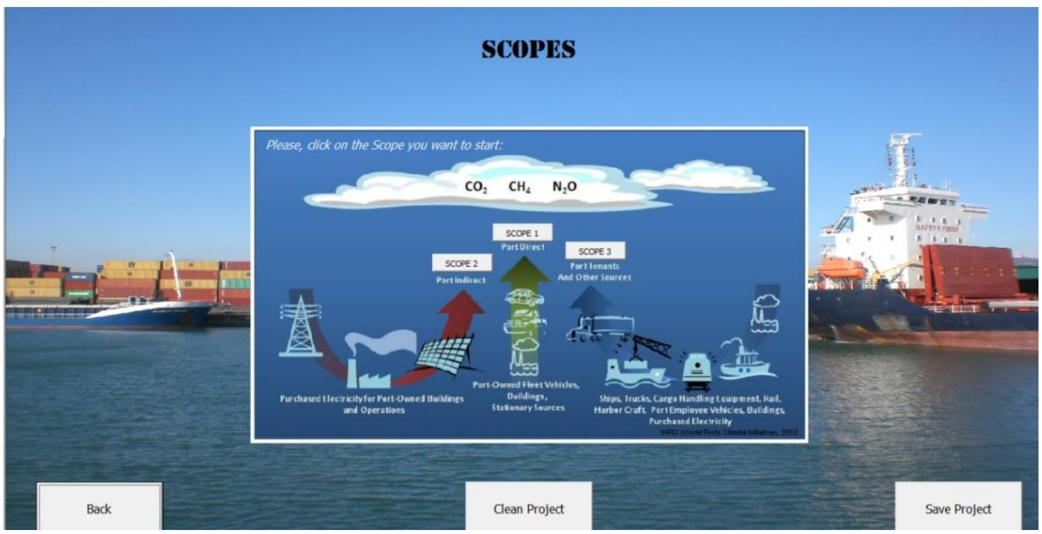



**Figure 4: Scopes' selection**

## 3. Scope 1

If you select to start your calculation with emissions from scope 1, you will be taken to the next page. In this step, a brief explanation of scope 1 is presented (Figure 5). By pressing the 'Next' button, you will go to the calculation page for scope 1. In this slide you can also download these guidelines in case you need it.

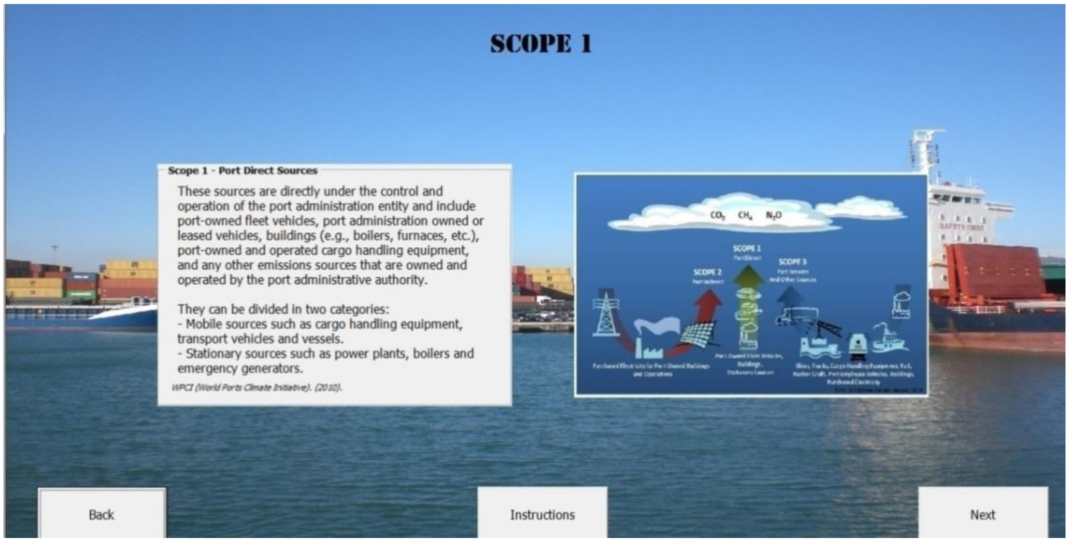



**Figure 5: Definition of scope 1**

Now in the next slides you will have to provide the data required to calculate the emissions sources related to scope 1. Emission sources in this scope are divided into two main groups: mobile sources and stationary sources. For the calculation of all sources of scope 1, you should fill in the related cells if appropriate with the required data. There will be two screens pages for scope 1 (Figures 6 and 7) that belong to mobile sources and two screen pages that belong to stationary sources (Figures 8 and 9).

In Figure 6, you can see the first screen page for scope 1 where you should fill in the data related to three categories of the mobile sources(if they exist in the port):

- Cargo Handling Equipment
- Heavy-Duty On-Road Vehicles
- Railroad Locomotives

For each cell, you should choose the source type, fuel type, consumption amount and consumption unit. Then by pressing the ‘Add’ button, you could add the source to the list. You can add all those sources that you have. At the same time, if you are mistaken you can press the “delete” button to erase those that you consider.

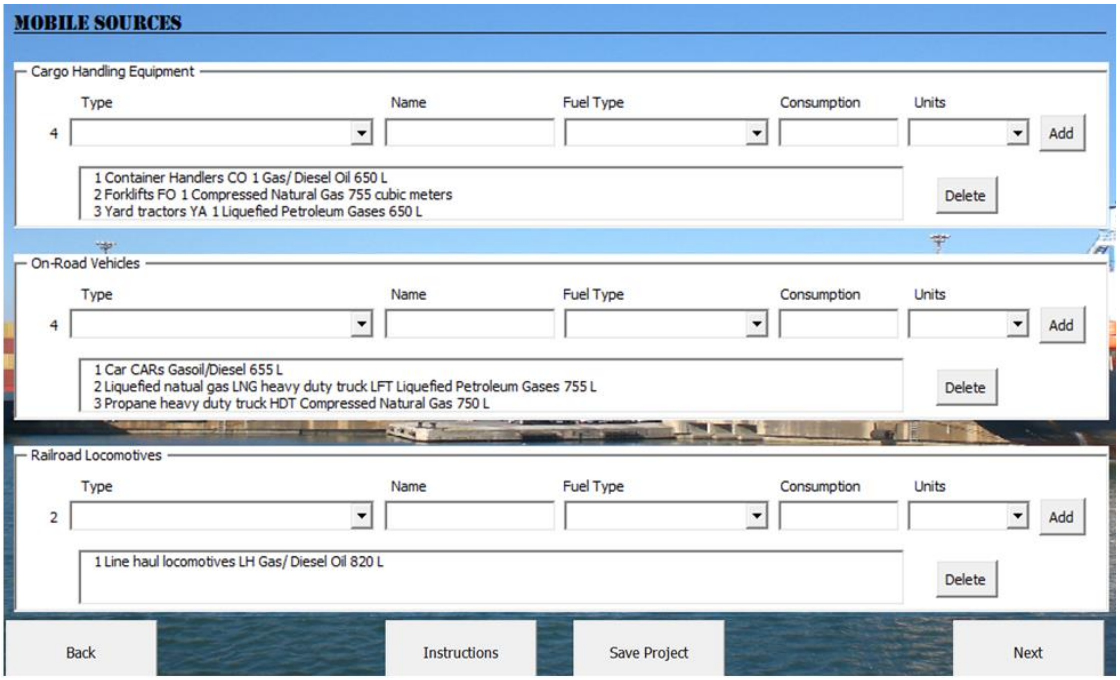



**Figure 6: First calculation screen of the mobile sources (scope 1)**

By clicking the 'Next' button, you will go to the next screen. In this slide of scope 1 (Figure 7), you should also fill in the data related to two other categories of mobile sources (if they exist in the port):

- Port owned vessels
- Construction Equipment

Again for each cell, you should choose the source type, fuel type, consumption amount and consumption unit. Then by pressing the 'Add' button, you could add the source to the list (see Figure 7).

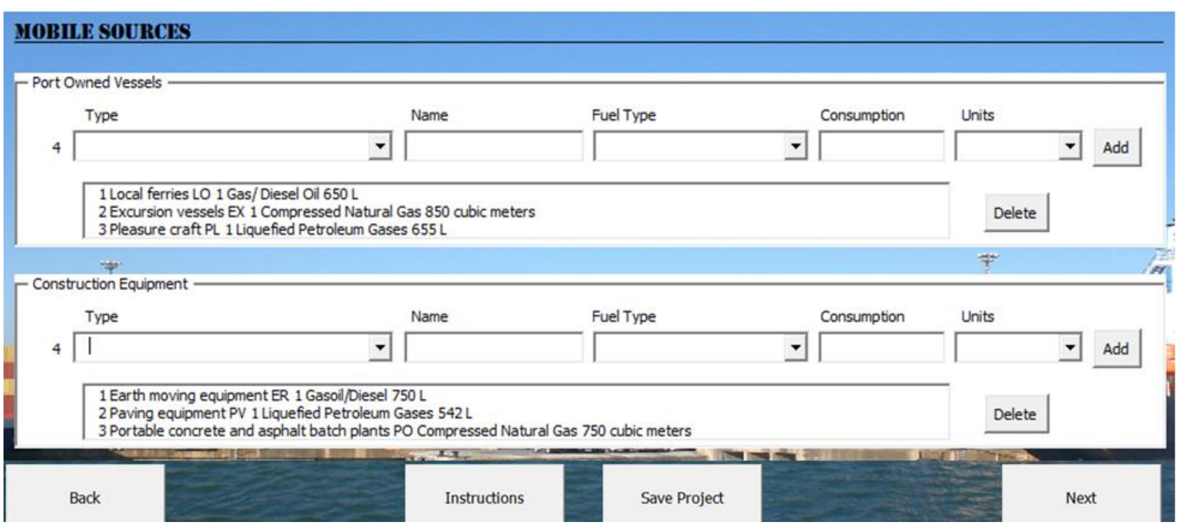



**Figure 7: Second calculation screen of the mobile sources (scope 1)**

Now if you click the "Next" button, you will proceed to fill in the first page of required data for stationary sources related with scope 1 (Figure 8). You should fill in the data (fuel type, consumption amount and consumption unit) related to 3 groups of stationary sources (if they exist in the port). These sources are:

- Power plants
- Boilers
- Incineration plants

By pressing the 'Add' button, you could add them to the calculation list. Please, remember to save the project from time to time to avoid losing all the information already introduced.

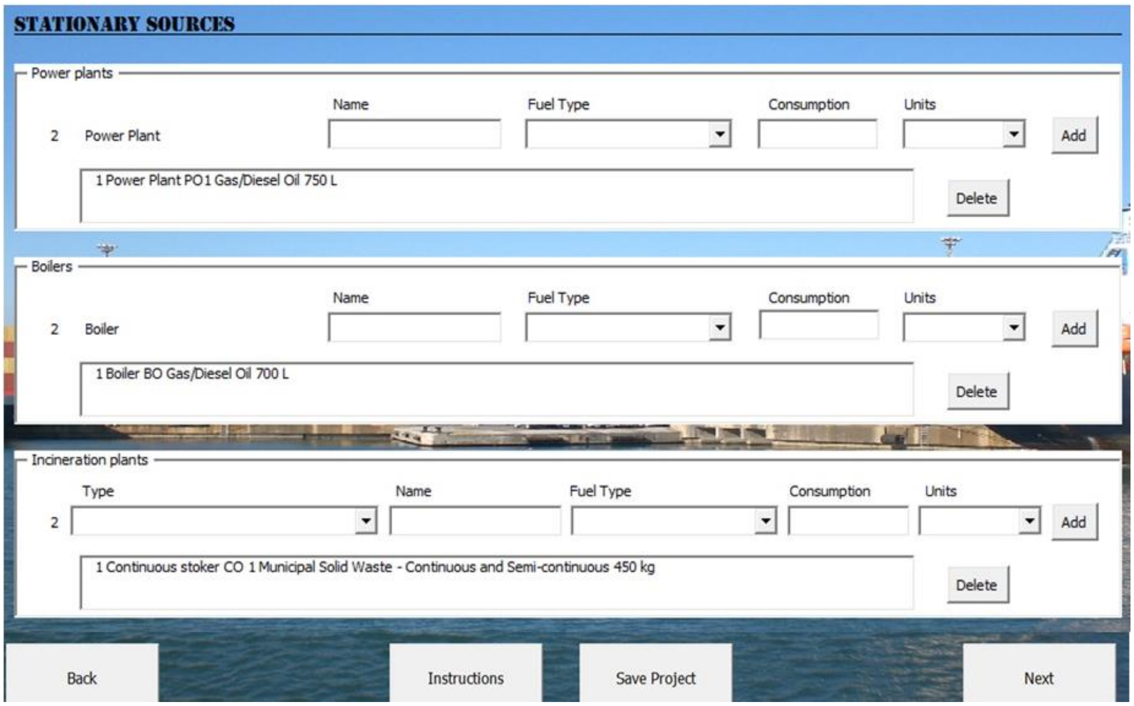



**Figure 8: First calculation screen of the stationary sources (scope 1)**

By pressing the 'Next' button, you will go to the last page of scope1. In this screen (Figure 9), you should fill in the required data (fuel type, consumption amount and consumption unit) related to three other groups of stationary sources (if they exist in the port):

- Generators
- Facilities that use combustion processes
- Wastewater treatment plants

In the case of wastewater treatment plants, you should choose the type of wastewater treatment plant and the type of industry where this water comes from. In addition, in order to obtain a final value, you should complete the data related to the "Organic component removed as sludge in inventory (kg COD)" and "Amount of $CH_4$ recovered in inventory (kg $CH_4$)".

Then you could get the total emissions of scope 1 by clicking the 'Results' button and save it as a pdf file. Alternatively, if you prefer to continue with the rest of the scopes and get the total amount of emissions at the end, you should click the 'Go to Scope 2' button. If want to go to "scope 3" you should click the button "Back to selection page".

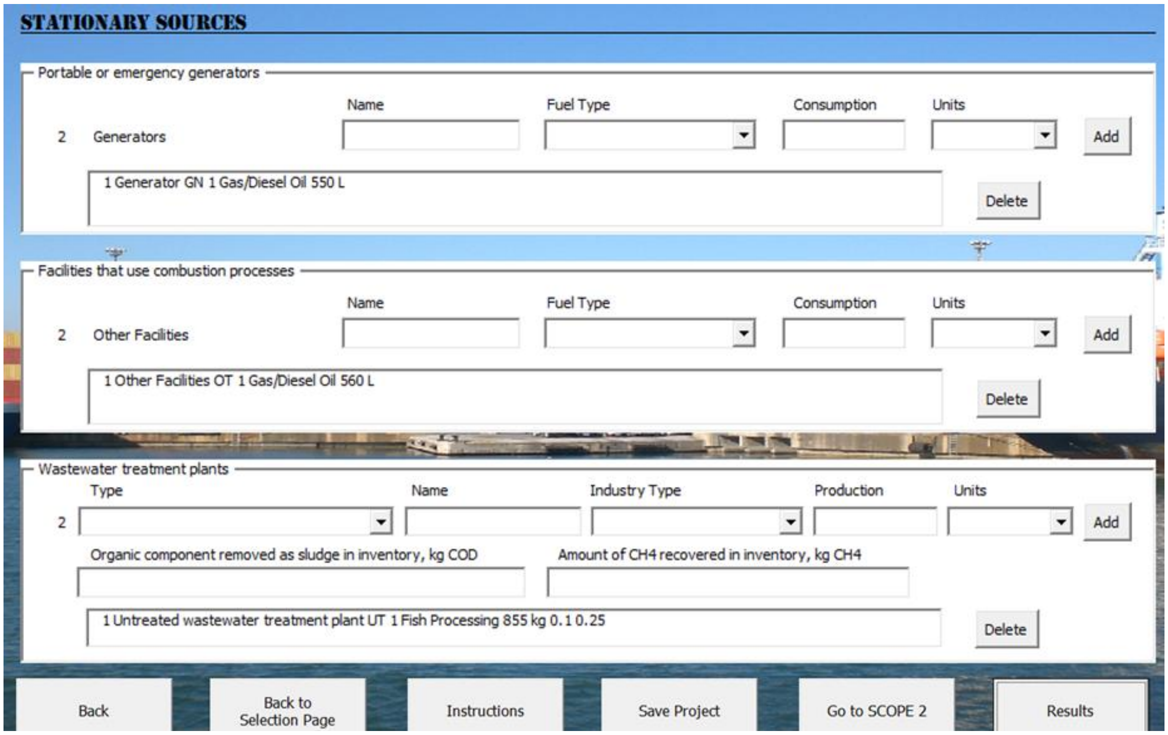



**Figure 9: Second calculation screen of the stationary sources (scope 1)**

## 4. <u>Scope 2</u>

Figure 10 presents the screen introduction to scope 2, where a brief definition of this scope is presented. By clicking the 'Next' button, you go to the calculation page for scope 2.

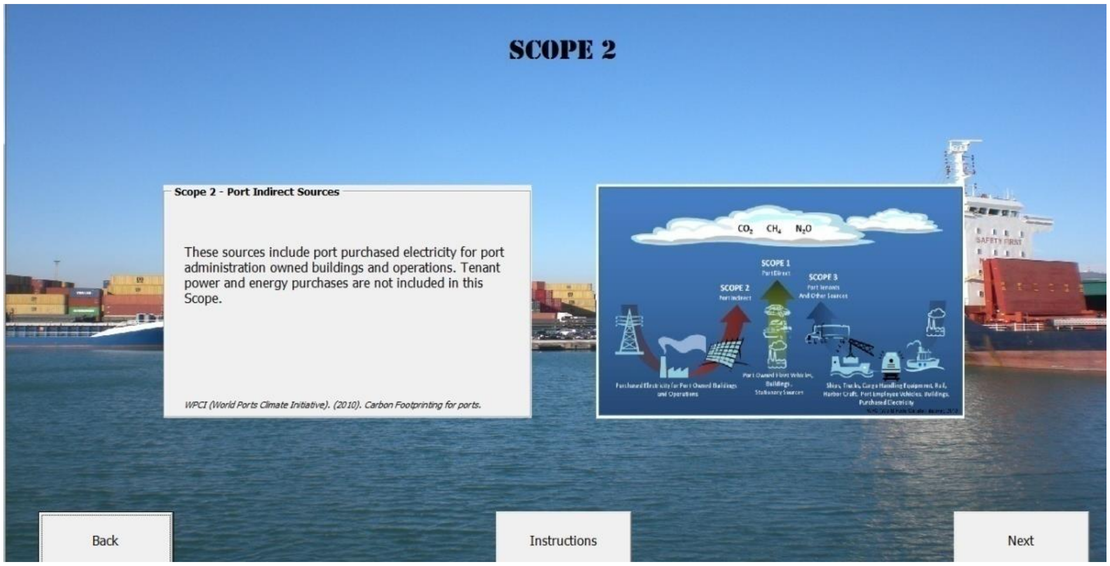



**Figure 10: Definition of scope 2**

In Figure 11, information on electricity data consumed by the port authority is required. The consumption amount has to be introduced and the intensity can be selected from a list according to the country. The mix of energy and therefore the emissions will vary in function of the country. If your country is not in the list or if you are not satisfied with the intensity value, you can choose the "other" and add your own value to the intensity box. By pressing the 'Add' button, different sources can be added to the emission list.

Then, the result of this scope can be obtained by clicking on the 'Results' button. Alternatively, you can press the button 'Go to Scope 3' and continue with the calculation.

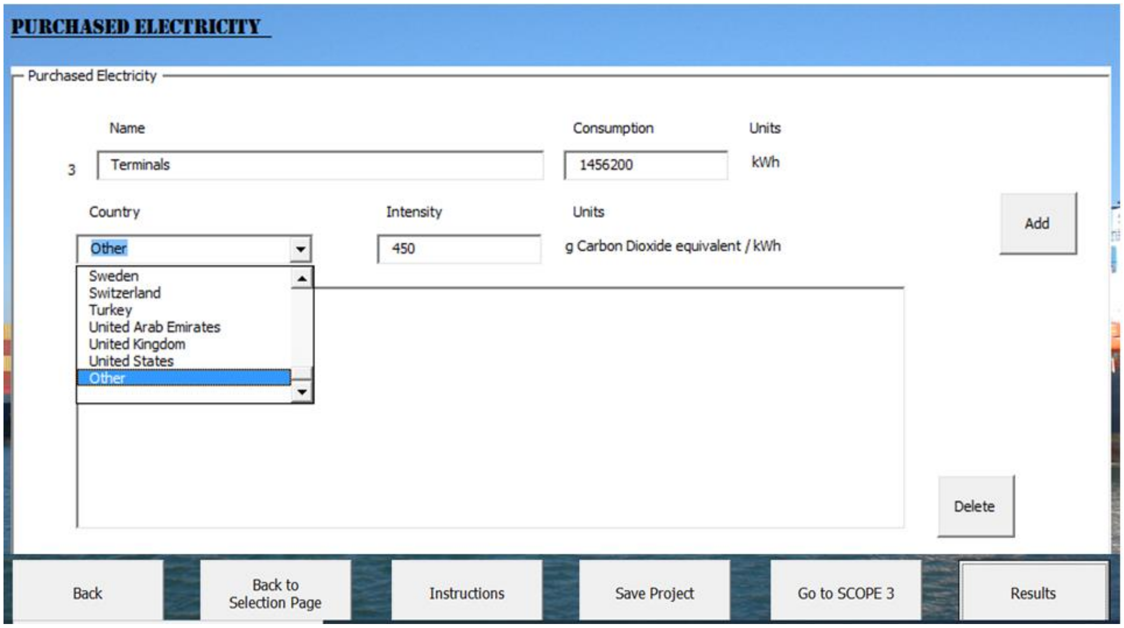



**Figure 11: Calculation screen of the scope 2**

**5. <u>Scope 3</u>**

If you have proceeded to scope 3, you will get a new screen (Figure 12) in which a definition of this scope is given. In this scope, you should provide data related to tenants 'emissions and only from those emissions produced by their activities inside the port area, not outside as mentioned in the note present in this screen.

These emissions are divided into four main groups: mobile sources, stationary sources, purchased electricity and employees' commuting. You should complete the needed data of these four sources in the next consecutive eight screens of the tool (Figures 13-21).

As it will be seen, most of the mobile and stationary sources are the same as scope 1, apart from 'Ocean-going vessels' in mobile sources that is included in this scope since they do not belong to the port authority.

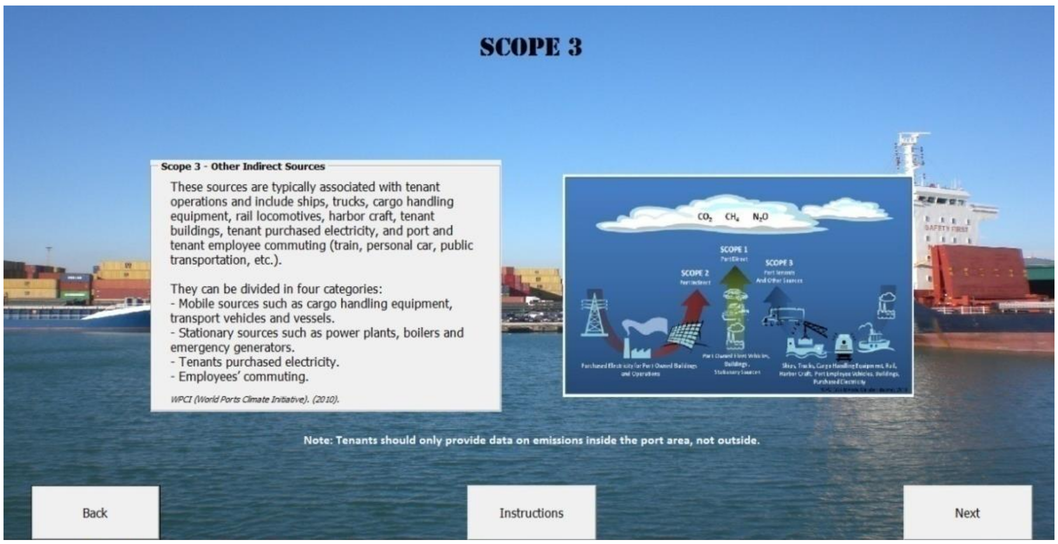


**Figure 12: Definition of scope 3**

By clicking on the 'Next' button in Figure 12, you could start to calculate the emissions of mobile sources of scope 3. As it can be seen in Figure 13, you should fill in the data related to the three categories of the mobile sources (if they exist in the port):

- Cargo Handling Equipment
- Heavy-Duty On-Road Vehicles
- Railroad Locomotives

In this step, the required data are fuel type, consumption amount and unit selection. Then, by pressing the 'Add' button, you could add all the sources you want to the list. By clicking on the 'Next' button, you will be taken to the next calculation page of scope 3.

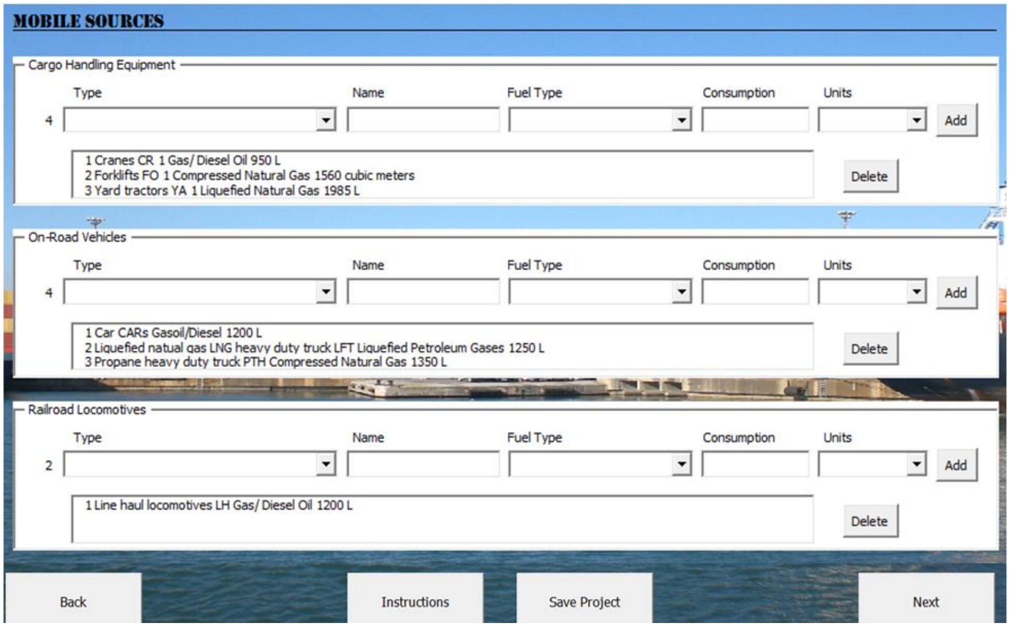


**Figure 13: First calculation screen of the mobile sources (scope 3)**

In the next page of the scope 3 (Figure 14), you should fill in the data related to three categories of mobile sources (if they exist in the port):

- Harbour craft and inland waterway vessels
- Ocean-going vessels
- Construction Equipment

Again for each cell, you should choose the source type, fuel type, consumption amount and consumption unit. Then by pressing the ‘Add’ button, you could add as many sources as you need to the list.

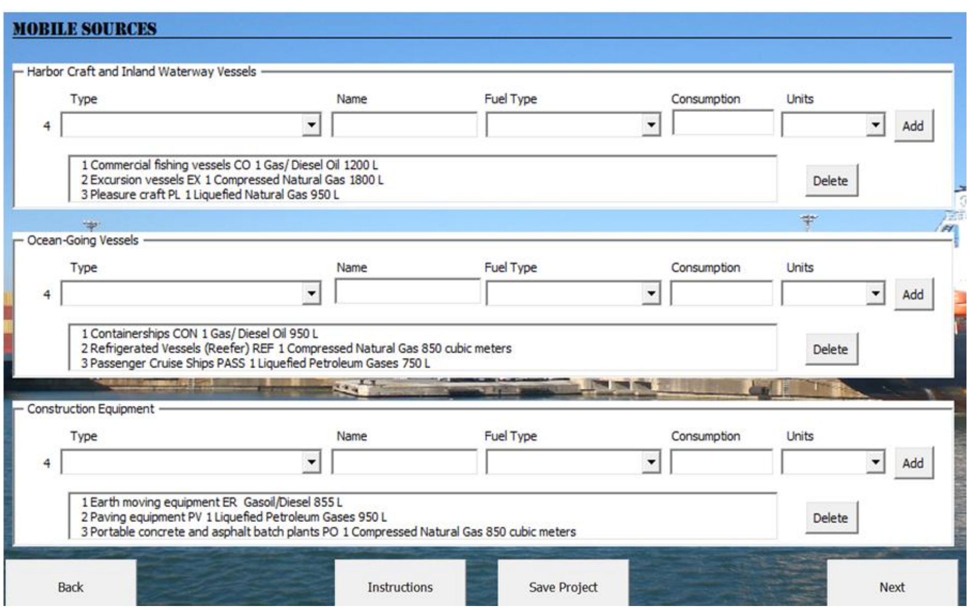


**Figure 14: Second calculation screen of the mobile sources (scope 3)**

In the next screen (Figure 15) you should fill in the required data (fuel type, consumption amount and consumption unit) related to 3 groups of stationary sources (if they exist in the port) which are:

- Power plants
- Boilers
- Incineration plants

By pressing the 'Add' button, you could add different sources to the calculation list. Please, remember to save the project from time to time to avoid losing the information provided.

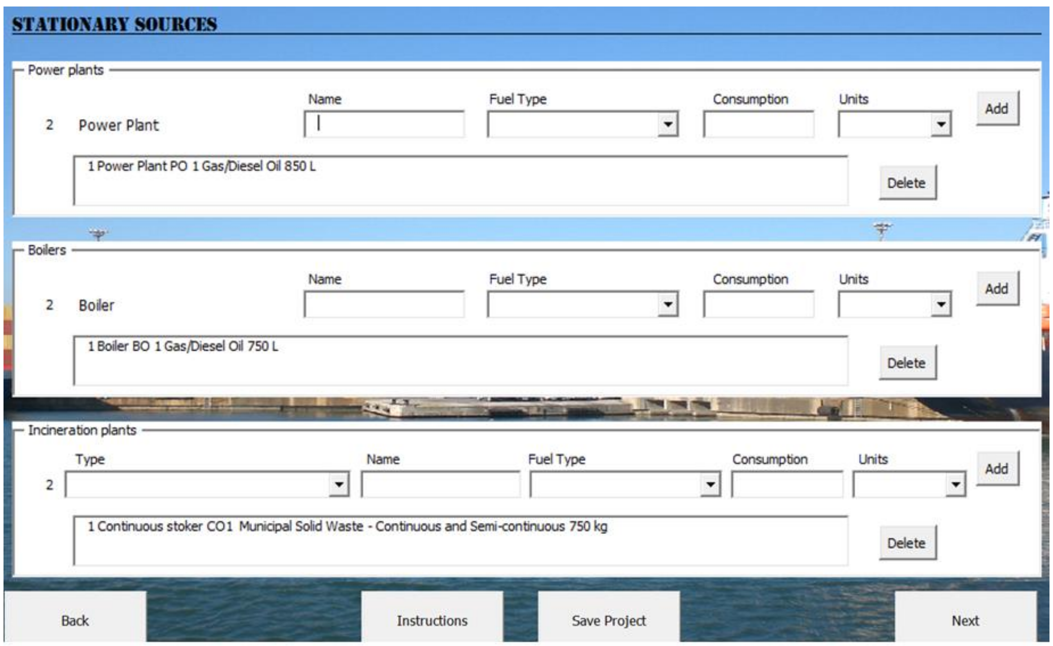



**Figure 15: First calculation screen of the stationary sources (scope 3)**

By pressing the 'Next' button, you will go to the next page of scope3. In this screen (Figure 16), you should fill in the required data (i.e. fuel type, consumption amount and consumption unit) related to three other groups of stationary sources (if they exist in the port) which are:

- Generators
- Facilities that use combustion processes
- Wastewater treatment plants

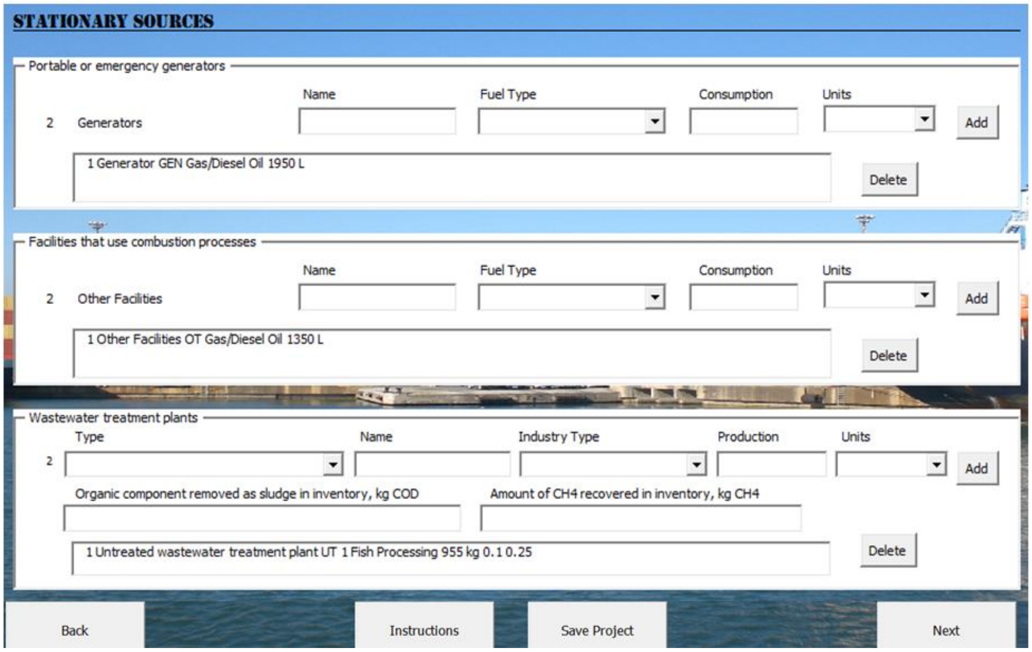


**Figure 16: Second calculation screen of the stationary sources (scope 3)**

By clicking on the 'Next' button you will calculate the emissions from tenant purchased electricity in scope 3. As in can be seen in Figure 17, the needed data of this stage are consumption amount and the intensity which should be chosen based on the country as explained before or it can be filled in manually in the "Intensity" box.

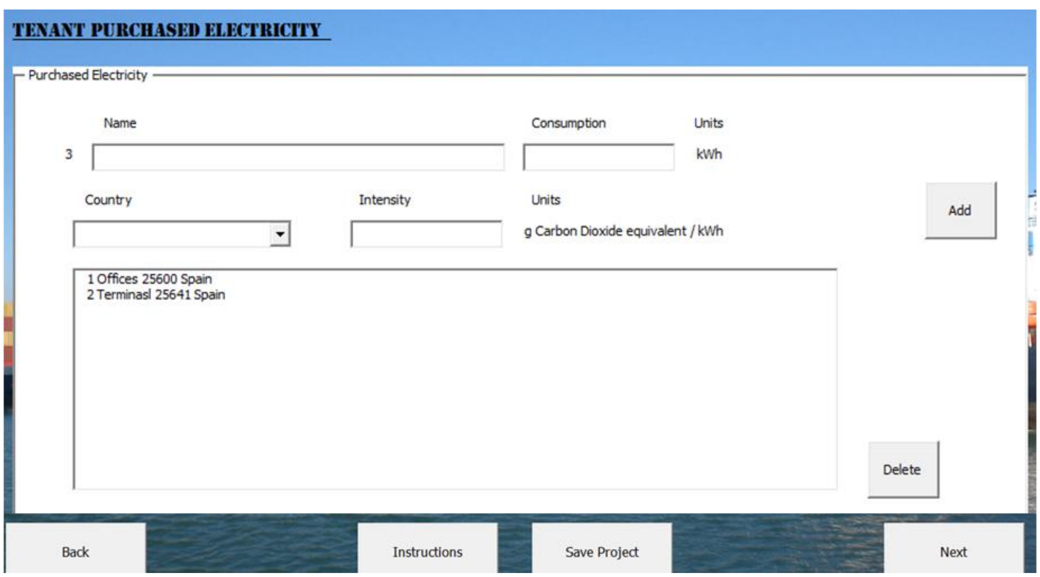


**Figure 17: Tenant purchased electricity emissions calculation screen (Scope 3)**

Finally, to calculate the emissions from employees 'commuting, you should decide which method is more convenient for you according to the available type of the data. Figure 18 offers a decision tree to select the most suitable calculation method for scope 3 emissions from employees' commuting. Ports may use one of the following methods (WRI and WBCSD, 2013):

- Fuel-based method: This method involves determining the amount of fuel consumed during commuting and applying the appropriate emission factor for that fuel.
- Distance-based method: This method involves collecting data from employees on commuting patterns (e.g. distance travelled and mode used for commuting) and applying appropriate emission factors for the modes used.
- Average-data method: This method involves estimating emissions from employees' commuting based on average (e.g., national) data on commuting patterns.

By clicking on the method, you will be taken to the related calculation page.

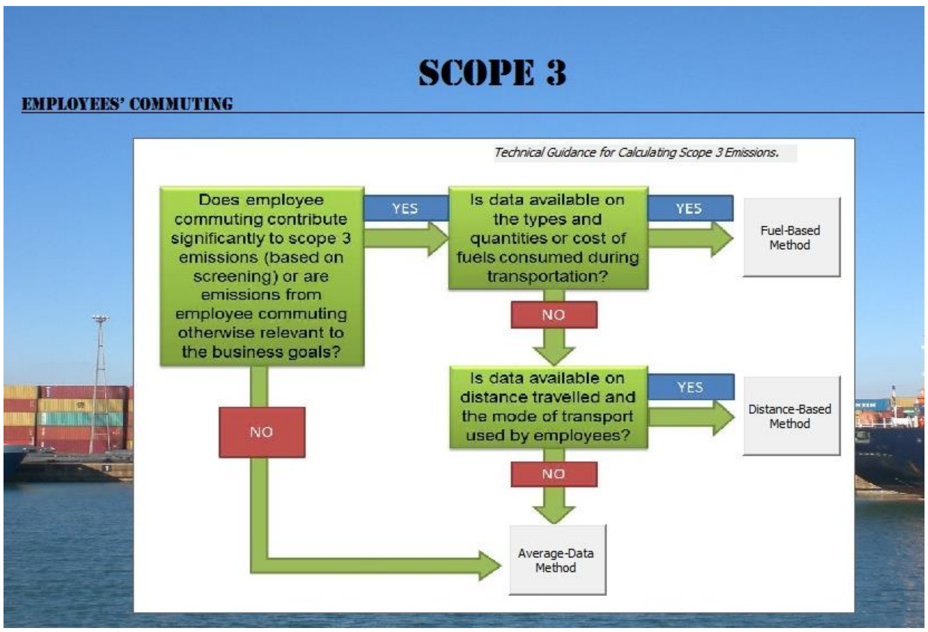



**Figure 18: Decision tree to select a calculation method for emissions from employees' commuting**

In Figure 19 you can see the calculation page of the Fuel-based method. As it can be seen, the required data are type of vehicle, fuel type, consumption amount and unit. By clicking on the 'Add' button, the data will be added to the list.

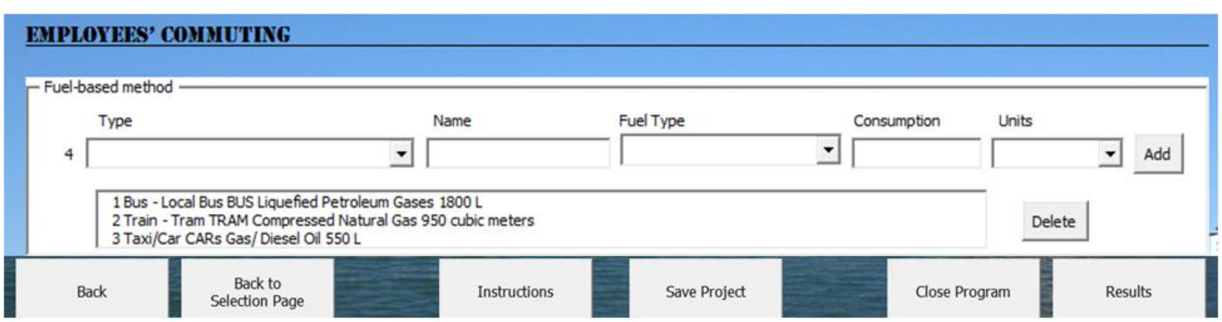



**Figure 19: Calculation screen of employees' commuting (Fuel-based method)**

Figure 20 shows the calculation page of the Distance-based method. As it can be seen, the required data are type of vehicle, working days, distance and unit. By clicking on the 'Add' button, the data will be added to the list.

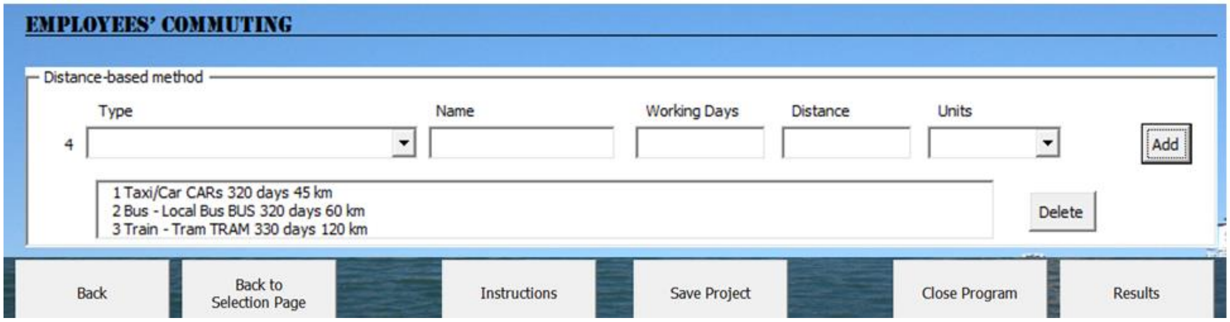



**Figure 20: Calculation screen of employees' commuting (Distance-based method)**

Figure 21shows the calculation page of the Average-data method. As it can be seen, the required data are total number of employees, working days, percentage of total commute based on the vehicle type and average one-way distance. By clicking on the 'Add' button, the data will be added to the list.

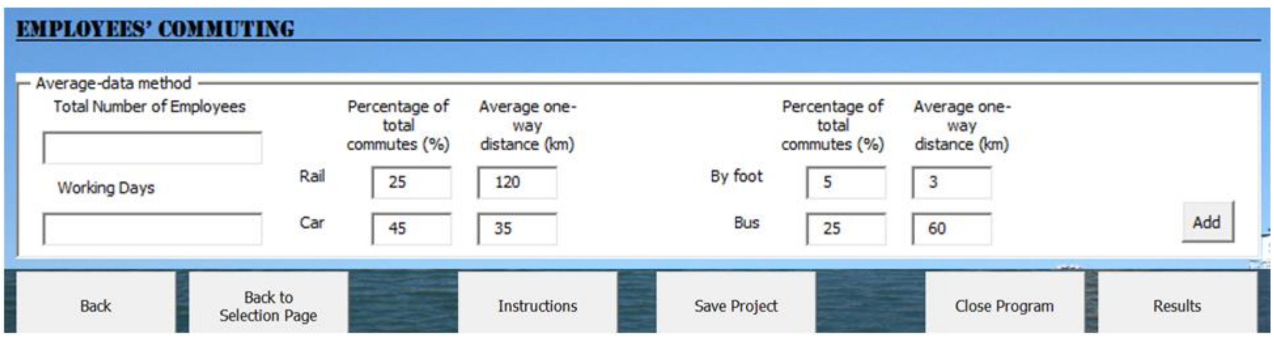



**Figure 21: Calculation screen of employees' commuting (Average-data method)**

## 6. <u>Results</u>

Finally, by clicking the 'Results' button, you can obtain a pdf file with the results. It includes the results for the total GHG emissions and also the emissions by each of the scopes and by capacity (TEUs or total cargo). A sample of the results is presented in Figures 22 and 23. The results of the tool are divided into four sections:

- **Total amount**

As it can be seen in figure 22, the first information that is presented is the name of the port, followed by the port address, the country and the capacity (TEU or tonnes). Then the total $CO_2$eq emissions are presented as well as the emissions by capacity (TEU/year or million tn/year). In addition, total values per scopes are displayed, including also a pie chart.

- **Scope 1**

In scope 1, the total amount of emissions and emissions of each of the mobile sources and stationary sources from this scope are presented including also two pie charts that summarize the information (Figure 22).

- **Scope 2**

As it is presented in figure 23, the total amount of emissions from purchased electricity is presented.

- **Scope 3**

In this part, the total amount of emissions and the emissions of each of the mobile sources, stationary sources, purchased electricity and employees' commuting from scope 3 are presented and their representation in two pie charts is included (Figure 23).

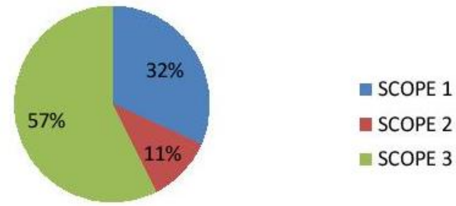
# Port Name

Port Address
Country

| | | |
|---|---|---|
| Capacity | 2550 TEU/yr. | 18555 million tn./yr. |

| | | |
|---|---|---|
| **TOTAL:** | 4866.281 $CO_2e$ tonnes | |
| **Carbon footprint:** | 1.908 $CO_2e$ tonnes/(TEU/yr.) | 0.3 $CO_2e$ tonnes/(million tn./yr.) |

| SCOPE | Emissions [$CO_2e$ tonnes] |
|---|---|
| 1 | 1547.035 |
| 2 | 529.321 |
| 3 | 2789.924 |
| TOTAL | 4866.281 |




Emissions by Scopes

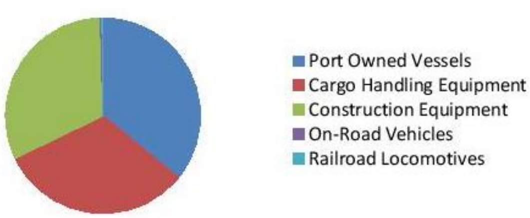
| | |
|---|---|
| **SCOPE 1:** | 1547.035 $CO_2e$ tonnes |

*Mobile Sources*

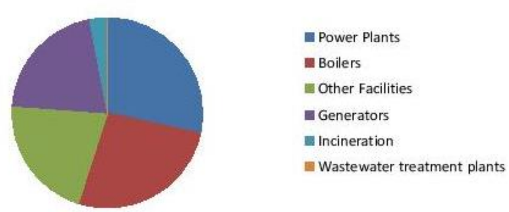
| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Port Owned Vessels | 482.069 | 35.92% |
| Cargo Handling Equipment | 428.502 | 31.92% |
| Construction Equipment | 425.775 | 31.72% |
| On-Road Vehicles | 3.454 | 0.26% |
| Railroad Locomotives | 2.423 | 0.18% |
| Total | 1342.223 | 100.00% |

*Stationary Sources*

| Field | Emissions [$CO_2e$ tonnes] | Percentage |
|---|---|---|
| Power Plants | 58.218 | 28.43% |
| Boilers | 54.337 | 26.53% |
| Other Facilities | 43.469 | 21.22% |
| Generators | 42.693 | 20.85% |
| Incineration | 6.083 | 2.97% |
| Wastewater treatment plants | 0.011 | 0.01% |
| Total | 204.812 | 100.00% |




Emissions by Mobile Sources




Emissions by Stationary Sources

**Figure 22: Sample of the results (Page 1)**

| SCOPE 2: | 529.321 | $CO_2$e tonnes |
|---|---|---|

*Purchased Electricity*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Electricity | 529.321 |

| SCOPE 3: | 2789.924 | $CO_2$e tonnes |
|---|---|---|

*Mobile Sources*

| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Cargo Handling Equipment | 884.636 | 47.96% |
| Construction Equipment | 483.116 | 26.19% |
| OGV | 461.694 | 25.03% |
| On-Road Vehicles | 6.094 | 0.33% |
| Harbor Craft | 5.496 | 0.30% |
| Railroad Locomotives | 3.545 | 0.19% |
| Total | 1844.582 | 100.00% |

*Stationary Sources*

| Field | Emissions [$CO_2$e tonnes] | Percentage |
|---|---|---|
| Generators | 151.367 | 38.76% |
| Other Facilities | 104.792 | 26.83% |
| Power Plants | 65.980 | 16.90% |
| Boilers | 58.218 | 14.91% |
| Incineration | 10.138 | 2.60% |
| Wastewater treatment plants | 0.015 | 0.00% |
| Total | 390.511 | 100.00% |

*Purchased Electricity*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Electricity | 14.757 |

*Employees' commuting*

| Field | Emissions [$CO_2$e tonnes] |
|---|---|
| Employees' commuting | 540.074 |

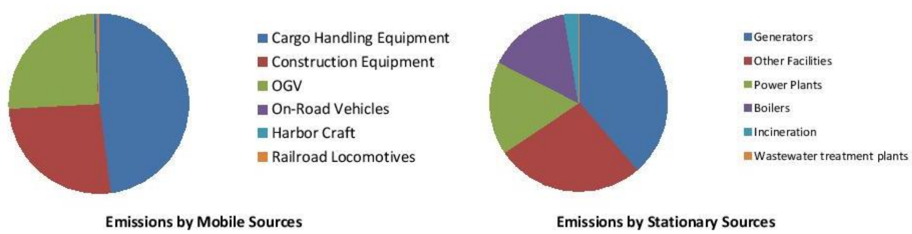



**Figure 23: Sample of the results (Page 2)**

## 7. References:

ESPO (European Sea Ports Organisation). (2019). Environmnetal report 2019 EcoPortsinSights 2019. *ESPO*, 1–23. Retrieved from https://www.espo.be/media/Environmental Report-2019 FINAL.pdf (Accessed 21.10.2019)

WPCI (World Ports Climate Initiative). (2010). *Carbon Footprinting for Ports, Guidance document*. Retrieved from http://wpci.iaphworldports.org/data/docs/carbonfootprinting/PV_DRAFT_WPCI_Carbon_Footprinting_Guidance_Doc-June-30-2010_scg.pdf (Accessed 15/11/2018)

WRI and WBSCD (World Resources Institute and World Business Council for Sustainable Development). (2013). *Technical Guidance for Calculate Scope 3 Emissions*. (Scope 3), 1–182. Retrieved from https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf (Accessed 07/02/2020)

# Appendix 6: Sources to create caste study model (Bandare-Bid port)

**Table 1: Estimation of fuel consumption by ship type and movement (Chang et al., 2013)**

| Ship type | Anchorage | Maneuvering to lock gates | Passing through lock gates | Approaching the dock | Docking | Total consumption (kg) | Vessel calls | Average per unit (kg) |
|---|---|---|---|---|---|---|---|---|
| LNG carrier | 2 | 63,440 | 1,327,790 | 969,122 | 16,788 | 2,377,143 | 146 | 16,282 |
| LPG carrier | 1246 | 78,894 | 980,256 | 425,534 | 8538 | 1,494,468 | 363 | 4117 |
| Towing tug | 12,482 | 233,720 | 2,265,307 | 518,508 | 29,467 | 3,059,484 | 1935 | 1581 |
| International car ferry | 0 | 761,409 | 20,756,867 | 17,233,040 | 134,148 | 38,885,463 | 1039 | 37,426 |
| Fuel supply vessel | 21 | 43,288 | 428,150 | 106,006 | 4506 | 581,972 | 396 | 1470 |
| Other tug vessels | 3589 | 228,542 | 1,946,797 | 195,228 | 12,330 | 2,386,485 | 713 | 3347 |
| Other chemical tankers | 37 | 3803 | 63,217 | 39,060 | 705 | 106,823 | 22 | 4856 |
| Other cargo vessels | 1345 | 17,264 | 170,251 | 41,699 | 3223 | 233,780 | 264 | 886 |
| Refrigerated cargo vessel | 36 | 1314 | 21,601 | 13,220 | 326 | 36,497 | 30 | 1217 |
| Sand carrier | 2348 | 29,720 | 293,665 | 72,447 | 1463 | 399,644 | 456 | 876 |
| Dry bulk carrier | 792 | 196,560 | 2,334,945 | 935,493 | 64,645 | 3,532,435 | 479 | 7375 |
| Chemical tanker | 1358 | 243,018 | 3,078,738 | 1,379,611 | 33,650 | 4,736,374 | 1724 | 2747 |
| Semi-container vessel | 59 | 25,853 | 355,118 | 178,827 | 4469 | 564,326 | 86 | 6562 |
| Cement carrier | 46 | 53,650 | 749,041 | 385,171 | 8269 | 1,196,176 | 226 | 5293 |
| Passenger ship | 8 | 50,365 | 870,880 | 556,448 | 4710 | 1,482,412 | 75 | 19,765 |
| Deep-sea fishing vessel | 8 | 1279 | 16,252 | 7321 | 128 | 24,987 | 16 | 1562 |
| Crude oil carrier | 145 | 46,125 | 471,845 | 131,125 | 3320 | 652,561 | 57 | 11,448 |
| General cargo vessel | 4197 | 539,931 | 7,460,719 | 3,786,142 | 178,033 | 11,969,021 | 2641 | 4532 |
| Car carrier | 81 | 182,303 | 7,870,446 | 7,496,605 | 141,082 | 15,690,517 | 401 | 39,128 |
| Chemical product carrier | 1611 | 185,121 | 2,538,387 | 1,275,347 | 18,955 | 4,019,420 | 855 | 4701 |
| Scrap carrier | 1015 | 95,444 | 925,035 | 211,691 | 5197 | 1,238,382 | 206 | 6012 |
| Full container vessel | 190 | 511,037 | 11,896,102 | 9,201,306 | 91,766 | 21,700,401 | 1654 | 13,120 |
| Total | 30,614 | 3,592,079 | 66,821,411 | 45,158,950 | 765,718 | 116,368,771 | 13,784 | |

**Table 2: Fuel consumed based on ship type and movement (Olukanni & Esu, 2018)**

| Ship type | Anchorage (kg) | Moving to lockgates (kg) | Passing through lockgates (kg) | Approaching the dock (kg) | Docking (kg) | Total consumption (kg) | Vessel calls | Average per unit (kg) | Total $CO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| LNG Carrier | 29,848.8 | 9,949.6 | 29,848.8 | 24,874.0 | 4,974.8 | 99,496.0 | 163 | 610.4 | 315,402.6 |
| LPG carrier | 26,725.6 | 8,908.5 | 26,725.6 | 22,271.4 | 4,454.2 | 89,085.6 | 155 | 574.7 | 282,401.4 |
| Cement ship | 64,996.5 | 21,665.5 | 64,996.5 | 54,163.7 | 10,832.7 | 216,655.0 | 96 | 2,256.8 | 686,796.5 |
| PMS | 12,2807.8 | 40,935.9 | 122,807.8 | 102,339.8 | 20,467.9 | 409,359.5 | 226 | 1,811.3 | 1,297,670 |
| General cargo vessel | 87,045.1 | 29,015.0 | 87,045.1 | 72,537.6 | 14,507.5 | 290,150.4 | 54 | 5,373.1 | 919,777 |
| Jet A-1 | 58,634.7 | 19,544.9 | 58,634.7 | 48,862.3 | 9,772.4 | 195,449.3 | 65 | 3,006.9 | 619,574.3 |
| AGO | 63,554.3 | 21,184.7 | 63,554.3 | 52,961.9 | 10,592.3 | 211,847.9 | 88 | 2,407.3 | 671,558.1 |
| Container vessel | 10,6505.6 | 35,501.8 | 106,505.6 | 88,754.6 | 17,750.9 | 355,018.7 | 262 | 1,355.0 | 1,125,409 |
| Passenger ship | 28,888.2 | 9,629.4 | 28,888.2 | 24,073.5 | 4,814.7 | 96,294.0 | 22 | 4,377.0 | 305,252.1 |
| Used vehicle carrier | 81,059.8 | 27,019.9 | 81,059.8 | 67,549.8 | 13,509.9 | 270,199.3 | 30 | 9,006.6 | 856,532.1 |
| Dry bulk carrier | 29,013.5 | 9,671.1 | 29,013.5 | 24,177.9 | 4,835.5 | 96,711.9 | 38 | 2,545.0 | 306,576.8 |
| Chemical products | 35,567.2 | 11,855.7 | 35,567.2 | 29,639.3 | 5,927.8 | 118,557.4 | 45 | 2,634.6 | 375,827.1 |
| Other chemicals | 38,282.5 | 12,760.8 | 38,282.5 | 31,902.0 | 6,380.4 | 127,608.3 | 31 | 4,116.3 | 404,518.4 |
| **TOTAL** | **772,930.1** | **257,643.3** | **772,930.1** | **644,108.4** | **128,821.6** | | **1,275** | | **8,167,296** |

**Table 3: Annual passenger transport (Passenger- km/capita) (Akerman & Hojer, 2006)**

| | 2000 | Reference 2050 | Sustainable 2050 |
|---|---|---|---|
| *Short-distance travel* (< 100 km) | | | |
| Car, combustion mode | 7600 | 9600 | 2300 |
| Car, electric mode | — | — | 700 |
| Small city vehicle | — | — | 700 |
| Bus | 700 | 700 | 1100 |
| Rail | 600 | 600 | 1100 |
| Bicycle | 200 | 300 | 900 |
| Walk | 300 | 300 | 800 |
| *Long-distance travel* (> 100 km) | | | |
| Car, combustion mode | 3200 | 6700 | 1400 |
| Bus | 400 | 200 | 700 |
| Rail | 500 | 700 | 1800 |
| Ferry (20 knots) | 50 | 300 | 100 |
| High-speed ferry (40 knots) | 20 | 100 | 40 |
| Air | 2900 | 13800 | 3000 |
| Total, passenger transport | 16500 | 33300 | 16900 |

**Table 4: Port of Olympia 2017 fleet GHG e missions summary (Akerman & Hojer, 2006)**

| Vehicle Category | Fuel Type | Fuel Used (gal) | Number of Vehicles | Total Emissions[1] (MT $CO_2e$) | Average Total Emissions per Gallon of Fuel (MT $CO_2e$/gal) |
|---|---|---|---|---|---|
| Downtown Olympia Vehicles | Gasoline | 6,968 | 26 | 55 | 7.9E-03 |
| | Diesel | 39,732 | 39 | 404 | 1.0E-02 |
| | Propane | 926 | 6 | 5.3 | 5.7E-03 |
| Downtown Olympia Boats | Gasoline | 1,169 | 4 | 10.3 | 8.8E-03 |
| | Diesel | 1,244 | 1 | 12.7 | 1.0E-02 |
| **Downtown Olympia Total** | **--** | **50,039** | **76** | **488** | **--** |
| Airport Vehicles | Gasoline | 1,599 | 7 | 13 | 7.9E-03 |
| | Diesel | 2,567 | 14 | 26 | 1.0E-02 |
| **Airport Total** | **--** | **4,166** | **21** | **39** | **--** |
| **Fleet Total** | **--** | **54,205** | **97** | **526** | **--** |

**Notes:**

[1] Total emissions for data reported by the Port of Olympia for January 1, 2017 through December 31, 2017.

--: Not calculated

**Table 5: Diesel consumption and corresponding emissions by various port-owned vehicles and equipment (Misra et al., 2017)**

| Sources of emission | Diesel consumption (L/year) | $CO_2e$ emissions (tonnes/year) | Total (%) |
|---|---|---|---|
| Generator | 16,000 | 43 | 0.62 |
| Vehicles | 142,186 | 381 | 5.52 |
| Mobile equipment | 163,143 | 437 | 6.34 |
| Diesel locomotives | 261,487 | 701 | 10.17 |
| Pilot launches | 125,896 | 337 | 4.89 |
| Mooring launches | 12,337 | 33 | 0.48 |
| Dredgers | 243,199 | 652 | 9.45 |
| Tugs | 1,606,692 | 4306 | 62.44 |
| Others | 2380 | 6 | 0.09 |
| Total | 2,573,320 | 6896 | 100 |

**Table 6: Energy consumption per type of equipment (Van Duin & Geerlings, 2011)**

| Energy | Type of equipment | Fixed consumption per container-move | Variable consumption | Terminals | Source |
|---|---|---|---|---|---|
| Electric | QC: Quay Crane | 6.00 kWh | | ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP | [18] |
| | BC: Barge Crane | 4.00 kWh | | ECT-D, APM, BCT, CTN, WIT | [18] |
| | RC: Rail Crane | 5.00 kWh | | ECT-D, APM | [18] |
| | ASC: Automated Stacking Crane | 5.00 kWh | | ECT-D | [18] |
| | RSC: Rail-mounted Stacking Crane | 7.25 kWh | | ECT-Ha, RST, UNP | ASC* |
| | P: Platform | 5.00 kWh | | RST | ASC* |
| Diesel | AGV: Automated Guided Vehicle | 1.10 l | 1.80 l/km | ECT-D | [18] |
| | SC: Straddle Carrier | 0.80 l | 3.50 l/km | ECT-D, ECT-Ho, APM, RST | [18] |
| | TT: Terminal Tractors | | 4.00 l/km | ECT-D, ECT-Ho, ECT-Ha, RST, UNP | [18] |
| | MTS: Multi-trailer System | | 4.20 l/km | ECT-D, ECT-Ho, APM, UNP | [18] |
| | RS: Reach Stacker/Top Lifter | | 5.00 l/km | ECT-D, ECT-Ho, ECT-Ha, APM, RST, UNP, BCT, CTN, WIT | [18] |

*Based on a comparison with the ASC on the ECT Delta terminal, in which the reach of the equipment (stack length) is taken into consideration.

**Table 7: Number of calls of ocean going vessels registered in the Port of Oslo and average annual operating time (AAOT), in hours (h), of the harbor vessels for 2013 (López-Aparicio et al., 2017)**

| Vessels | |
|---|---|
| *Oceangoing vessels* | *Calls* |
| Bulk carrier | 251 |
| RO-RO | 153 |
| Container | 449 |
| Cruise | 158 |
| International ferry | 1029 |
| General cargo | 667 |
| Oil/chemical tankers | 297 |
| Total | 3004 |
| *Harbour vessels* | *AAOT (h)* |
| Commercial fishing | 7 |
| Domestic ferry | 545 |
| Recreational | 140 |
| Supply vessels | 60 |
| Tug - push boat | 120 |
| Work boats | 30 |
| Other vessels | 140 |

## Appendix 7: Publications derived from this thesis

As it can be seen in this section, from the results of this thesis 3 papers were published. In addition, the tool and its results were presented at the 8th international conference on Maritime Transport in Barcelona (September 2020), at the online meeting of the Digital and Green Route Community working group (June 2021) and at the 17th International Conference on Environmental Science and Technology in Athens in Greece (September 2021). These are the references of these papers and in the following pages that articles are presented:

1. Azarkamand,S., Balbaa,A., Wooldridge,Ch., and Darbra,RM .,Climate Change—Challenges and Response Options for the Port Sector, Sustainability Journal, 12, 6941. 2020. doi:10.3390/su12176941
2. Azarkamand,S., Wooldridge,Ch., and Darbra,RM., Review of initiatives and methodologies to reduce $CO_2$ emissions and Climate Change effects in ports. International Journal of Environmental Research and Public Health.17, 3858. 2020. doi:10.3390/ijerph17113858
3. Azarkamand,S., Ferré,G. and Darbra,RM., Calculating the Carbon Footprint in ports by using a standardized tool. Science of the Total Environment (STOTEN 139407). 734 139407. 2020. doi:10.3390/ijerph17113858
4. Azarkamand,S., Ferré,G. and Darbra, RM. Development of a standardized tool to calculate Carbon Footprint in ports. 8th International conference on Maritime Transport, Barcelona, Spain. September 2020.
5. Azarkamand,S., Ferré,G. and Darbra, RM. Carbon Footprint in Ports: Standard Tool to calculate GHG emissions. The online meeting of the Digital and Green Route Community working group. June 2021.
6. Azarkamand,S., Ferré,G. and Darbra,RM. Calculating Carbon Footprint in ports through a new Standard Tool: case study applications. 17th International Conference on Environmental Science and Technology. Athens, Greece, September 2021.