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D.1.3: Results of demo-ports' LCA & ESG sustainability assessments

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List of Abbreviations

Abbreviation	Description
APOS	Allocation at the Point of Substitution
1,4-DCB	1,4-DiChloroBenzeen
CO2eq	Carbon Dioxide Equivalents
CFC	Chloro Fluoro Carbons

Abbreviation	Description
CML	Centrum voor Milieukunde Leiden Methodology
EC	European Commission
EU	European Union
EPS	Environmental Priority Strategies Methodology
eq	Equivalent
ESG	Environmental, Social, and Governmental Assessment
EHOO	Ennshafen Port
FU	Functional Unit
FV	Fundacion Valenciaport
GW	Global Warming
GHG	GreenHouse Gas
GRI	Global Reporting Initiative
Kg CO2	Kilograms of Carbon Dioxide
KBq Co-60	Ionising Radiation
Kg CFC11 eq	Kilograms of Chloro Fluoro Carbons 11 equivalent
IPCC	Intergovernmental Panel on Climate Change
L	Liters
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LNG	Liquified Natural Gas
MP	Master Plan
MJ	Mega Joules
m^3	Cubic meter
NOx	Nitrogen Monoxide

Abbreviation	Description
ODS	Ozone Depleting Substances
PV	Port of Valencia
PM2.5	Particulate Matter Formation
ReCiPe	ReCiPe method
RTG	Rubber Tyred Gantry crane
SASB	Sustainability Accounting Standards Board
SDGs	Sustainable Development Goals
SEANERGY	Sustainability EducationAl programme for greeNEr fuels and enerGY on ports
SP	Syros Port
SOD	Stratospheric Ozone depletion
SOx	Sulfur Monoxides
TEU	Twenty-foot equivalent unit
WMU	World Maritime University

Executive Summary

The deliverable « *D1.3_ Results of demo-ports' sustainability assessments (M7) - Report on LCA, ESG, and EU strategies desk research* » led by ZER0-E and WMU, belongs to the SEANERGY project (**Grant agreement ID: 101075710**). As part of the « *WP1_Understanding the current EU ports' situation and stakeholders* », « *Task 1.3 Holistic sustainability assessment of current European port energy and fuel technologies* » is divided into « *Task 1.3.1 Black-Box LCA Approach led by ZER0-E* » aiming to address the feasibility of the energy and fuels technologies used in standard ports' daily operations. LCA methodologies applied in this report follow the ISO 14040: 2006 and ISO 14044: 2006. « *Task 1.3.2 ESG Assessment of Energy and Fuels on Ports led by WMU* » aims to examine the environmental, social, and governmental factors related to the energy and fuel technologies used in the port industry.

The purpose of this document is to present an overview of the current technological situation of the DEMO ports selected by the SEANERGY project analysing the use of energy and fuel technologies to quantify the carbon footprint and GHG emissions generated by standard operations in the daily activities. Life cycle assessment of the DEMO sites has been developed using a « Black-Box approach ». This report provides an interpretation of the results given recommendations for improvement on the demo sites' daily operations. It also helps to complete the E-S-G assessment of energy and fuels on ports which is developed by WMU, giving a relationship between the stakeholders and the community involved in the port operations.

1. Introduction

1.1. Background and Purpose

The EU port industry is currently one of the economic pillars of the European community. Although being hit by the economic recession caused by COVID-19's restrictions, on average, around 74% of goods imported and exported, and 37% of exchanges with outside entities, go through seaports. However, these vital infrastructures are responsible for a significant rise in environmental impacts in terms of carbon emissions, soil & water pollution, and loss of biodiversity, among others (European Parliament, 2021). Not in vain, maritime transport in the EU accounts for approximately 13% of its transport GHG emissions. This fact puts the greening of the port's emitting activities as necessary to achieve the ambitious goals for 2030 (55% reduction) and 2050 (net zero). In parallel, the Sustainable and Smart Mobility Strategy, flowing from the European Green Deal, set as a flagship the achievement of zero-emission ports, becoming "clean energy hubs for integrated electricity systems, hydrogen and other low-carbon fuels, and testbeds for waste reuse and the circular economy" (European Commission, 2021). Consequently, the EC is proposing measures to incentivize the deployment of renewable and low-carbon fuels and feeding stationed vessels with renewable power instead of fossil energy, incentivizing the development and use of new, cleaner, and quieter vessels, greening port services and operations, optimisation of port calls, and through wider use of smart traffic management (European Commission, 2021).

The SEANERGY project aims to provide a solution to this challenge through the creation of the SEANERGY Master Plan (MP), a strategic, dynamic document that will guide and standardize the transition of European ports towards more sustainable practices. It will allow all the port industry's stakeholders, regardless of their geographical context, to assess, plan and execute the necessary activities towards transforming ports into clean energy hubs. The MP will be, therefore, the main reference for all port institutions approaching the preparation of an environmental and energy planning document. Activities such as training, reskilling, awareness spreading and communication channels creation, will set the basis of the green port transitioning, creating spaces of dialogue and teaching among all agents of the industry (academia, private and public), which will boost the development and integration of these technologies, along with prepared professionals that will be able to manage and implement them promptly, securely, and efficiently.

To achieve the above objectives from the point of view of sustainability, taking into account the technological, social, economic and environmental issues, the project has proposed the development of Task 1.3 referred to as the Holistic Sustainability Assessment of EU port energy and fuel technologies, which in turn is divided into Subtask 1.3.1 referred as Life Cycle Assessment (Black-Box LCA Approach) and Subtask 1.3.2 referred as Environmental, Social, Governmental Assessment of energy and fuel on ports (ESG Assessment Approach). The exercise is properly the development of deliverable D1.3 Results of DEMO-ports´sustainability assessments on LCA, ESG, and EU strategies desk research.

1.2. Scope and Objectives

The purpose of deliverable D1.3 is to establish a baseline of the impacts in ports. By studying three DEMO ports such as Valencia Port, Syros Port and Ennshafen Port. This will include a Black Box Approach to the Life Cycle Assessment (LCA) and Environmental, Social and Governance Analysis (ESG). The first step is the elaboration of the LCA analyses and the results of them will be possible to make the ESG study. Once the results of the impacts are shown, it is possible to identify the major source of contribution to the impacts. This information is key to developing the Master Plan of the SEANERGY project considering the defined stakeholder framework (Figure 1).

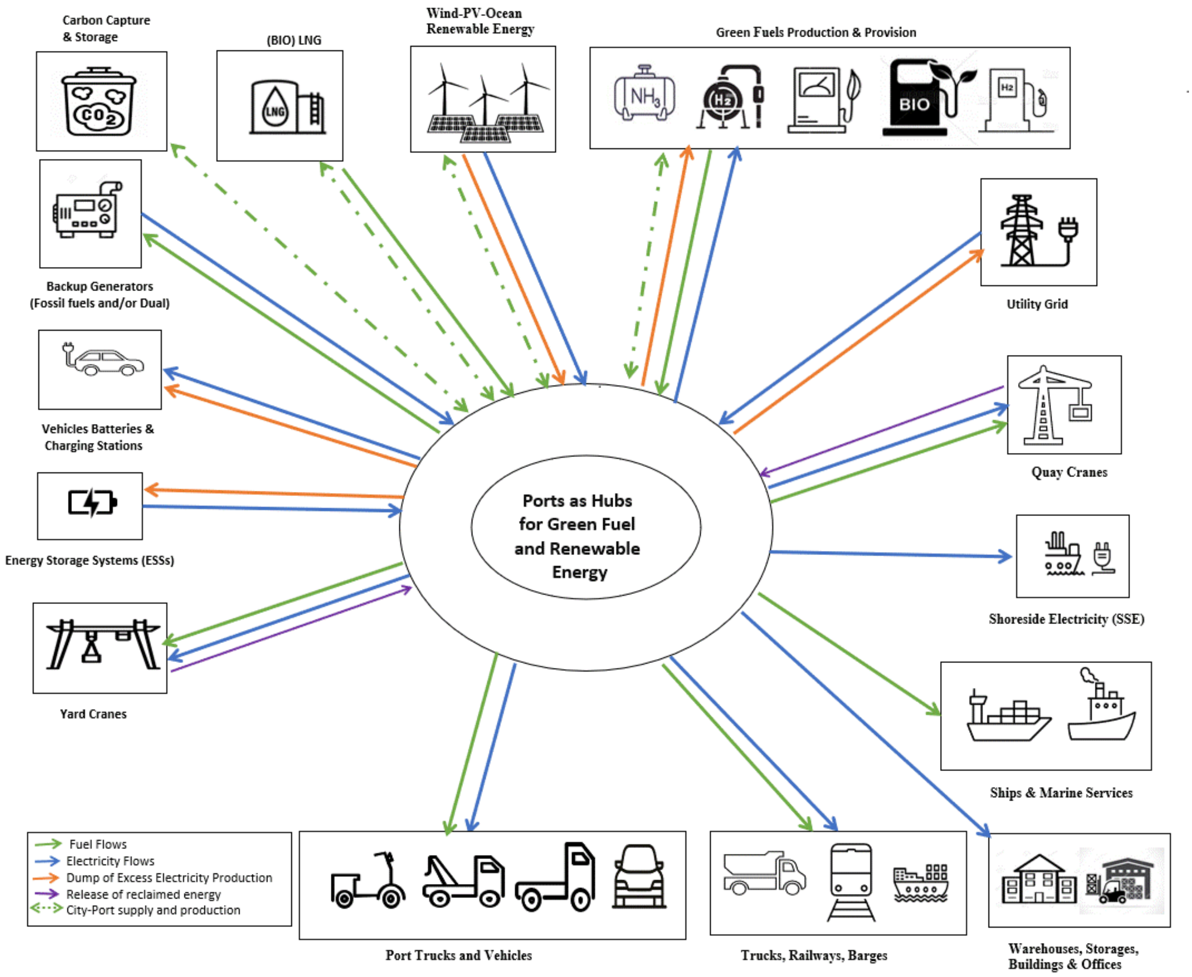


Figure 1 SEANERGY stakeholder framework

On the other hand, the E-S-G analysis serves as a framework for achieving sustainability. It is fundamental in the decision-making process and the creation of long-term plans. Given the above, this document seeks to identify the best technical, operational, and governance strategies to reduce CO_2 emissions and integrate social and environmental aspects in the port industry, which in turn could lead to improving the financial results of the interested parties.

1.3. Task Overview (role of Leaders and Participants)

For this task, it was involved the participation of 6 partners from the consortium:

- ZER0-E: Leader of task 1.3 and responsible for the LCA development.
- WMU: Responsible for the ESG study.
- RINA: Support for the LCA and ESG studies.
- Fundacion Valenciaport (FV): Valencia's Port contact, responsible for data collection for the inventory.
- SP-DAFNI: Syros Port contact, responsible for data collection for the inventory.
- Ennshafen OÖ GmbH: Ennshafen Port contact, responsible for data collection for the inventory.

1.4. Relation to other project deliverables

The subtask (1.3.2) is in completing task 1.3.1 (Black-Box LCA Approach) to analyse how the energy transition can impact the port's environmental, social, and governance aspects. In addition to that, some aspects developed in subtask 1.4.1 (Desk Research on EU Strategy), and subtask 1.4.2 (Tech-Port Matchmaking), were incorporated to develop the ESG analysis for port decarbonization.

2. Demo Ports Introduction

2.1. Port of Valencia (PV)

Located in the east of Spain, Valencia Port has become a port to prioritize the transition to a sustainable pathway to achieve zero emissions in 2030. It has implemented different strategies to decrease its carbon footprint, like hydrogen-powered trucks and renewable energy suppliers.

Its location plays a key role in shipping lines operating in the Western Mediterranean. It also influences the routes between Europe and North African countries. Valencia's Port Authority shares on the official website "Port of Valencia is the best and most efficient option for maritime trade in southern Europe, with connections to over 1,000 ports worldwide. The Port of Valencia has port and intermodal infrastructure, making port activities and goods transport highly efficient and with competitive charges and tariffs." (Valenciaport, s.f.)

According to the statistical report 2022 from Port of Valencia, the accumulated TEU traffic in 2022 was higher than 5 million. This data is going to be used to measure the impact of the port.

2.2. Ennshafen Port (EHOO)

The Ennshafen port is located between two of Europe´s main transportation corridors, the Rhine-Main-Danube canal system, which links the North Sea to the Black Sea, and the north-south connection from the Baltic Sea to the Adriatic. Ennshafen Port connects the business parks of Enns and Ennsdorf, making the port a high stakeholder for that industrial area.

As a multi-modal logistics hub, the Container Terminal Enns is a major hinterland terminal for the big seaports. Spanning some 275,000 square meters and with a capacity of 500,000 twenty-foot equivalent units (TEUs), it has some of the most modern transhipment infrastructure in Austria. Block train rail connections, modern gantry cranes, and a full range of services ensure optimum container handling. The roll-on/roll-off terminal offers best-in-class service for heavy lift and project cargo; vehicles and agricultural machines can drive straight on and off vessels without additional facilities. The port is a trimodal transhipment center. It provides services such as transhipment, heavy cargo transhipment, warehousing, packaging, and bunkering (ENNSHAFEN, s.f.).

2.3. Syros Port (SP)

Syros Port is on Syros Island in the Cyclades. It connects the island with the Greek mainland and the Islands of Kalymnos, Iraklia, Mykonos, Patmos, Crete, Amorgos, Anafi, Naxos, Kos, Symi, Rhodes, Paros, Ios, Donoussa, Ikaria, Andros, Chios, Folegandros, Fournoi, Samos, Kea, Kimolos, Kythnos, Leros, Limnos, Lesbos, Oinousses, Schinoussa, Serifos, Sifnos, Sikinos, Thira, Thirasia, Tinos, Milos, and Euboea (THE SHIPPING PLATFORM, s.f.). It has passenger facilities, dry bulk, liquid, containers, and break bulk. Today, apart from the offices, the travel agencies and other port services, the port hosts primarily recreational functions with numerous restaurants, cafes, and nightclubs, making it the busiest area of Syros, until the early morning hours (Port of Syros Hermoupolis, s.f.). The main traffic in this port is passengers since it is a tourist area, there are a lot of cruise and tourist movements. For this port, the unit used to measure the impact is going to be shipments.

3. Black-Box Life Cycle Assessment Approach (LCA)

3.1. Methodology

The Life Cycle Assessment (LCA) measures the environmental impacts of a process, product, or service. The studies done in this deliverable follow the ISO 14040:2006 and ISO 14044:2006.

- **ISO 14040:2006** Environmental management- Life Cycle Assessment-Principles and framework.
- **ISO 14044:2006** Environmental management- Life Cycle Assessment- Requirements and guidelines.

There are 4 phases to build an LCA (Figure 2):

- **Goal and Scope definition**: this part is to define the objective and range of study (scope) of the process, product, or service. Moreover, it is defined as the functional unit (FU), which is the reference for the calculations in the impact. Depending on the study the FU, can be through volume, weight, energy, and quantity of product, among others.
- **Inventory analysis (LCI):** after the goal and scope definition, it follows all the data collection needed for the analysis. According to the scope, the inputs and outputs from the study will be required.
- **Impact Assessment (LCIA):** for this phase, it is calculated the environmental impact. It is important to mention that there are a variety of methodologies (IPCC, ReCiPe, ecological scarcity, EPS, ecosystem damage potential, and CML, among others). The measure of the impact corresponds to the FU, for example, $kgCO_2eq/FU$.
- **Interpretation:** finally, after the LCIA the interpretation of the results must be shown. What are the recommendations, where are the opportunity areas, what process stands out, and what conclusions.

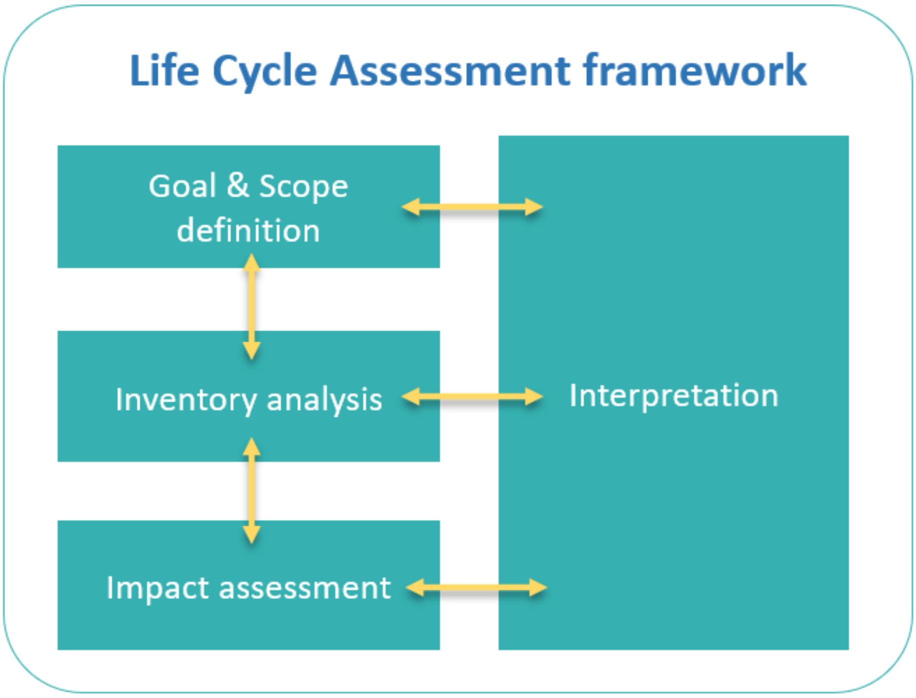


Figure 2 LCA framework

3.2. LCAs´ Goal and Scope Definition

The goal of the following LCAs is to measure the environmental impact of each demo port. The results of the LCA will help establish a baseline to identify opportunity areas in the demo ports to implement strategies into the Master Plan increasing energy efficiency and reducing CO2 emissions. To achieve this objective, the impact indicators to be considered will be as follows (Table 1) (SimaPro, 2020):

Table 1 Environmental impact indicators definition

IMPACT INDICATOR	UNIT
Total energy consumption	MJ
Global Warming (GW). Expresses the amount of additional radiative forcing integrated over time (20 years) caused by the emission of 1kg of GHG relative to the additional radiative forcing integrated over that same time horizon caused by the release of 1 kg of CO2.	Kg CO_2 eq

IMPACT INDICATOR	UNIT
Human Carcinogenic Toxicity. A calculated index that reflects the potential harm of a unit of chemical released into the environment, is based on both the inherent toxicity of a compound and its potential (Hertwich EG et al., 2001). The unit for this index is Dichlorobenzene.	Kg 1,4-DCB
Human non-carcinogenic toxicity. Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation.	Kg 1,4-DCB
Ozone formation human health. Ozone is not directly emitted into the atmosphere, but it is formed because of photochemical reactions of NOx and Non-Methane Volatile Organic Compounds.	kg NOx eq
Ionizing radiation. Form of energy that acts by removing electrons from atoms and molecules of materials that include air, water, and living tissue. Ionizing radiation can travel unseen and pass through these materials.	kBq Co-60 eq
Fine Particle matter formation. Indicator that measures a group of substances: ammonia, Nitrate Nitrogen monoxide, Nitrogen oxides, particulates <2,5 um, sulfur dioxide, sulfur oxides and sulfur trioxides.	kg PM2.5 eq
Stratospheric Ozone depletion (SOD). One of the planetary boundaries measures the contribution of the degradation of the ozone layer. The World Meteorological Organization (WMO) defines the ozone depletion potential of different gases relative to the reference substance chlorofluorocarbon.	kg CFC11 eq
Terrestrial ecotoxicity. The chemical 1,4-dichlorobenzene (1,4-DCB) is used as a reference substance in the midpoint calculations by dividing the calculated potential impact of the chemical by the potential impact of 1,4-DCB emitted to urban air for human toxicity, to fresh water for freshwater ecotoxicity, to seawater for marine ecotoxicity and industrial soil for terrestrial ecotoxicity.	kg 1,4-DCB
Freshwater ecotoxicity. The chemical 1,4-dichlorobenzene (1,4-DCB) is used as a reference substance in the midpoint calculations by dividing the calculated potential impact of the chemical by the potential impact of 1,4-DCB emitted to urban air for human toxicity, to fresh water for freshwater ecotoxicity, to seawater for marine ecotoxicity and industrial soil for terrestrial ecotoxicity.	kg 1,4-DCB
Fossil resource scarcity. Obtained by dividing the higher heating value of extracted fossil resources by the higher heating value of crude oil.	kg oil eq
Water consumption	m^3

The project's scope is to analyse the port-hinterland interface to the ship-port interface (Figure 3).

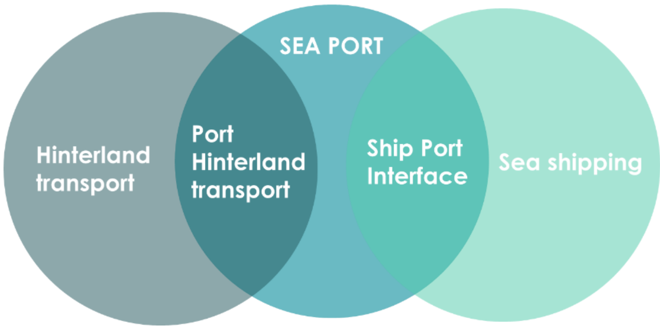


Figure 3 SEANERGY LCA scope

The Functional Unit (FU) defines the quantification of a product or product system based on the performance it delivers in its end-use. This measure provides a reference to which the inputs and outputs can be related, allowing the comparison of alternative systems. For the ports, no guideline suggests the functional unit recommended to carry out an LCA, therefore based on other scientific publications related to this topic, the utilization of an FU related to the type of operations or cargo capacity (RTG, ships, TEUs, tkm, etc.) is recommended. After defining the goal and scope, system boundaries and functional unit, a template was elaborated to collect each DEMO port's Life Cycle Inventory (LCI) focused on fuel and energy consumption to continue with the LCA methodology. Each partner was asked to fill out the basic data required for the port (port, location and area) in this template. Also, the energy and fuel consumption data were requested (Figure 4):

- Docks: Logistics and maintenance in the ship-port interface. Considering boats, security, and pumps.
- Storage: Logistics and maintenance of the storage.
- Intern-transportation: Port hinterland, such as operation buildings, upload cargos for delivery, lightning, etc.

Figure 4 LCI template

The following sections present the inventory, assumptions and the results of the impact obtained in SimaPro software of each DEMO port.

Attributional approach cut-off criteria

The attributional approach has been followed for modelling the LCI in SimaPro. This approach assigns relevant physical flows and potential environmental impacts to a specific product system to and from a life cycle, giving an estimate of what part of the global environmental burdens belongs to the study object. To achieve that, the basis for this allocation has to be a property that the process's products and/or functions have in common: mass, energy content, economic value, etc. The total output of the process can be quantified in terms of this property, and the burdens of the process can be partitioned and allocated to the different products/functions in proportion to this property (Ekvall, 2019).

Within the attributional approach, two different modelling methods exist in SimaPro (Ecoinvent, s.f.):

- The cut-off allocation method. In this system model, wastes are the producer's responsibility ("polluter pays"), and there is an incentivisation to use recyclable products, that are available burden-free (cut-off).
- The Allocation at the Point of Substitution (APOS). It follows an attributional approach in which the responsibility over wastes (burdens) is shared between producers and

subsequent users benefiting from the treatment processes by using valuable products generated in these.

Considering all of this, the cut-off allocation method has been followed in this analysis. In general, most of the data included in the LCI tables was collected directly from each port and modelled directly in SimaPro using the available datasets from Ecoinvent v3.9.1.

Furthermore, it is important to highlight that the results presented are normalized and calculated by ReCiPe 2016 v1.1 midpoint. The ReCiPe 2016 method is a new version of ReCiPe 2008, created by the Dutch National Institute for Public Health and the Environment (RIVM), Radboud University Nijmegen, Norwegian University of Science and Technology and PRé Sustainability (ReCiPe, s.f.).

3.3. Port of Valencia LCA

Port of Valencia is located in the city of Valencia, Spain with a total area of 5.6 km^2. The port has specialized high-performance facilities for all types of traffic (liquid bulk, solid bulk, conventional general cargo, containerized general cargo and passengers). In addition, the port has more than 12,000 m of docks with drafts of up to 17 meters that make it possible for the largest container ships to scale, more than 30 gantry cranes specialized in the handling of containerized and non-containerized general merchandise and 300 hectares of storage (Valenciaport, s.f.).

For the assessment, the FU used as a common reference to report the results in the Port of Valencia study is 1 TEU (Twenty-foot equivalent unit). TEU is an exact unit of measurement used to determine cargo capacity for container ships and terminals. In 2021 and 2022, as the statistical report of the Port of Valencia shows, the port received 5,604,478 TEU and 5,052,272 TEU, respectively (Valenciaport, s.f.).

3.3.1. LCI

The LCI of the Port of Valencia is listed in Table 2. This provides a list of equipment, their quantities and energy consumption (electricity or fuel oil) per year. The data was given by the Fundacion Valenciaport across the LCI template completed in February of the present year, through calls and emails. Furthermore, to complete some missing information, the following reports were used:

- “Informe de emisiones de gases de efecto internadero del Puerto de Valencia – 2016”.
- “Guía metodológica para el cálculo de la huella de carbono en puertos – 2020”.

Table 2 LCI Port of Valencia (2023)

SOURCE EQUIPMENT	QUANTITY	TYPE OF FUEL	CONSUMPTION PER EQUIPMENT	
			CONSUMPTION	UNIT
Tugboats	6	Marine gas oil	-	
Commercial vessels	6500	Marine gas oil	-	
Quay Crane	40	Certified renewable energy	-	
Container handler, Top handler	24	Diesel	30000	L
Reach Stacker	23	Diesel	37500	L
RTG Crane (D)	105	Diesel	54000	L
Terminal tractor	236	Diesel	21000	L
Forklift	3	Certified renewable energy	-	
RTG crane (E)	24	Certified renewable energy	-	
Trucks	3500	Diesel	-	
Electricity consumption port facilities	-	Certified renewable energy	-	

To fill out the table the following assumptions were considered:

- For the tugboats and commercial vessels, the consumption data was obtained from the *"Informe de emisiones de gases de efecto invernadero del Puerto de Valencia – 2016"* establishing a consumption of 36,305,933.25 kWh and 88,305,890.39 kWh for tugboats and commercial vessels, respectively (UPV, 2016). To unify a useful unit in [kg] to introduce into the SimaPro software, the average calorific value of 41.24 MJ/kg (Repsol, s.f.) of the marine gas oil (fuel-oil) was used. This value was converted to kWh/kg using the conversion factor of 1 MJ = 0.2778 kWh, which was multiplied by the consumption of marine gas oil of the tugboats and commercial vessels per year, obtaining the final quantity consumed.

- The port has approximately 3,500 trucks, which make a total of 5,500 trips per day, as some of them make between 2 or 3 trips per day. The port operates 260 days a year, for a total of 1,430,000 trips per year. To calculate the diesel consumption of trucks, the following data were considered:

    - A truck travels 10 km within the port, and
    - Each truck consumes 40 L diesel/100 km.

  With these assumptions, all the trucks in the Port of Valencia travelled 14,300,000 km per year, and their consumption is 5,720,000 L of diesel per year.

- The diesel consumption for the container handles & top handles, reach stacker, RTG crane, terminal tractor, and trucks given in liters (L) was necessary to convert into kg, using the diesel density of 0.85 g/cm^3 (Chevron, s.f.). Electricity consumption in port facilities includes lighting, building equipment, street lighting, air conditioning units, and others. The data on this consumption was obtained from *"Informe de emisiones de gases de efecto invernadero del Puerto de Valencia – 2016".*

- It is possible to find diesel or electric forklifts on the market. Based on 2,500 operating hours per year, electric forklifts can achieve energy savings of 75% compared to diesel ones (Kalmar, s.f.). The Port of Valencia has the advantage of having electric forklifts, thus it is expected that their energy consumption and environmental impacts are low. To calculate the impacts, it used 2,500 operating hours per year, with a diesel consumption of 8 liters/hour and electricity consumption of 17 kWh/hour (Kalmar, s.f.). Regarding the consumption of electric RTG cranes, it is suggested to use a saving of 35% compared to conventional ones. A value of 341,759.93 kWh per unit was obtained using the calorific power of diesel mentioned above.

- The Port of Valencia's electricity grid is certified and comes from Spain's renewable energy mix, which is mainly composed of wind, hydro, and photovoltaic energy.

- For the cases of the Quay Cranes, it was difficult to perform the LCA analysis since the Port of Valencia does not have enough information regarding the type of renewable energy that supports those electrical systems.

Considering the estimated information and the assumptions mentioned before, Table 3 summarises the inputs entered into SimaPro software to calculate the different impact emissions. For each input, the fuel consumption is supplied and the corresponding dataset is selected to perform the calculation. It is important to highlight that only for the tugboats, commercial vessels, and trucks, the quantity expressed is the total consumption, and for the others is indicated per unit.

Table 3 Port of Valencia´s Life Cycle Inventory

SOURCE	QUANTITY	UNIT	LCI DATASET	DATABASE
Tugboats	3,169,286.123	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
Commercial vessels	7,708,564.632	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
Container Handler, Top Handler	25,500	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
Reach Stacker	31,875	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
RTG Crane (Diesel)	45,900	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
Terminal tractor	17,850	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
Trucks	4,862,200	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
RTG crane (Electric)	341,759.93	kWh	Electricity, medium voltage {ES}| market for electricity, medium voltage | Cut-off, S	Ecoinvent v3.9.1
Forklift	42,500	kWh	Electricity, medium voltage {ES}| market for electricity, medium voltage | Cut-off, S	Ecoinvent v3.9.1
Electricity consumption port facilities	8,874,954	kWh	Electricity, medium voltage {ES}| market for electricity, medium voltage | Cut-off, S	Ecoinvent v3.9.1

3.3.2. LCIA and Interpretation

After introducing the LCI datasets (Table 3) into the SimaPro software, the results obtained for the Life Cycle Impact Assessment of the Port of Valencia were summarized in Table 4, which shows the total emissions of the port in each impact category per unit of TEU.

Table 4 LCIA Port of Valencia results

IMPACT CATEGORY	TOTAL	UNIT
Global warming	7.9410086	kg CO2 eq
Stratospheric ozone depletion	0.0000010	kg CFC11 eq
Ionizing radiation	0.7195070	kBq Co-60 eq
Ozone formation, Human health	0.0141776	kg NOx eq
Fine particulate matter formation	0.0010799	kg PM2.5 eq
Terrestrial ecotoxicity	5.3584793	kg 1,4-DCB
Freshwater ecotoxicity	0.1021261	kg 1,4-DCB
Marine ecotoxicity	0.0332151	kg 1,4-DCB
Human carcinogenic toxicity	0.0012436	kg 1,4-DCB
Human non-carcinogenic toxicity	0.0852916	kg 1,4-DCB
Fossil resource scarcity	5.8419633	kg oil eq
Water consumption	0.0204112	m^3

In the chart below (Figure 5) it is possible to appreciate the contribution percentage of each source, listed in the inventory, to the total impact in each category. Commercial vessels, RTG cranes (diesel), terminal tractors, and trucks are the primary contributors to the emissions in most categories.

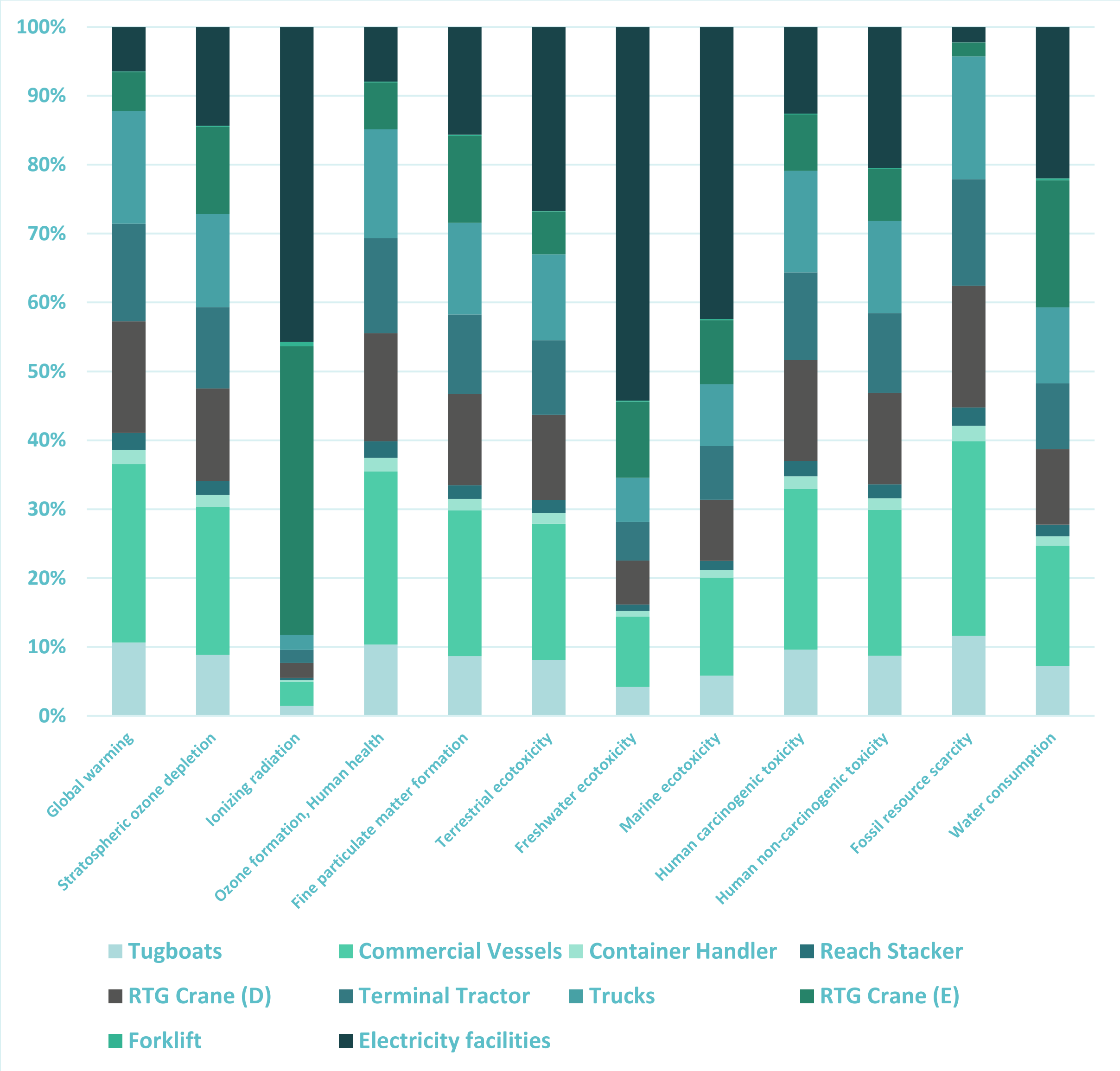
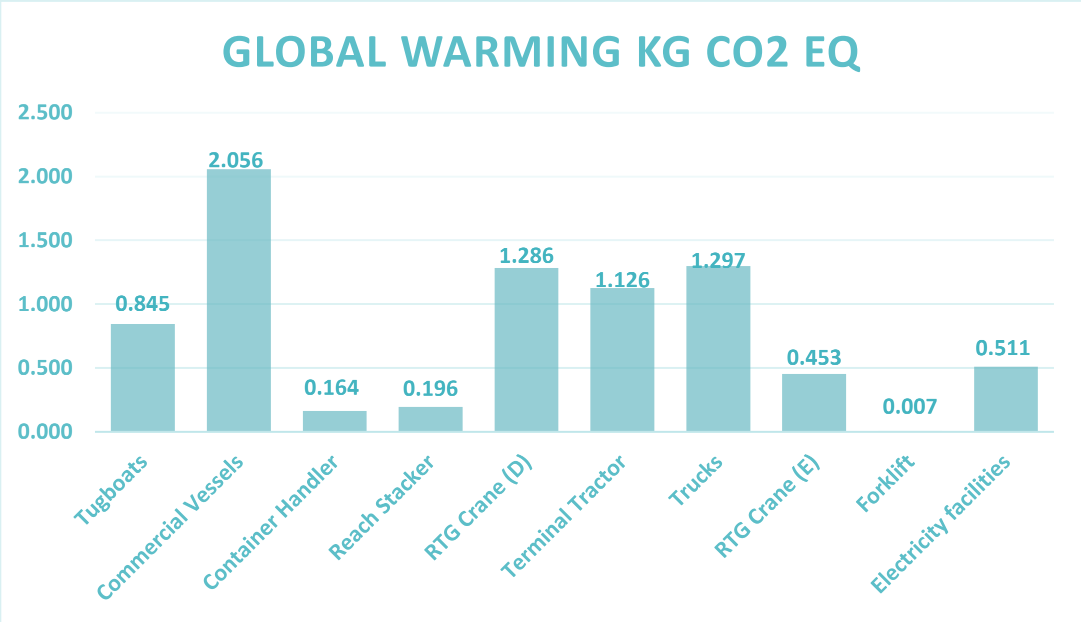


Figure 5 Port of Valencia results per environmental impact categories

As mentioned before, the main sources of negative impact are diesel-powered sources covering about 70% of the total emissions. This result was expected since this equipment consumes diesel, a fuel derived from petroleum that significantly affects the environment. For clarity of the results, the coming of the impact categories is shown below (Figure 6), where the contribution of each source in each category can be viewed.


GLOBAL WARMING KG CO2 EQ
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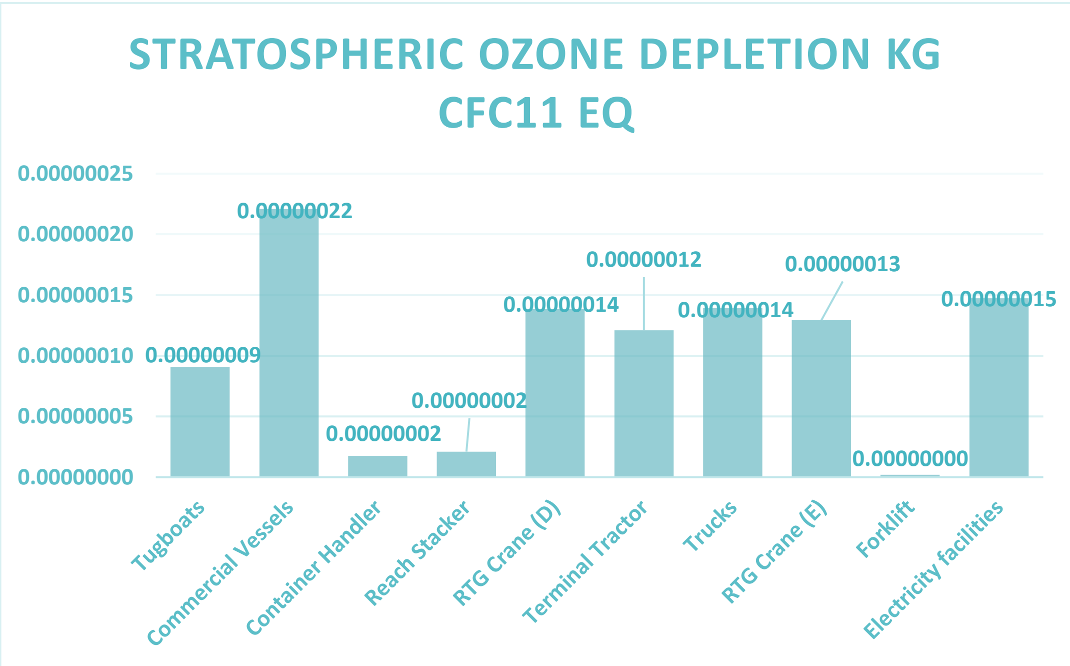
2.000
1.500
1.000
0.500
0.000
0.845
2.056
0.164
0.196
1.286
1.126
1.297
0.453
0.007
0.511
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


STRATOSPHERIC OZONE DEPLETION KG CFC11 EQ
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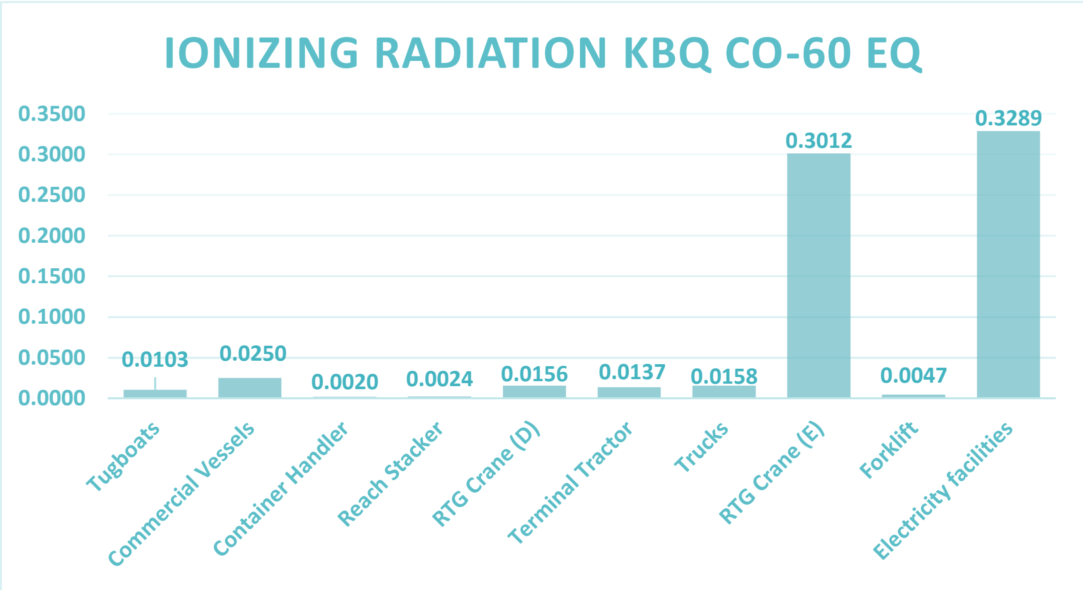
0.00000020
0.00000015
0.00000010
0.00000005
0.00000000
0.00000009
0.00000022
0.00000002
0.00000002
0.00000014
0.00000012
0.00000014
0.00000013
0.00000000
0.00000015
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


IONIZING RADIATION KBQ CO-60 EQ
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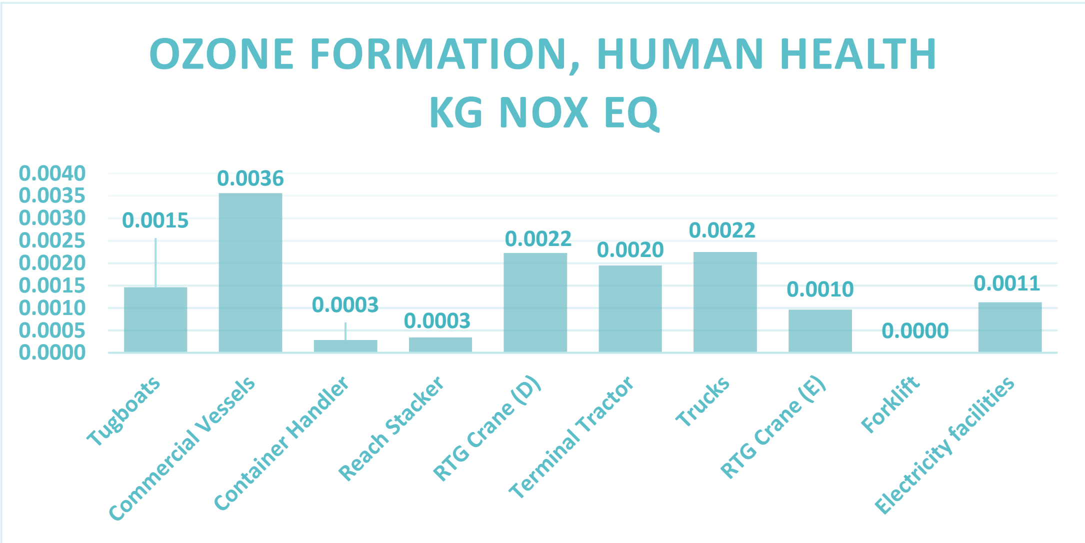
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
0.0103
0.0250
0.0020
0.0024
0.0156
0.0137
0.0158
0.3012
0.0047
0.3289
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


OZONE FORMATION, HUMAN HEALTH KG NOX EQ
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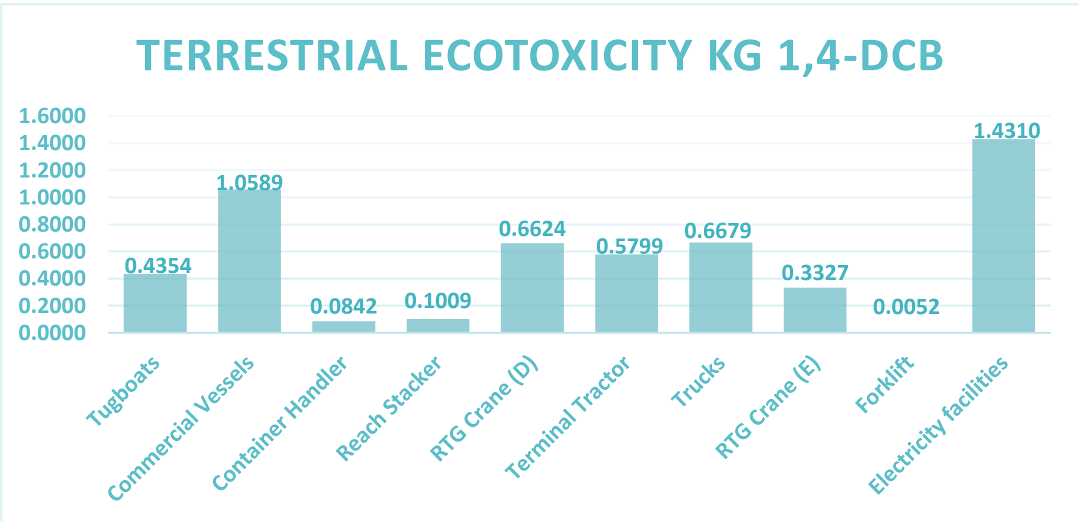
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0.0015
0.0036
0.0003
0.0003
0.0022
0.0020
0.0022
0.0010
0.0000
0.0011
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


TERRESTRIAL ECOTOXICITY KG 1,4-DCB
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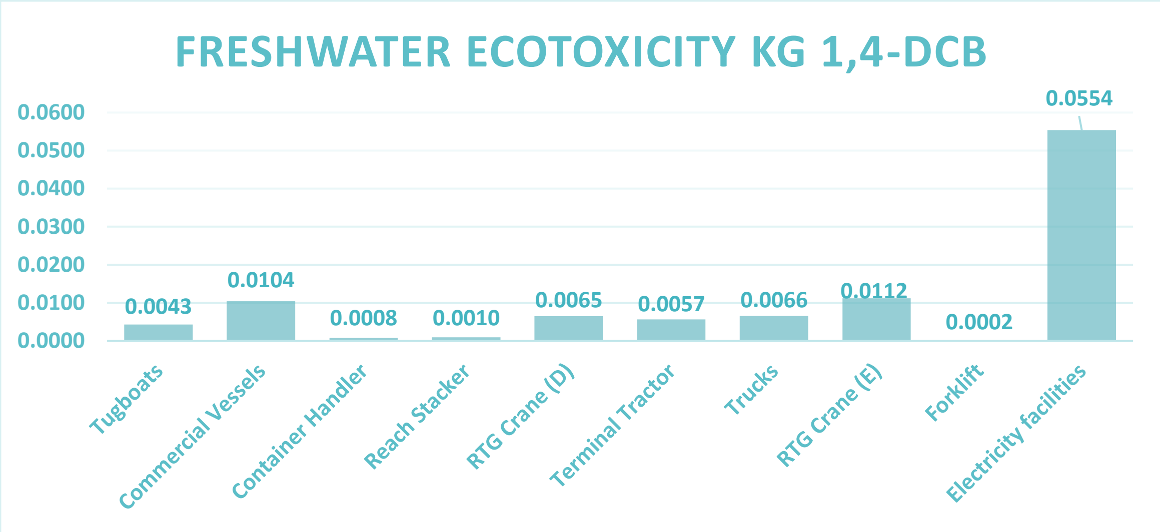
1.4000
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
0.4354
1.0589
0.0842
0.1009
0.6624
0.5799
0.6679
0.3327
0.0052
1.4310
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


FRESHWATER ECOTOXICITY KG 1,4-DCB
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0.0300
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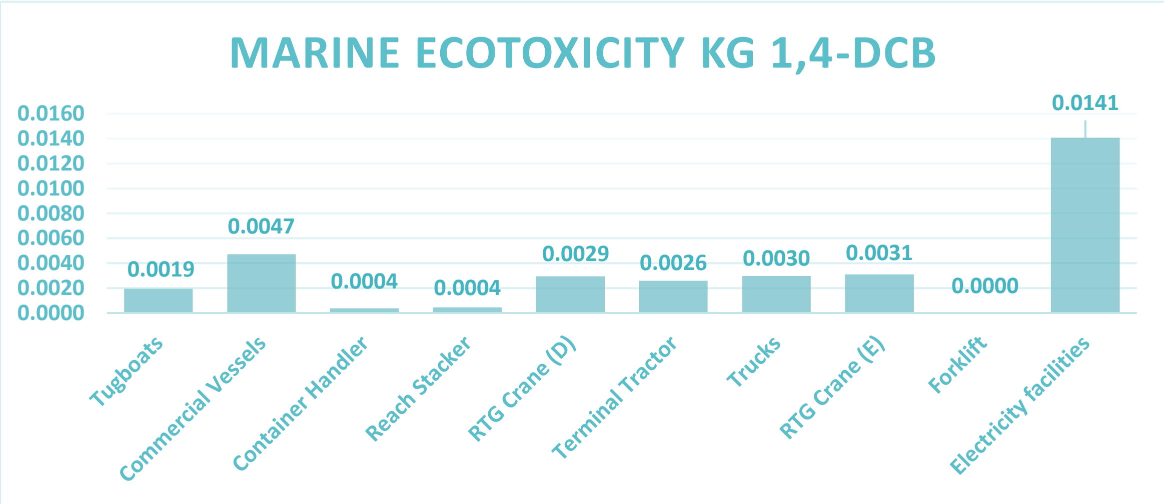
0.0100
0.0000
0.0043
0.0104
0.0008
0.0010
0.0065
0.0057
0.0066
0.0112
0.0002
0.0554
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


MARINE ECOTOXICITY KG 1,4-DCB
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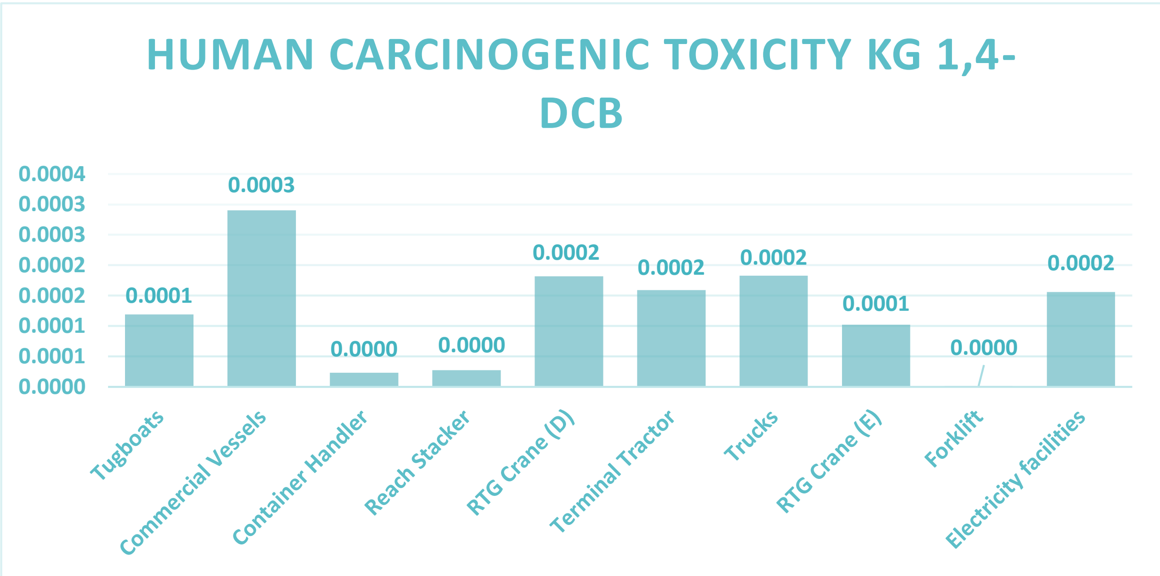
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
0.0019
0.0047
0.0004
0.0004
0.0029
0.0026
0.0030
0.0031
0.0000
0.0141
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


HUMAN CARCINOGENIC TOXICITY KG 1,4-DCB
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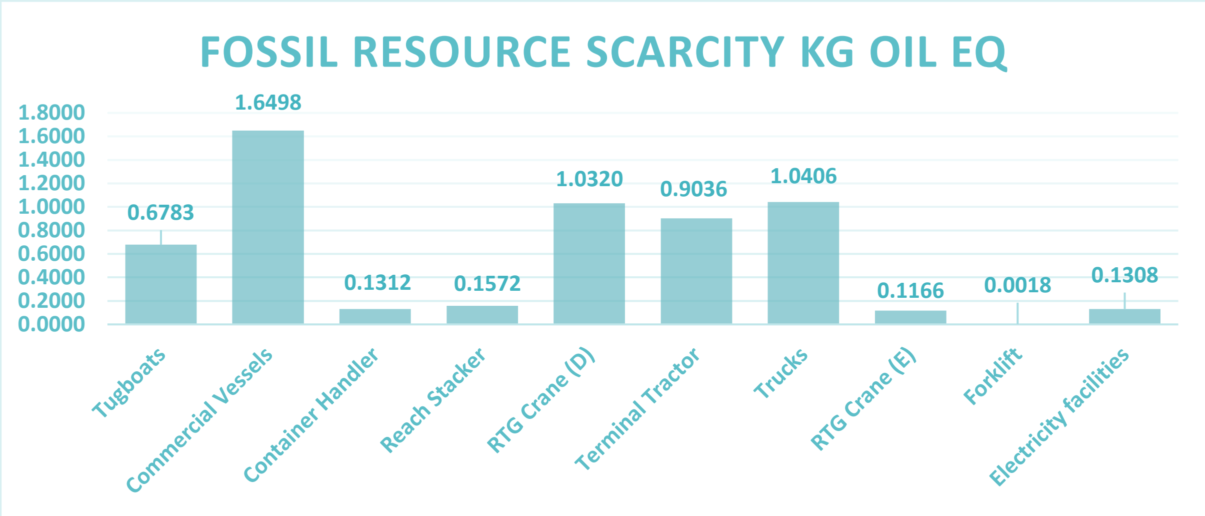
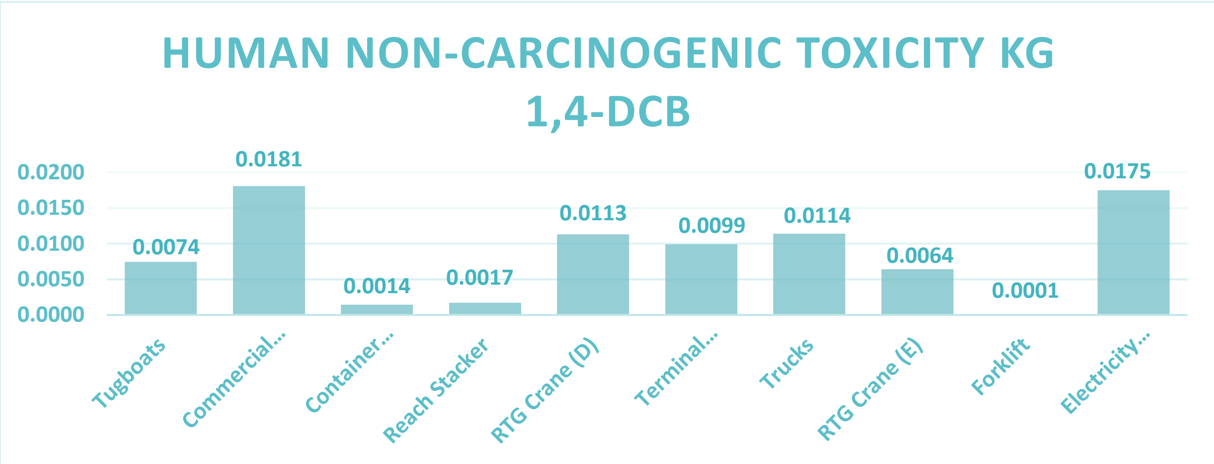
0.0003
0.0002
0.0002
0.0001
0.0001
0.0000
0.0001
0.0003
0.0000
0.0000
0.0002
0.0002
0.0002
0.0001
0.0000
0.0002
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities





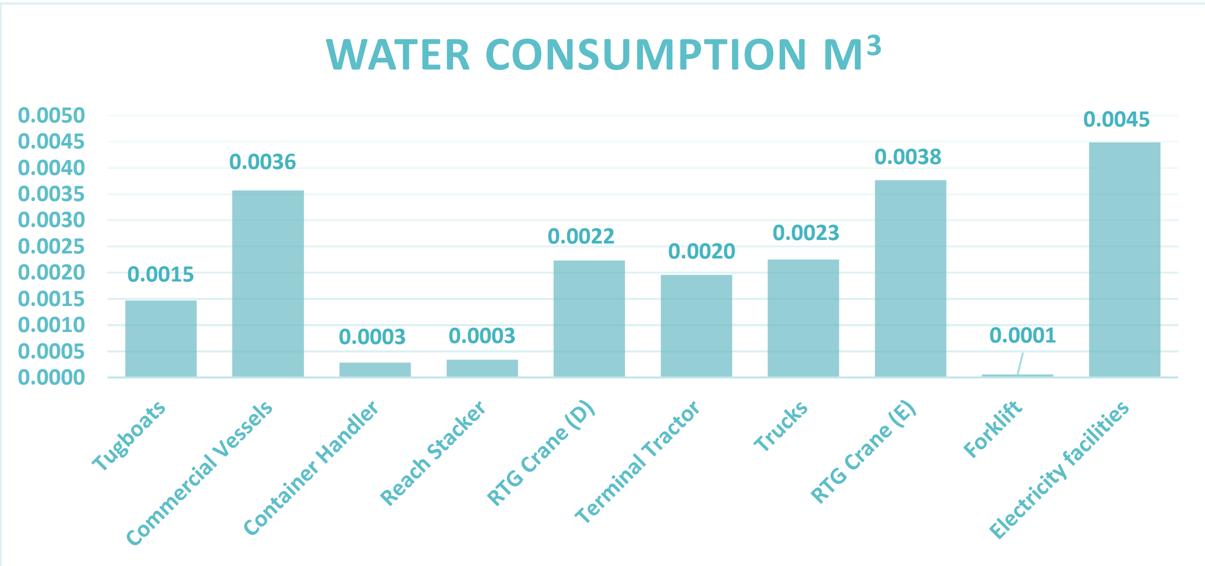


Figure 6 Port of Valencia´s impact categories in charts

It is possible to affirm that logistics in ports is divided into three stages: i) port hinterland transport, ii) port storage, and iii) ship port interface. Each stage has different equipment or sources of energy consumption. The Port of Valencia uses renewable energy as a source supplier of electricity, and the evidence is that equipment focused on the ship port interface is electrical (Cranes and Forklifts).

Table 5 shows the results for 1 TEU. As mentioned before, the Port of Valencia received approximately 5.6 million TEUs in 2021, then, using 3.2 tonnes of CO_2/tonnes of fuel (MGO or Diesel) as an emission factor (Verifavia shipping, s.f.), the total emissions from each source are shown in Table 5. As well it is also important to recognize the implementation of renewable energy because, without it, the impact would increase considering lightning and the building's operation.

Table 5 Port of Valencia´s total CO2 emissions

SOURCE	TOTAL EMISSIONS (kgCO2)
Tugboats	10,140,000
Commercial Vessels	24,669,000
Container Handler	916,484.7069
Reach Stacker	1,098,229.1854
RTG Crane (D)	7,207,680.9655
Terminal Tractor	6,310,468.4892
Trucks	15,558,000
RTG Crane (E)	2,540,496.7069
Forklift	39,490.8457
Electricity facilities	2,865,311.0668
TOTAL	**71,345,161.9664**

According to the results, to reduce the carbon footprint in the Port of Valencia, it is recommended:

- Substitute diesel in trucks with Liquefied Natural Gas (LNG) of renewable origin. LNG offers significant savings in fuel consumption and a drastic reduction of the most harmful emissions, nitrous oxides, sulfur compounds and solid particles (savings of 30% compared to diesel). The use of LNG is also proposed for maritime transport, as recent reports indicate that the use of LNG as a fuel in maritime transport reduces SOx emissions by practically 100%, NOx emissions by 85-90% and CO_2 emissions by 23% compared to conventional fuels (Axpo, s.f.).

- The transition from diesel consumption for port machinery to 100% certified renewable electricity consumption. Furthermore, the use of Hydrogen for this machinery may be considered, as in the H2PORTS project (Port of Valencia, s.f.).

- To visualize these results, the CO_2 emissions per category were recalculated, making the following calculations and summarising in
-
- Table 6:
  - Tugboats: 36,305,933.25 kWh / 0.2778 MJ/kWh = 130,690,904.43 MJ / 48.6 MJ/kg (Verifavia shipping, s.f.) = 2,689,113.26 kg LNG / 431 kg/m^3 (Repsol, s.f.)= 6,239.24 m^3 and using 2.75 tonnes CO_2 / tonnes LNG as the emission factor (Verifavia shipping, s.f.), then, 2,689.11 tonnes LNG * 2.75 = 7,395 tonnes CO_2.
  - Commercial vessels: 88,305,890.39 kWh / 0.2778 MJ/kWh = 317,875,775.34 MJ / 48.6 MJ/kg = 6,540,653.81 kg LNG / 431 kg/m^3 = 15,175.53 m^3 and thus 6,540.65 tonnes LNG * 2.75 = 17,986.79 tonnes CO_2.

- It is possible to find electric container handlers with battery efficiencies of 95% and savings of around 15% in fuel consumption (Kalmar, s.f.). Also, the electric Reach Stacker solution will reach around 25% to 40% savings in fuel consumption (Kalmar, s.f.).

- Diesel RTG cranes were converted to electric and added to the existing ones.

Table 6 Suggested Port of Valencia´s CO2 emissions

SOURCE	TOTAL EMISSIONS (kgCO2)
Tugboats	7,395,000
Commercial Vessels	17,986,790
Container Handler	916,484.7069
Reach Stacker	1,098,229.1854
RTG Crane (D)	7,207,680.9655
Terminal Tractor	6,310,468.4892
Trucks	15,558,000
RTG Crane (E)	2,540,496.7069
Forklift	39,490.8457
Electricity facilities	2,865,311.0668

SOURCE	TOTAL EMISSIONS (kgCO2)
TOTAL	**61,917,951.96**

When comparing both analyses and considering just tugboats and commercial vessels, there is a CO_2 emissions reduction of 27% using LNG compared to MGO.

Finally, the implementation of environmentally friendly fuels, such as biodiesel, or liquefied natural gas of renewable origin, as well as the electrification of the machinery used in the port, powered by a renewable energy mix (as is currently done), allows a significant reduction of emissions within the port, especially those associated with kg CO_2 (Figure 7).

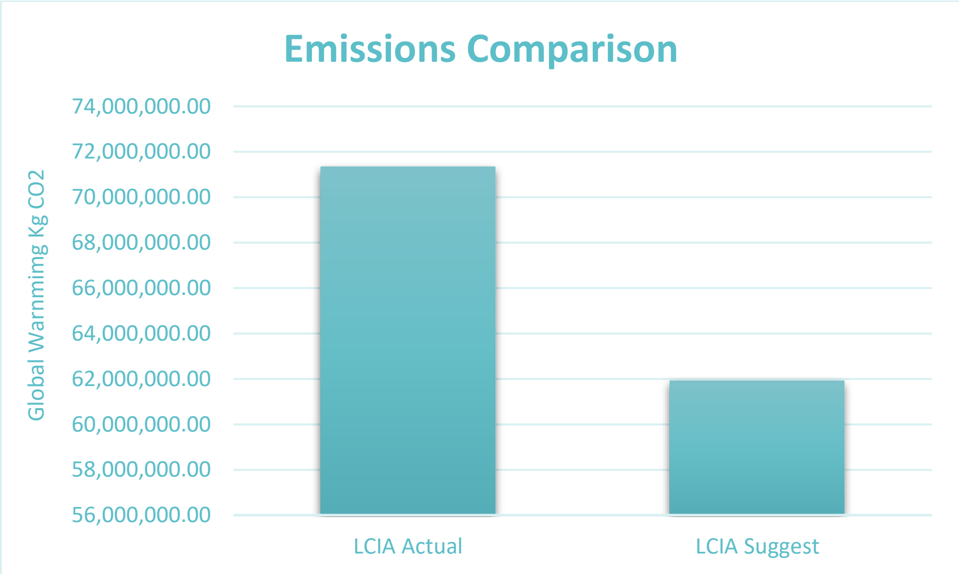


Figure 7 Comparison between actual LCIA and suggested LCIA in Valencia Port

3.4. Ennshafen Port LCA

In this case, the difficulty was not having the necessary data and information to carry out the environmental impact assessment. As mentioned by the Ennshafen partner, it will take more time to develop the structure to collect the data for an LCA assessment according to ISO standards. Inland ports are not so far developed compared to the seaports, they even have different structures and processes, so they have to find a way to implement the tools as seaports do.

3.5. Syros Port LCA

6,887 ships between cruisers, and commercial and private vessels transited in the Syros Port in the year 2021. For the assessment, the functional unit (FU) selected is 1 ship, regardless of the type of them.

3.5.1. LCI

The LCI of Syros Port is listed in Table 7. It provides a list of equipment, quantities and consumption per year. Through the "Syros port consumption and breakdown analysis template" the data were obtained. For this analysis, the information from the year 2021 was used, due to there was still a lack of data to be updated for the year 2022.

Table 7 Syros Port´s Life Cycle Inventory (2021)

SOURCE	QUANTITY	TYPE OF FUEL	CONSUMPTION PER SOURCE	
			CONSUMPTION	UNIT
Ferries	5,038	Marine diesel	35,583,618.00	kWh
Cruise ships	28	Marine diesel		
Commercial and private vessels	1,614	Marine diesel		
Commercial, private and small vessels for fishing	207	Marine diesel		
Lightning	35%	Electricity	71,284.42	kWh
Buildings and facilities	30%	Electricity	61,100.93	kWh
Touristic boat pillars	25%	Electricity	50,917.44	kWh
Auxiliary systems	10%	Electricity	20,366.98	kWh
Vehicles and heating in buildings	-	Diesel	179,836.00	kWh

Table 8 summarises data entered in SimaPro software to calculate different environmental impact categories. The fuel consumption is provided for each source, and the database is selected to perform the calculation. It is clarified that the consumption of marine diesel was given for the total number of vessels.

Table 8 LCI datasets Syros Port in SimaPro

SOURCE	CONSUMPTION	UNIT	LCI DATASET	DATABASE
Vessels	3,000.00	ton	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1
Electricity consumption-lightning	71,284.42	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off, SS	Ecoinvent v3.9.1
Electricity consumption-building and facilities	61,100.93	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off, SS	Ecoinvent v3.9.1
Electricity consumption-touristic boat pillars	50,917.44	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off, SS	Ecoinvent v3.9.1
Electricity consumption-auxiliary systems	20,366.98	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off, SS	Ecoinvent v3.9.1
Vehicles and heating in buildings	15,087.62	kg	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1

3.5.2. LCIA and Interpretation

The Life Cycle Impact Assessment of the Syros Port is presented in Table 9. It shows the port's total emissions in each environmental impact category per ship.

In the case of the global warming impact category, and considering an emission factor (Verifavia shipping, s.f.) of 3.2 tons of CO_2 per ton of marine diesel (MGO), the total CO_2-eq emissions is 3,000 tonnes of MGO * 3.2 tonnes CO_2/tonnes of MGO = 9,618 tonnes CO_2 eq.

Table 9 LCIA Syros Port results

IMPACT CATEGORY	TOTAL	UNIT
Global warming	678.3691	kg CO2 eq
Stratospheric ozone depletion	0.000076	kg CFC11 eq
Ionizing radiation	8.595666	kBq Co-60 eq
Ozone formation, Human health	1.162554	kg NOx eq
Fine particulate matter formation	0.088762	kg PM2.5 eq
Terrestrial ecotoxicity	355.2055	kg 1,4-DCB
Freshwater ecotoxicity	4.4891	kg 1,4-DCB
Marine ecotoxicity	1.881891	kg 1,4-DCB
Human carcinogenic toxicity	0.107802	kg 1,4-DCB
Human non-carcinogenic toxicity	6.448438	kg 1,4-DCB
Fossil resource scarcity	532.5348	kg oil eq
Water consumption	1.268183	m^3

The contribution percentage of each source to the total environmental impact in each category is appreciated in the chart below (Figure 8). The primary contributor to CO_2 emissions is marine diesel associated with commercial vessels in all the environmental impact categories.

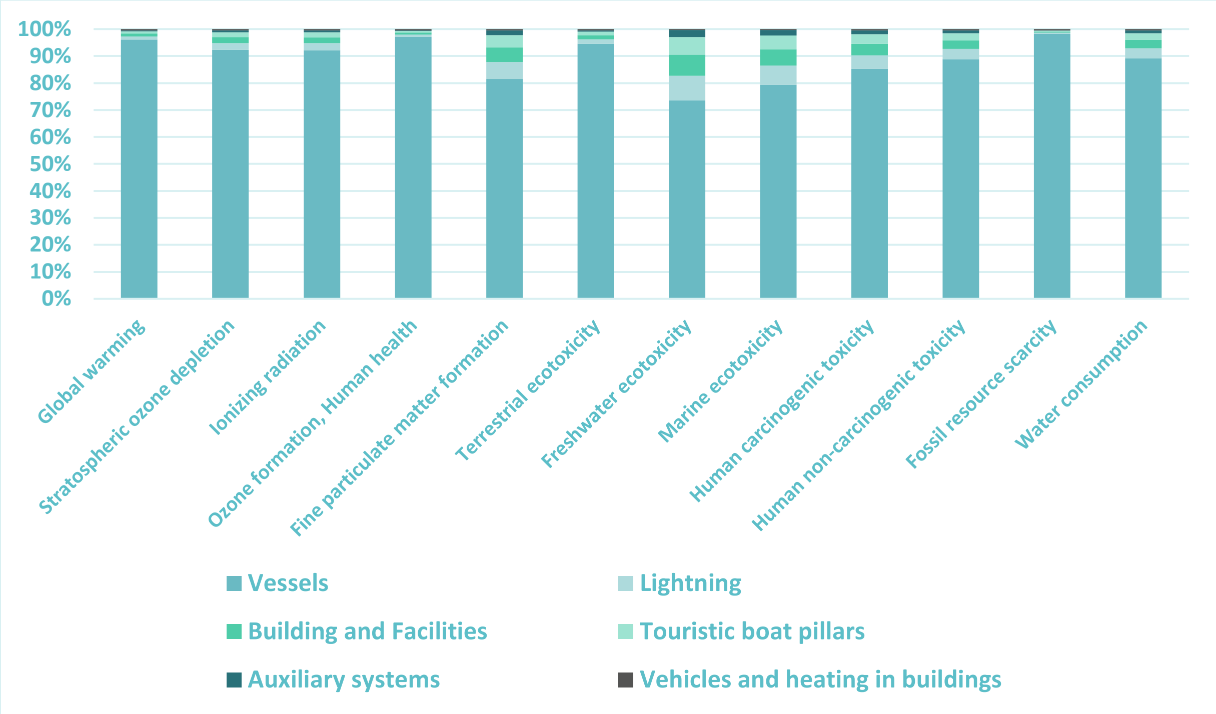
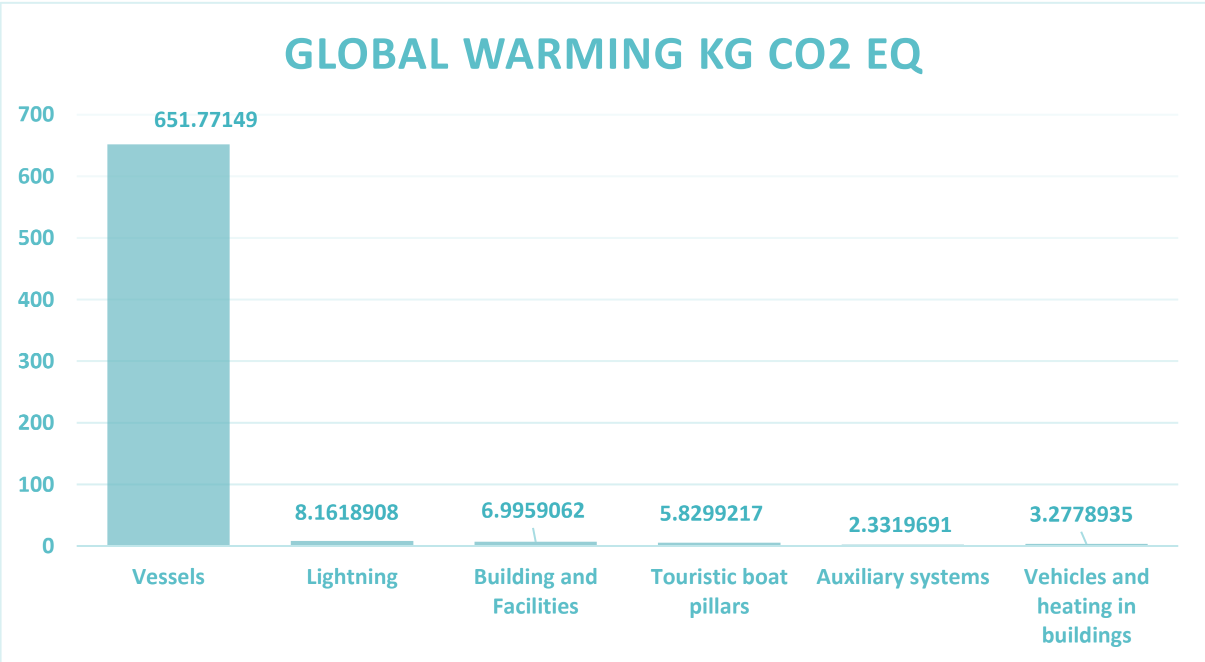
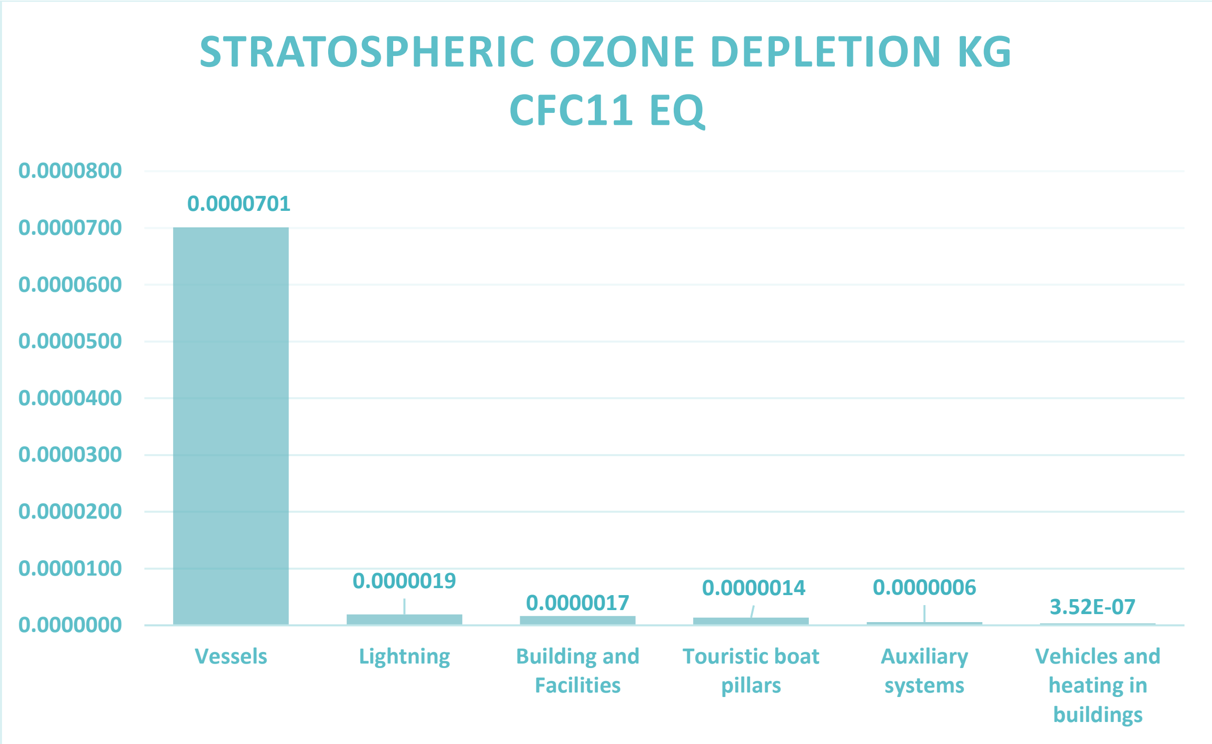


Figure 8 Syros Port results per environmental impact categories

Next, is shown in detail the chart of each impact mentioned above (Figure 9).




STRATOSPHERIC OZONE DEPLETION KG CFC11 EQ
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0.0000700
0.0000600
0.0000500
0.0000400
0.0000300
0.0000200
0.0000100
0.0000000
0.0000701
0.0000019
0.0000017
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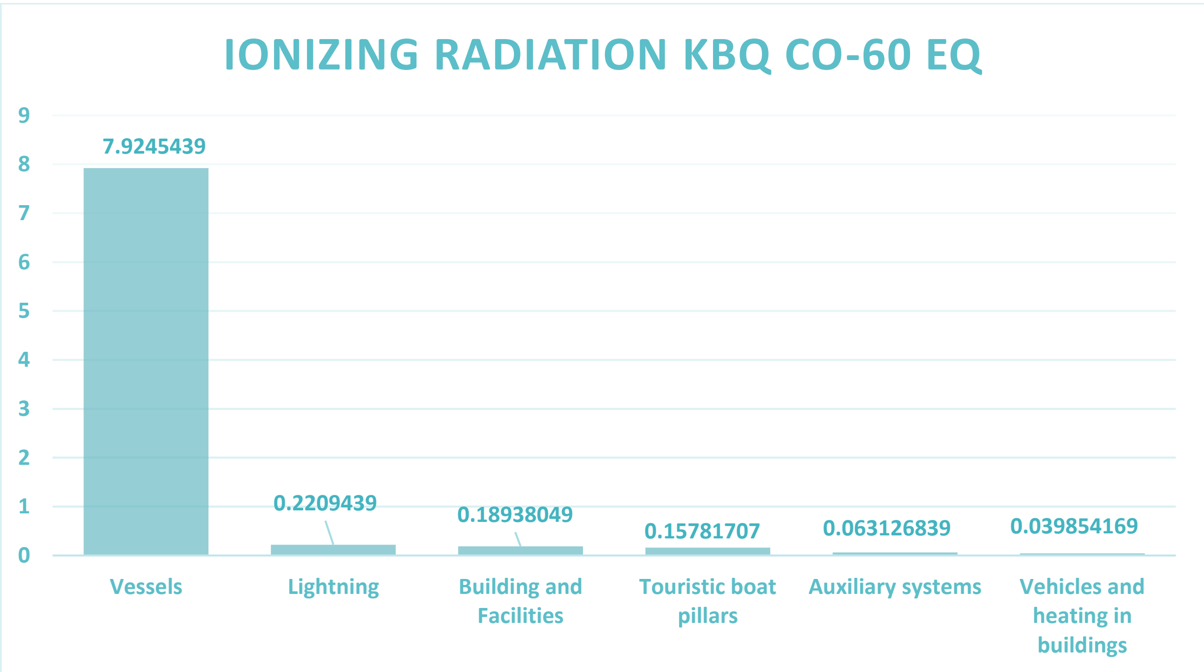
3.52E-07
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


IONIZING RADIATION KBQ CO-60 EQ
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8
7
6
5
4
3
2
1
0
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0.18938049
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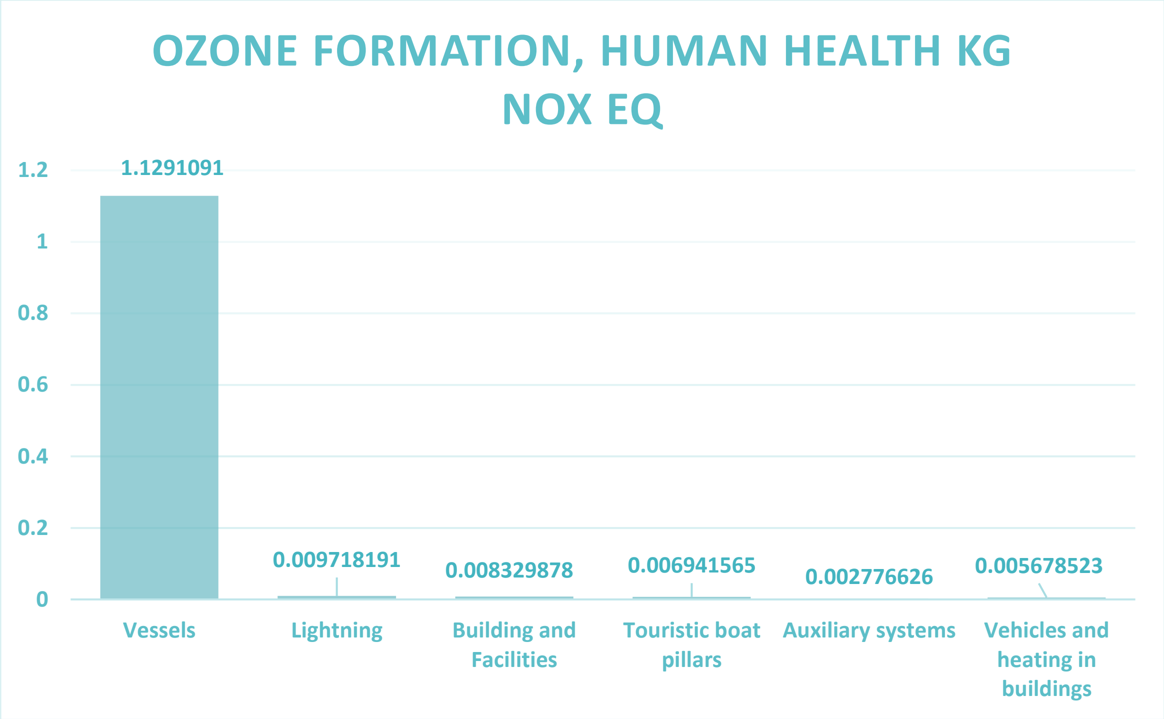
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


OZONE FORMATION, HUMAN HEALTH KG NOX EQ
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0.4
0.2
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0.008329878
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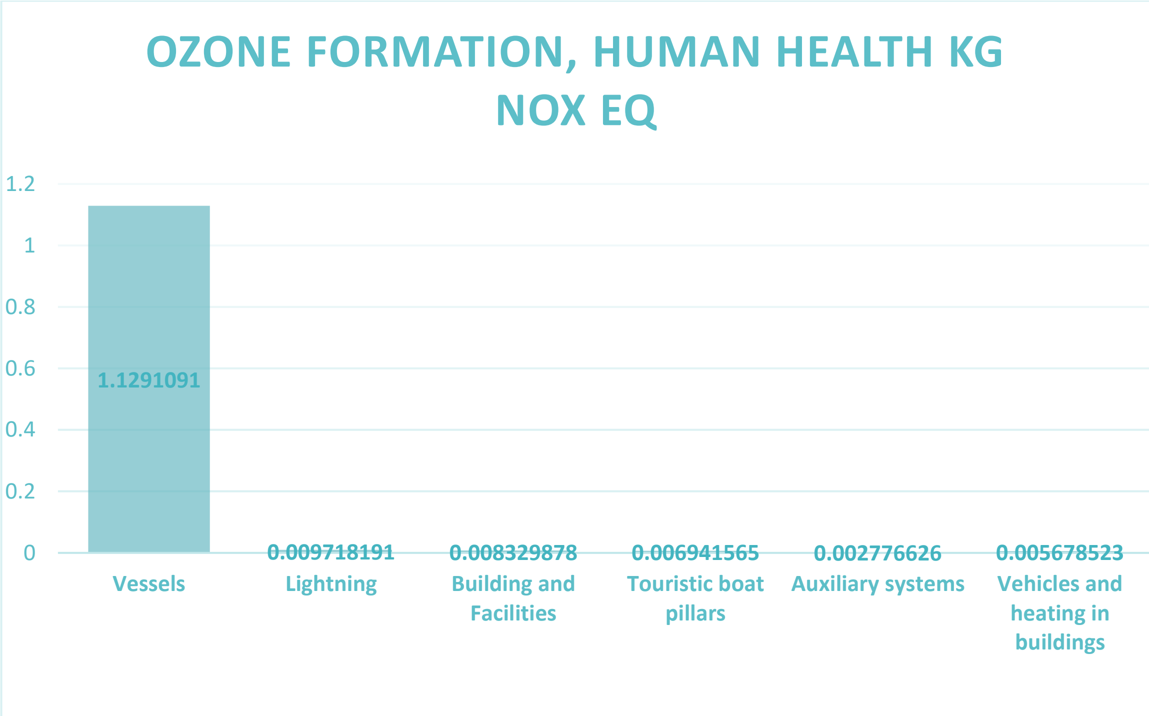
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


OZONE FORMATION, HUMAN HEALTH KG NOX EQ
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0.008329878
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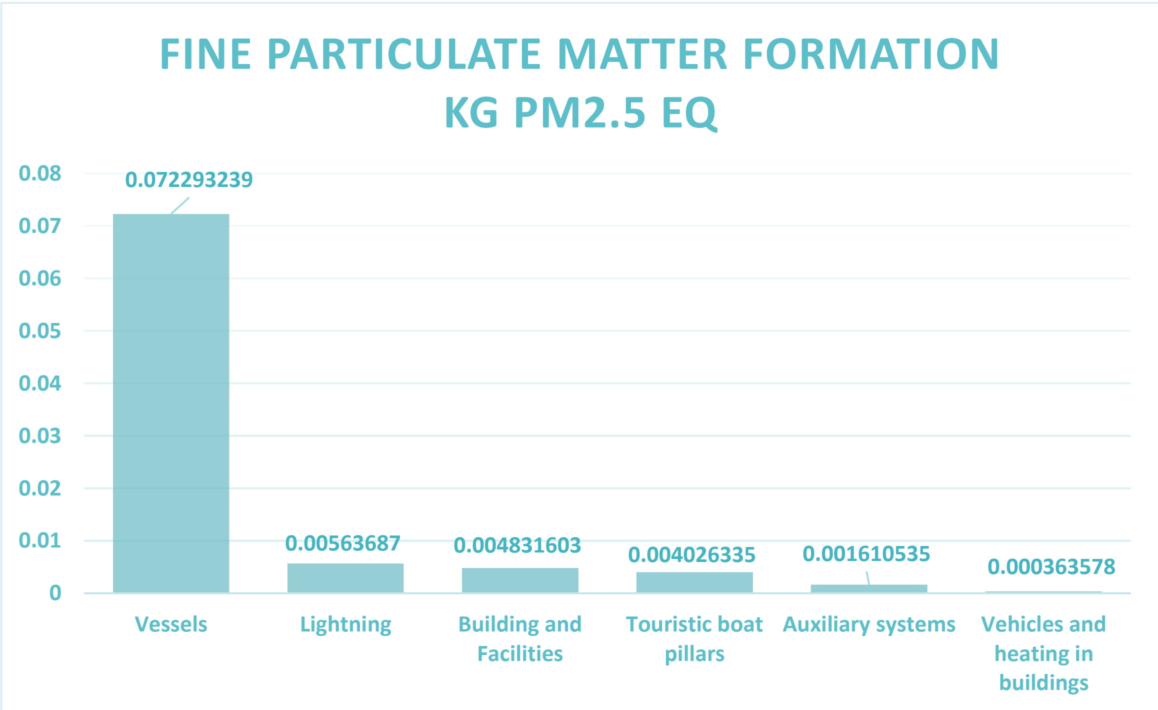
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


FINE PARTICULATE MATTER FORMATION KG PM2.5 EQ
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0.04
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0.00563687
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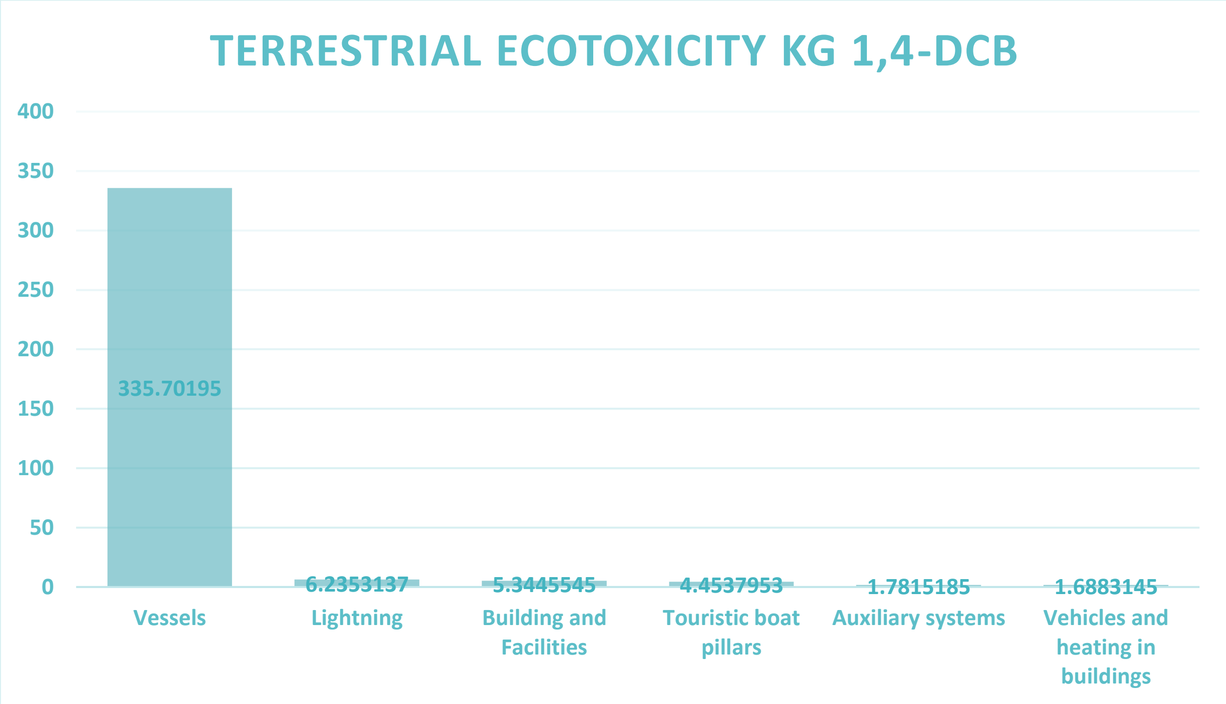
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


TERRESTRIAL ECOTOXICITY KG 1,4-DCB
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200
150
100
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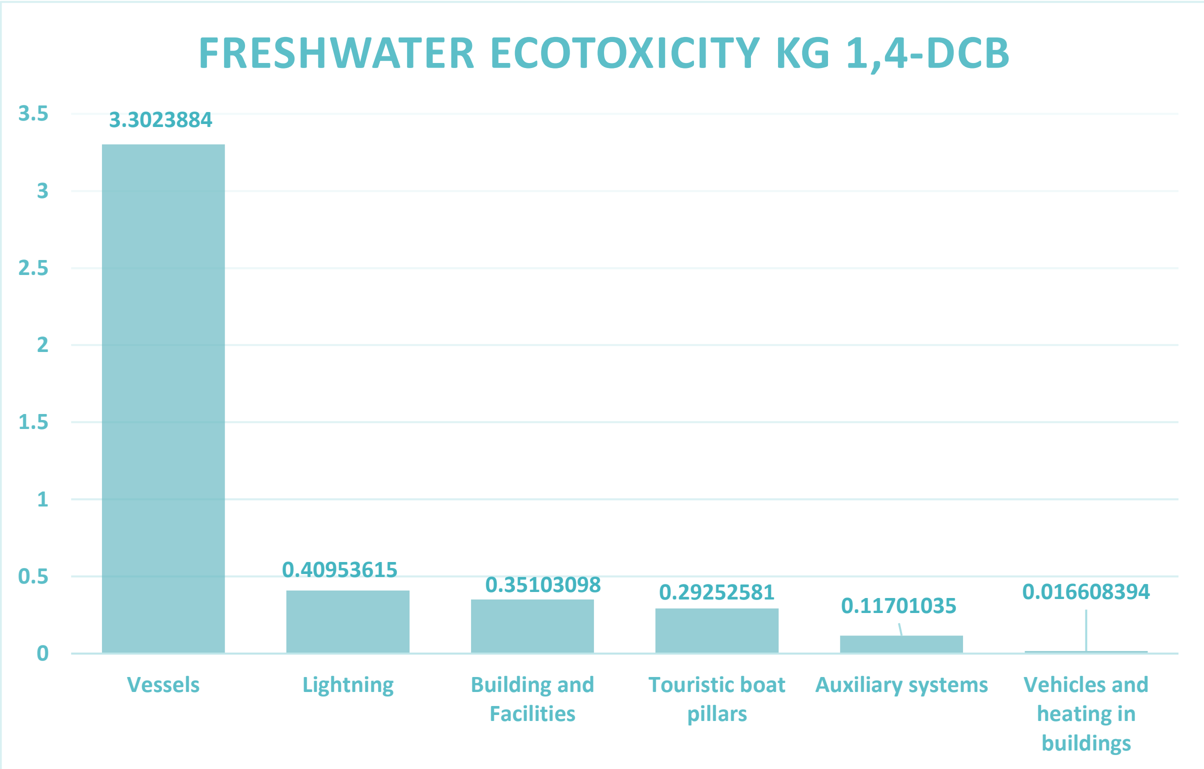
1.6883145
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


FRESHWATER ECOTOXICITY KG 1,4-DCB
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1.5
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0.5
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0.40953615
0.35103098
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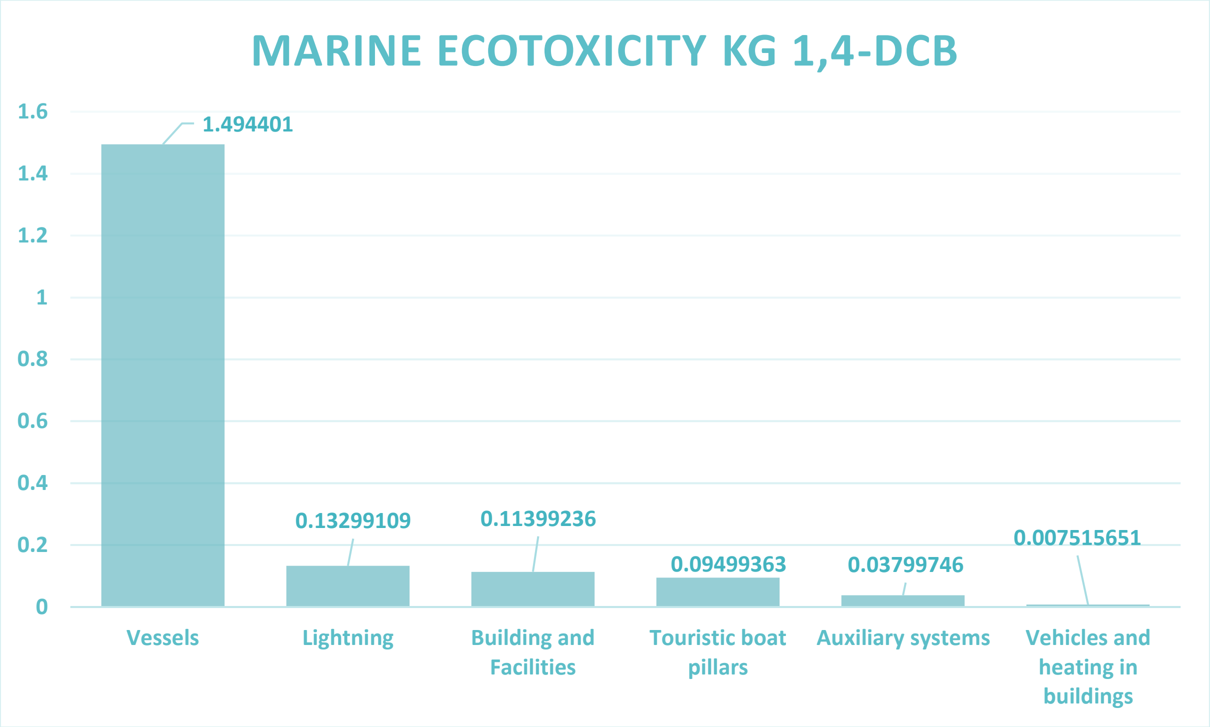
0.11701035
0.016608394
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


MARINE ECOTOXICITY KG 1,4-DCB
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1.2
1
0.8
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0.4
0.2
0
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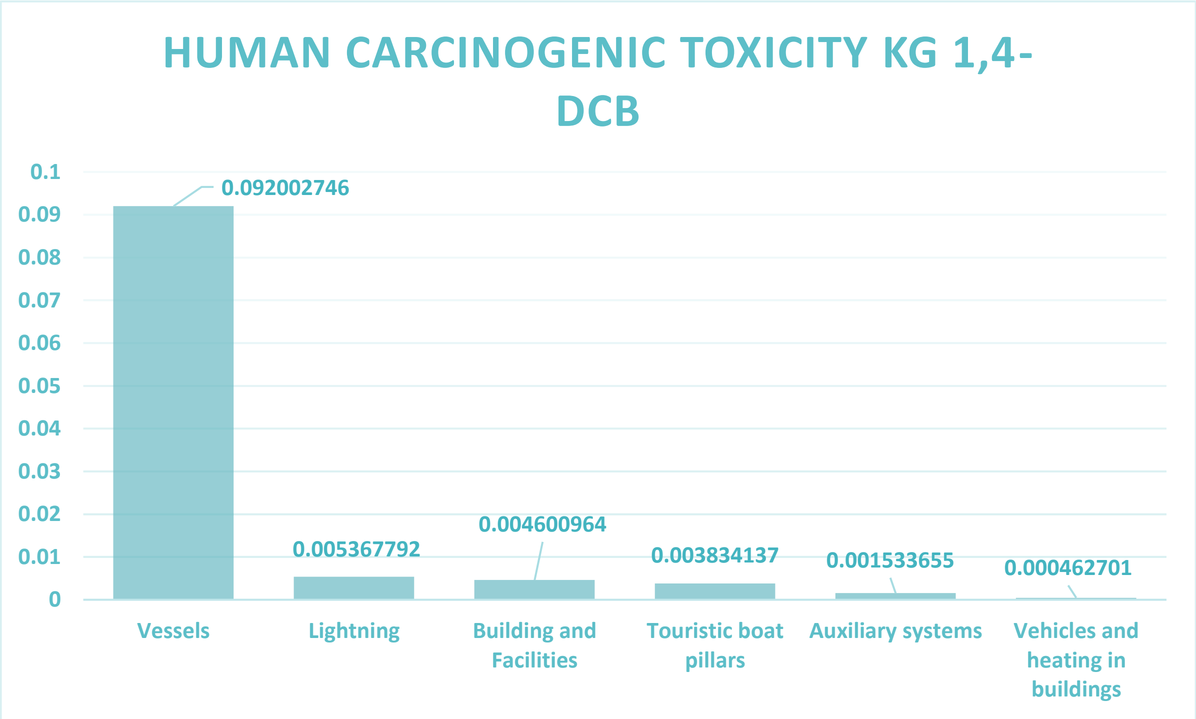
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


HUMAN CARCINOGENIC TOXICITY KG 1,4-DCB
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0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.092002746
0.005367792
0.004600964
0.003834137
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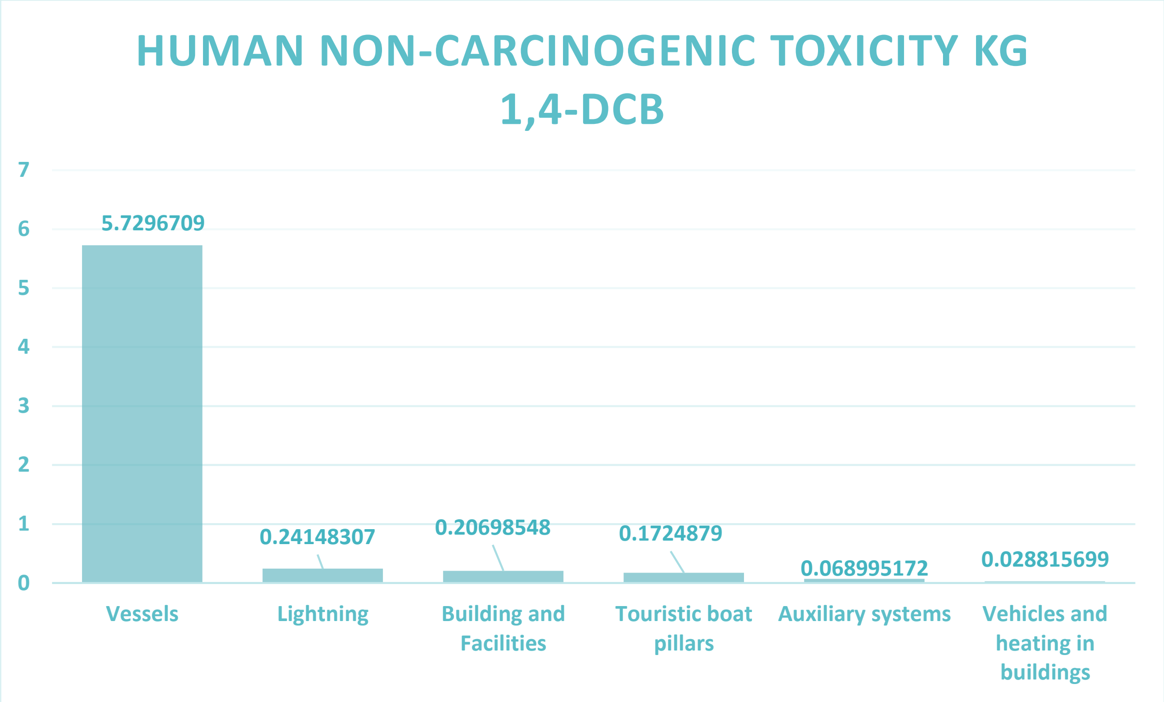
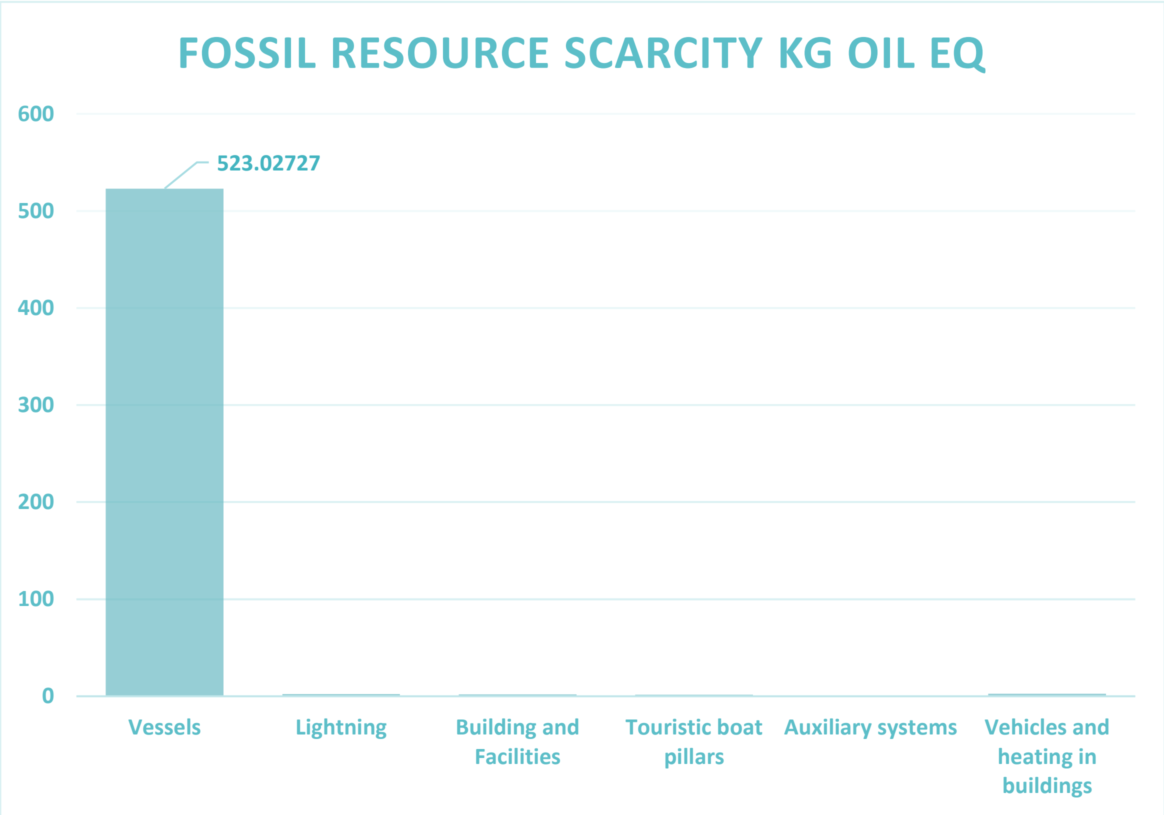
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


HUMAN NON-CARCINOGENIC TOXICITY KG 1,4-DCB
7
6
5
4
3
2
1
0
5.7296709
0.24148307
0.20698548
0.1724879
0.068995172
0.028815699
Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings


FOSSIL RESOURCE SCARCITY KG OIL EQ
600
500
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Vessels
Lightning
Building and Facilities
Touristic boat pillars
Auxiliary systems
Vehicles and heating in buildings

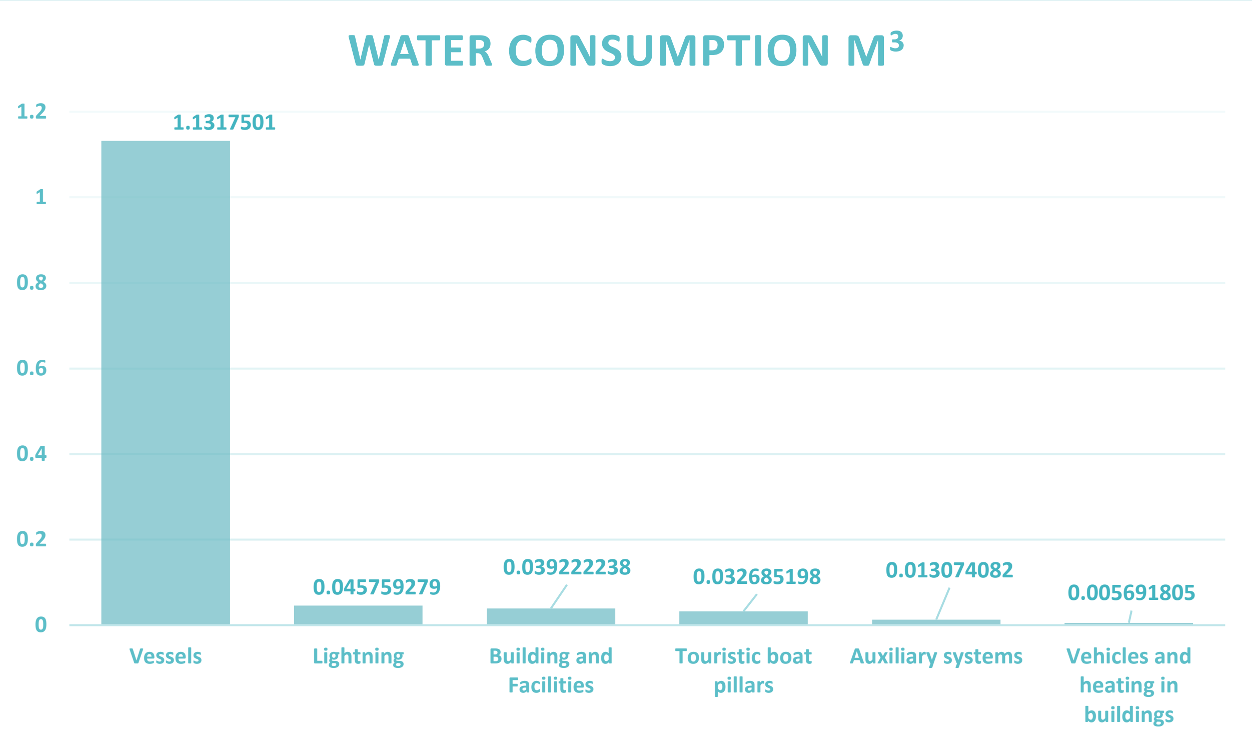

Figure 9 Syros Port´s impact categories in charts

The results are for 1 ship as a functional unit (FU), and as mentioned before, for the 2021 year, the Syros Port received approximately 6,887 ships. Therefore, the total emissions from each source are shown in Table 10.

Table 10 Syros Port´s total emissions

SOURCE	TOTAL EMISSIONS KgCO$_2$
Vessels	9,618,000
Lightning	56,210.94194
Building and Facilities	48,180.806
Touristic boat pillars	40,150.67075
Auxiliary systems	16,060.27119
Vehicles and heating in buildings	22,574.85253
TOTAL	**9,801,177.54**

3.5.3. Syros Port results

The Syros Port inventory brings the focus to the consumption sector, in contrast to the Port of Valencia where the data was detailed by equipment. At the Syros Port, the main source of environmental impact is marine diesel (MGO). It is used for boats and ship motors. Marine diesel is consumed on average by 25 vessels per month. These vessel motors consume a high amount of fuel. There are a few possible ways to reduce this impact by increasing efficiency in the routes, constant maintenance in motors, updating motors or upgrading the vessels.

Without considering marine diesel the next two higher sources are lighting, buildings and facilities. For these variables, the LCI dataset was the country mix of Greece. There are two strategies to decrease this impact; change the source of electricity to renewable ones or increase the current system's efficiency. The second strategy requires us to have a more detailed inventory to understand consumption. For both sources, the principal solutions without a deep study are:

- Substitute the actual equipment for a modern one that uses less power.
- Only use the equipment when it is needed.

The fuel consumed in land transportation is not the top source of impact because this port does not move containers as much as the Port of Valencia. The engine fuel consumption is correlated to the weight carried on and the distance travelled, and it is possible to claim that the weight carried on land transportation at the Syros Port is lower than at the Port of Valencia. Therefore, in this type of port, it is possible to conclude the main source of impact is equipment from the ship port interface.

According to the results, to reduce the environmental impacts at the Syros Port, it is recommended:

- Substitute the use of diesel in vehicles with an “eco-friendly” fuel or liquefied natural gas (LNG) of renewable origin. LNG offers significant savings in fuel consumption and a drastic reduction of the most harmful emissions, nitrous oxides, sulfur compounds and solid particles (savings of 30% compared to diesel). Also, it is proposed to use LNG in vessels because, as mentioned before, the use of LNG as a fuel in maritime transport reduces SOx emissions by practically 100%, NOx emissions by 85-90% and CO_2 emissions by 23% compared to conventional fuels (Axpo, s.f.).

- The use of renewable energy for electricity consumption, such as wind, hydro and solar power.

To visualize these suggestions, the emissions sources were recalculated, considering the new inventory shown in Table 11 and the following assumptions:

- Vessels' total energy consumption at the Syros Port (Table 7) is 35,583,618 kWh, which is equivalent to 128,090,777 MJ (1 MJ = 0.2778 kWh). Using the Low Calorific Value

(LCV) of LNG equal to 48.6 MJ/kg (The Engineering Toolbox, s.f.), then 118,090,777 MJ/48.6MJ/kg = 2,635,612 kg of LNG = 6,115 m^3 LNG consumption (average LNG density = 431 kg/m^3) (GIIGNL, s.f.). Then, CO_2 emissions are equal to 2,635.6 tonnes LNG * 2.75 tonnes CO_2/tonnes LNG = 7,247.9 tonnes CO_2. 7,247.9 tonnes CO_2 emissions due to LNG shows a 24% reduction compared to 9,618 tonnes CO_2 emissions due to MGO or diesel consumption.

- For this analysis, it is impossible to change the diesel consumption of vehicles for natural gas since the amount is unknown, and only general data in conjunction with heating is available.

Table 11 Suggested LCI Syros Port

SOURCE	CONSUMPTION	UNIT	LCI DATASET	DATABASE
Vessels	6,115	m^3	Natural gas, liquefied {GLO}| market for natural gas, liquefied | Cut-off, S Gas natural (155grGNL/kWh)	Ecoinvent v3.9.1
Electricity consumption-lightning	71,284.42	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off	Ecoinvent v3.9.1
Electricity consumption-building and facilities	61,100.93	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off	Ecoinvent v3.9.1
Electricity consumption-touristic boat pillars	50,917.44	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off	Ecoinvent v3.9.1
Electricity consumption-auxiliary systems	20,366.98	kWh	Electricity, medium voltage {GR}| market for electricity, medium voltage | Cut-off	Ecoinvent v3.9.1
Vehicles and heating in buildings	15,087.62	m^3	Diesel {Europe without Switzerland} | market for diesel | Cut-off, S	Ecoinvent v3.9.1

When comparing both analyses, a significant reduction in the emissions of the different impact categories is obtained, especially in global warming, terrestrial ecotoxicity and fossil resource scarcity. The results of the comparison are shown in Figure 10.

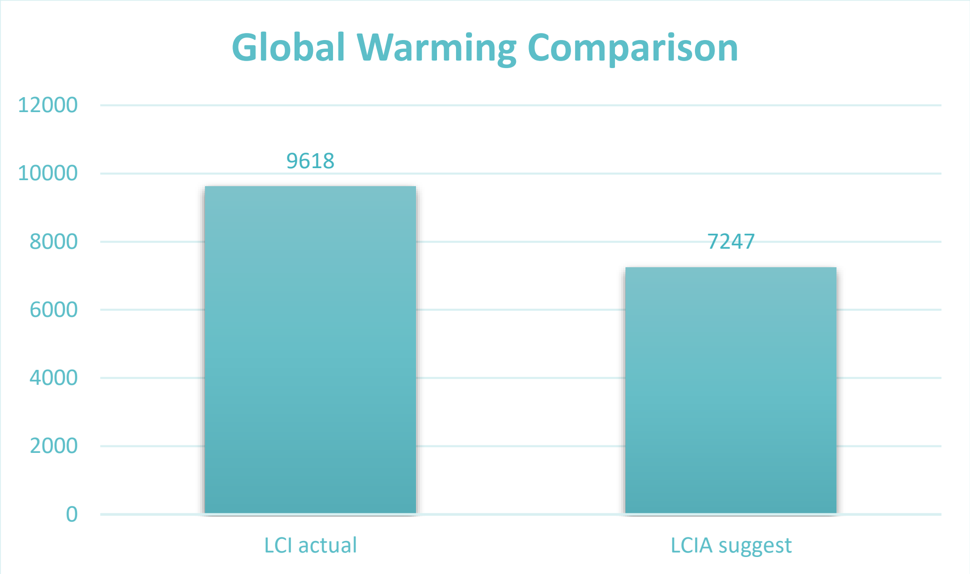

Figure 10 Comparison between actual LCIA and suggested LCIA in Syros Port

Finally, the use of environmentally friendly fuels, such as biodiesel, or liquefied natural gas of renewable origin in marine transportation allows a significant reduction of emissions within the port, especially those associated with kg CO_2.

Environmental problems can be assessed at three levels: pressure, impact, and damage to ecosystems and human health. Environmental-related pressures are all emissions (to air, water, and soil), resource use (minerals, fossil fuel, renewables) as well as physical emissions such as noise and radiation resulting from human activity. Environmental Impacts are exerted by the pressures via several different environmental processes, following the so-called cause-effect chains eventually producing damage to the environment. The Life Cycle Assessment (LCA) is an integrated method that may support systematically the evaluation of the impacts that can emerge from the life cycle of a product, chemical, material, and/or system (JRC, 2022). In this study, the systems to be analyzed were the three SeaNergy demo ports such as Port of Valencia, Syros Port, and Ennshafen. The LCA analyses were performed following the four stages of the methodology i) Scope and definition, ii) Life Cycle Inventory (LCI), 3) Life Cycle Impact Assessment (LCIA), and 4) Interpretation of results/recommendations.

The goal of the LCA analyses was to measure the environmental impact of each DEMO port. The results of the analyses will help establish a baseline to identify opportunity areas in the DEMO ports to implement strategies into the Master Plan of SEANERGY to increase energy efficiency and reduce CO_2 emissions (Table 12).

Table 12 Demo ports LCA´s analyses results

Demo port/LCA´s variables	Port of Valencia	Port of Syros
Functional Unit	1 TEU	1 SHIP
Main operational equipment responsible for CO2 emissions	Tugboats, Commercial Vessels, Trucks	Commercial Vessels (Cargo & Passengers)
Type of fuel	Marine Gas Oil (MGO) and Diesel	Marine Gas Oil (MGO)
LCI (CO_2 emissions)	15,740.3 Ton CO_2	3,000 Ton CO_2
LCIA (CO_2 emissions)	Global Warming (7.94 kg CO_2) SimaPro	Global Warming (678.4 kg CO_2) SimaPro
Total CO_2 emissions	50,367 Ton CO2	9,618 Ton CO2
CO_2 emissions reduction strategy	Replace the use of MGO with LNG	Replace the use of MGO with LNG
Total CO_2 emissions reduction	40,939 Ton CO2	7,248 Ton CO2
Total CO_2 emission reduction (%)	19%	25%

Regardless of the operational nature of each demo port, it was possible to establish the functional unit in each one and its main CO_2 emissions equipment. This is how, in the case of the Port of Valencia, its functional unit is 1 TEU and for the Port of Syros is 1 SHIP. Its main CO_2 emissions equipment are those that use marine gas oil (MGO) and diesel. These fuel-oil sources can be replaced by liquefied natural gas (LNG) which is a more environmentally friendly fuel, thus reducing CO_2 emissions in the port operation and, in turn, their carbon footprint.

4. ESG Assessment of Energy and Fuels on Ports

Today environmental, social, and governance (ESG) performance is gaining relevance among investors who want to finance companies that possess a good profit-earning capacity and add value in environmental and social aspects (Hill, 2020; Li et al., 2021). Dathe et al. (2022) define ESG as a corporate initiative to save and maintain resources that also include voluntary efforts that are not driven by country or global regulations. Moreover, van Duuren et al. (2016) argue that the ESG investment approach is less focused on the performance of shares, giving more relevance to the environment, social, and governance dimensions.

Currently, ESG has been used as a framework system or as a strategy to achieve sustainability. Furthermore, ESG is directly linked to strategic planning since these decisions have a long-term impact, and imply the inclusion and implementation of new technologies, the use of natural resources, and the interaction between employees and the community (van Duuren et al., 2016). Most of the companies that possess strong sustainability standards and ESG performance, demonstrate lower costs of capital, and better cash flows due to improved operational performance and better financial metrics (Hill, 2020).

Several positive findings have been associated with ESG performance among investors (Henisz et al., 2019; Li et al., 2021). J.P.Morgan (2022) describes four key characteristics that can relate to ESG performance as “efficiency gains” where there is evidence of a positive relationship between ESG and financial performance, “consumer sentiment” since today consumers tend to prefer products and services that meet high standards in all environmental, social, and governance factors. On the other hand, leaders are interested in “mitigation of regulatory risks” especially those related to the transition towards a net-zero economy. Finally, the increasing interest of investors in green bonds will lead to a decrease in “capital costs” for issuers.

From an environmental point of view, awareness of climate change and the search for cleaner energy sources became relevant not only for sustainable investments and operations but also for national and international legislators that looking for policies that reduce the environmental impact caused by transportation. To that effect, several national and international strategies have been implemented in the port industry and are becoming stricter in their enforcement. On the other hand, social pressure towards environmental and social issues is increasing, and the availability of innovative technologies showed a behavioural change in terms of consume and demand. Today, the availability of information through social media influences the willingness to establish sustainable businesses. Indeed, investors will not participate in corporations that do not consider labour rights, environmental good practices, and good corporate governance.

Financial and firm performance and *firm value* have become hot topics since 2006 among the ESG literature, and economic consequences represent a relevant topic in ESG research (Li et al., 2021). Indeed, the economic aspects in terms of efficiency, safety and profitability immersed in ESG performance, such as new technologies that possess the power to reduce waste and emissions, improve energy efficiency and reduce risks, are becoming relevant. These changes impact the adjacent areas' communities, improving the business reputation and their relationships with the community.

Although there is a trend towards an increase in investments that consider ESG aspects, today there exists some remaining issues to solve in terms of consistent use of ESG terminology, data collection and reliability to measure ESG performance (Hill, 2020). Moreover, some authors argue that ESG initiatives and measurement need to be specific, practical, and real to create value not only for investors and companies but also for society and the environment, omitting generalizations and considering the various characteristics of each country, its industries and backgrounds (Henisz et al., 2019; Li et al., 2021). Moreover, there is a need to create some guidelines or benchmarking from which a unified definition of the concept of ESG is derived, the measurement and evaluation systems are improved, and good practices are promoted to facilitate the decision-making process (Li et al., 2021).

4.1. Methodology

This subtask will follow a methodology composed of four steps (Figure 11). The aim is to identify the necessary actions and strategies framed in ESG performance for port decarbonization using relevant information obtained from the LCA results and the applicable mitigation measures.

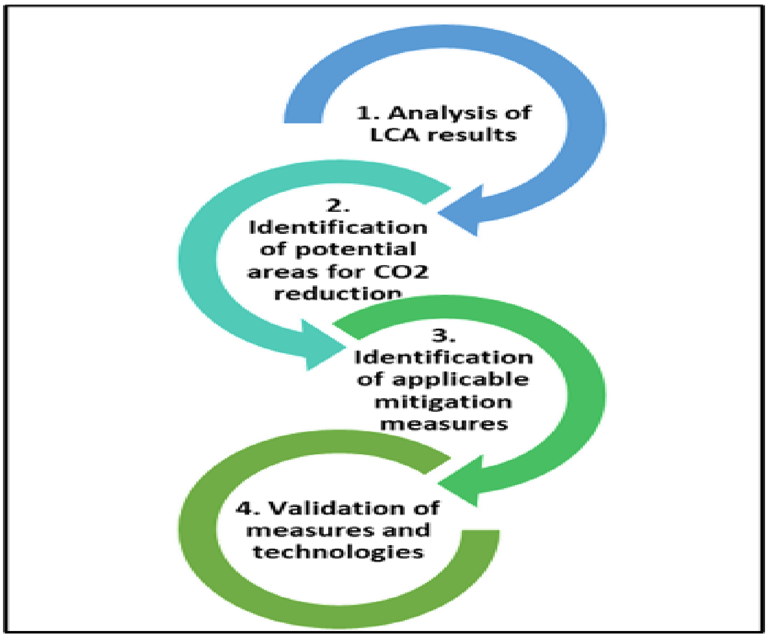

Figure 11 ESG Methodology

Step 1. Analysis of the LCA results

The LCA results were analysed, which allowed us to measure the environmental impact generated by each demo port, and to identify the applicable environmental, social and governance strategies for each case. Intending to reduce CO_2 emissions associated with ports, this study considered not only available technologies for all the equipment used in port operations (e.g., tugboats, vessels, cranes, tractors, trucks, and port facilities among others) but other operational and governance actions that directly impact emissions reduction.

Step 2. Identification of the potential areas for CO_2 reduction

Given the diverse characteristics that each port possesses, this stage analysed the key areas to reduce CO_2 emissions in the demo ports (see also subtask 1.4.2 Tech-Port Matchmaking). In this stage, the authors assessed the equipment and infrastructure as well as the main sources of emissions with a high reduction potential.

Step 3. Identification of applicable mitigation measures

For this stage desk research was conducted, to gather relevant information from diverse sources such as academic literature, policy reports for decarbonization and environmental strategies (e.g., Port Environmental Review System), shipping and port sustainability reports, and other relevant material. These allowed the researchers to comprehensively collect relevant information to understand and analyse the best technologies applicable for each demo port and other strategies that positively impact the environmental, social, and governance performance in each case. Moreover, the authors used the results of the desk research to develop a questionnaire for demo ports, to understand the applicability of the proposed port decarbonization measures in each case.

Step 4. Validation of decarbonization strategies

During the final stage, the responses obtained through the questionnaire about the proposed operational and governance measures and technologies for each demo port are used to depict an overall view of the port energy transition. This method allows us to understand the strategies implemented or planned for future implementation in each case, or the reasons for not implementing them.

4.2. LCA Results

In cooperation with Zero-E Engineering, LCA analysis data are used to describe CO2 emissions sources in each Demo Port, and further identify the potential areas for CO2 reduction. The latest version of the LCA report by Zero-E Engineering shows the following sources of CO2 emission for the port of Valencia and Syros Table 13 and Table 14.

Table 13 LCA results Ports of Valencia (ESG analysis)

	Commercial vessels	Tugboats	Container Handler	Reach Stacker	RTG Crane (D)	Terminal tractor	Trucks	RTG Crane (E)	Forklift	Electricity facilities	Total
kg CO2 eq per TEU	2.056	0.845	0.164	0.196	1.286	1.126	1.297	0.453	0.007	0.511	7.941

Table 14 LCA results Port of Syros (ESG analysis)

	Marine diesel	Lighting	Building & facilities	Touristic boats	Auxiliary systems	Automobiles and heating in buildings	Total
kg CO2 eq per SHIP	651.77	8.16	6.99	5.83	2.33	3.28	678.37

4.3. Proposed mitigation measures for demo ports

In addition to a literature review, the following documents prepared by other partners in the SEANERGY project were utilized to identify the CO_2 reduction measures.

- D.1.2: Catalogue of Technologies for Maritime and Coastal Communities and Ports
- Subtask 2.1.2- Identifying key tools and certifications
- Subtask 1.4.1- Desk research on EU strategy
- Subtask 1.1.1- Analysis of motivation, drivers and barriers of target stakeholders
- Subtask 1.4.2- Port technology matchmaking

It is noteworthy that the mitigating measures comprise technical, operational, and governance measures. A questionnaire was designed based on a combination of these decarbonization measures and sent to three demo ports. Through that, port managers were requested to raise their comments about the applicability of these measures in their ports. The responses to the questionnaire from the port of Valencia, Syros, and EHOO are presented in appendices A, B, and C, respectively.

4.4. ESG analysis

4.4.1. ESG or Sustainability reporting

"ESG reporting is the disclosure of environmental, social, and corporate governance performance. Its purpose is to shed light on a company's ESG initiatives while improving transparency for investors and comparability between competitors. It also holds markets accountable for its impacts on the planet and its people" (Wolters Kluwer, 2023). There are various sustainability and ESG reporting examples in the maritime industry specifically for shipping and offshore companies as well as ports. These reports are seen as a guideline and do not constitute a reporting standard. In the case of ports, these reports underline various requirements and expectations for relevant information from ports. The ESG reports by different ports that are pioneers in data reporting and dissemination, not only can outline the scope of such reports but can be a showcase for best practices and areas with high potential for improvement. In preparation and publication of ESG reports usually following three initiatives with the objective of harmonization of reporting across the industry are considered (NSA, 2021):

- Global Reporting Initiative (GRI) (GRI, 2022)
- The Value Reporting Foundation: Integrated reporting and the SASB standards (Sustainability Accounting Standards Board) (SASB, 2023)
- UN Sustainable Development Goals (SDGs)

"Generally, the financial markets prefer ESG reporting that outlines clear ESG targets, performance against those targets - preferably over a 3-5-year horizon - and relevant governance information on how material issues are managed by the company. A critical success factor is to focus on material ESG topics for the company and its stakeholders" (NSA, 2021). While SASB has provided a standard for marine transportation with a focus on ship operation (SASB, 2023), there is no specific standard defined by SASB for port ESG reporting.

4.4.2. Port energy transition and ESG scope

A fundamental issue with climate change and global warming is that the local effect of CO_2 emission at the point of generation is not tangible, rather the consequences could emerge somewhere else in various forms. Identification and measurement of the CO_2 emission externalities is a challenging and complex issue; however, societal awareness is growing in this regard. For instance, it could be consistently observed that the port CO_2 emission is a major part of port externalities that are included in the ESG reporting format of many ports.

The ESG analysis of port energy transition necessitates defining a scope for this process and identifying the interface between the port ESG framework and the port energy transition.

Figure 12 and Figure 13 illustrate this interface in environmental and social aspects, respectively. Figure 12 and Figure 13 illustrate that port decarbonization and port energy transition are just a subsidiary set of actions out of the vast scope of the port ESG.

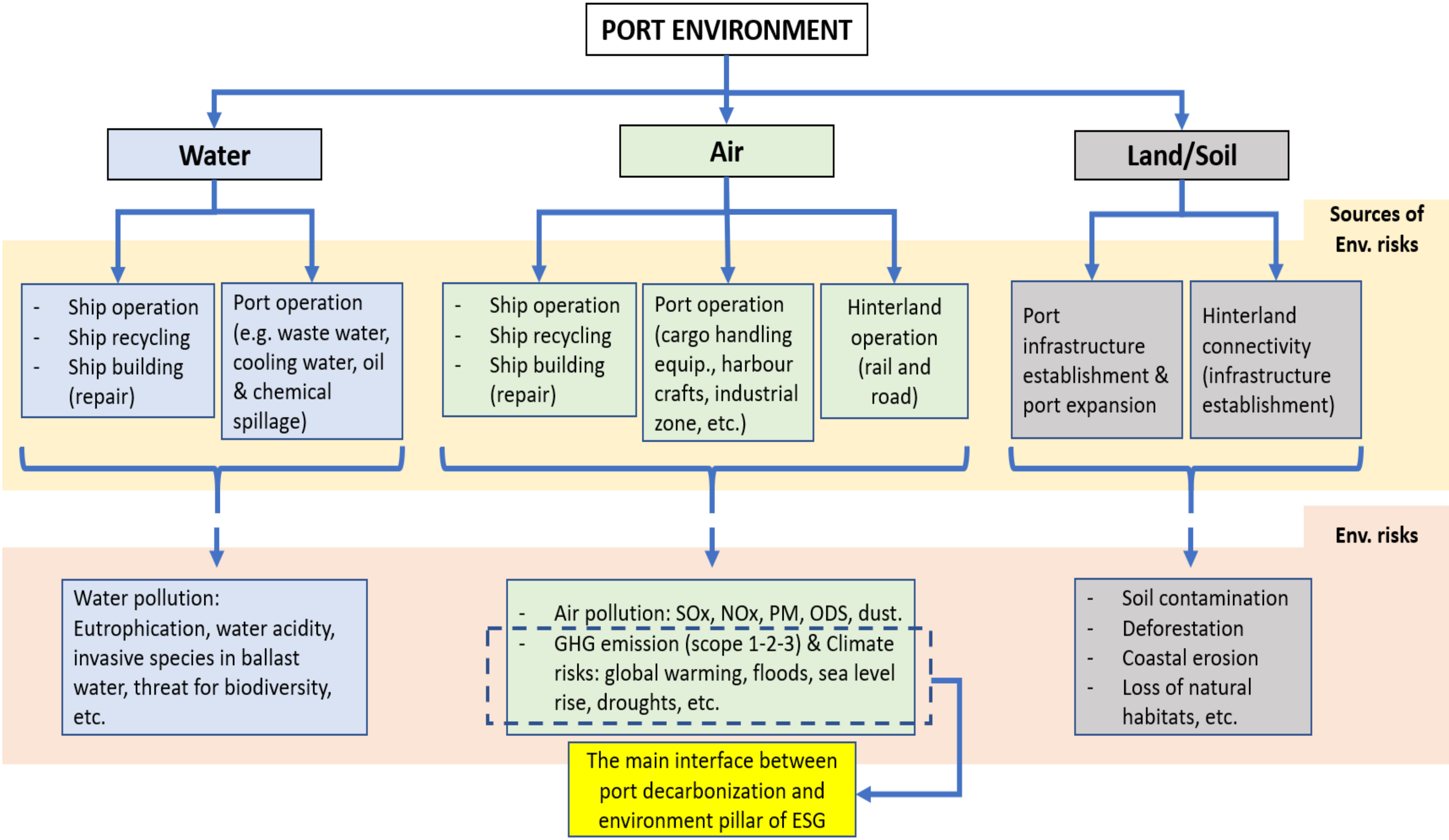

Figure 12 Share of port decarbonization from the entire ESG environmental coverage

SOCIAL NEEDS / PORT SOCIETY GROUPS	Port authorities	Port workers (contractors)	Ship staff (in port)	Hinterland operators (in port)	Port visitors	Port Neighbouring residents	Global society	Notes
Health Management (air, water, soil, and noise pollutants)	✔	✔	✔	✔	✔	✔	Indirect (mainly local effect)	
Health Management (global warming, droughts, floods, and sea level rise due to **GHG emission**)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	Direct impact of GHG emission on society
Securing and Development of Human Resources (e.g. training)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔	✔	✔ (highlighted)	Training of managers and employers (ship-port-hinterland) to achieve CO2 reduction targets
Diversity & Inclusion (e.g. gender equality)	✔	✔	✔	✔	✔	✔	Indirect (mainly local effect)	
Respect for Human Rights	✔	✔	✔	✔	✔	✔	✔	
Stakeholder Engagement	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔	✔ (highlighted)	✔ (highlighted)	Cooperation between stakeholders for CO2 reduction
Relationship with the community	✔	✔	✔	✔	✔	✔	Indirect (mainly local effect)	
Safety and quality management	✔	✔	✔	✔	✔	✔	✔	It is assumed that safe and high quality port service does not increase the CO2 emission
Supply chain labour standards	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔ (highlighted)	✔	✔	✔ (highlighted)	High skilled labour and managers to achieve CO2 reduction targets
Privacy and data security	✔	✔	✔	✔	✔	✔	Indirect (mainly local effect)	

✔ these are the society needs for different society groups engaged in ports
✔ (highlighted) in these cases there is some sort of GHG footprint in society needs

Figure 13 Social impacts of port CO2 emission as a subsidiary of social coverage of the ESG framework

4.4.3. Port ESG materiality matrix

In the absence of a specific standard for seaport ESG reporting, the ESG or sustainability report of some ports was reviewed such as Vancouver[1], Tianjin[2], Rotterdam[3], Peel Ports Group[4], Newcastle[5], Montreal[6], Melbourne[7], Gothenburg[8], Adani Ports and logistics[9], Houston[10], Geelong[11], Hutchison Ports[12], and AD ports group[13]. The objective of this review was to identify the common environmental, social, and governance material issues in the port ESG (or sustainability) reports and filtration of the issues relevant to CO_2 emission and decarbonization among them. The result of this review was a consolidated list of material issues regarding the environment, social, and governance in the form of an ESG materiality matrix (Table 15). The content of the materiality matrix was discussed and investigated through focus group sessions by the WMU research team. Table 16 shows the port decarbonization KPIs and best practices categorized based on environmental, social, and governance aspects.

[1] Vancouver Fraser Port Authority. (2020). Sustainability Report.
[2] Tianjin Port Development Holdings Limited. (2022). Environmental, Social and Governance Report.
[3] Port of Rotterdam. (2015). Port Environmental Review System (PERS).
[4] Peel Ports Group. (2022). Environmental Policy.
[5] Port of Newcastle. (2022). Sustainability Report.
[6] Montreal Port Authority. (2023). Summary Report of Achievements in Sustainable Development.
[7] Port of Melbourne. (2021). Sustainability Report.
[8] Port of Gothenburg. (2020). Sustainability Report.
[9] Adani Ports and Logistics. (2021). Information Memorandum on ESG.
[10] Port Houston. (2022). Environment, Social, Safety, and Governance.
[11] Geelong Port. (2022). Sustainability Report.
[12] Hutchison Ports. (2021). Building a Smart & Sustainable Port, Sustainability Report.
[13] AD ports group. (2022). Sustainability Report.

Table 15 Port ESG materiality matrix

E-S-G Interrelation	Material Subjects
Environment-Social	- Minimizing the impacts of air, water, soil, and noise pollution on society groups including port authorities, port workers (contractors), ship staff (in port), hinterland operators (in port), port visitors, and port neighbouring residents - Life expectancy - Mortality rate - Facilitate the stakeholders' dialogues about environmental issues - Social impact assessment of environmental projects - Environmental awareness
Social-Governance	- Stakeholders' engagement (Identifying stakeholders and their interests) - Materiality Assessment: management of all material topics identified as material to stakeholders - Information dissemination by sharing best practices and lessons learnt (e.g., participation in regional associations of ports) - Employee engagement - Workplace health and safety - Labour market indicators - Employee benefits and wellbeing - Satisfaction level of employees - Work-life balance and organisational culture - Diversity and inclusion (e.g., gender balance in leadership and decision-making and gender equality in recruitment and career progression) - Empowering staff and contractors to stop work if unsafe conditions or unsafe behaviour arise - Anti-bribery, anti-corruption and fair competition policy - Whistleblowing policy with a defined line of report - Rights of indigenous peoples - Human rights and grievances: code of business ethics and code of conduct - Community engagement - Occupational health and safety management system: ISO 45001 - Risk and crisis management- Enterprise Risk Management (ERM): ISO 31000 - Operational risk assessment - Information security management system: ISO/IEC 27001 Certification - Training hours and subjects
Governance-Environment	- EnMS (energy management system): ISO 50001 - EMS (environmental management system): ISO 14001 - PERS (Port Environmental Review System) as the only port-specific environmental standard - Transparency and environmental reporting (e.g., ESG or sustainability reporting) - Waste management - Management of hazardous substances (chemicals and cargo) - Ocean health and biodiversity conservation - Systems of practices, control, and procedures - Green procurement and supply chain - Management (quality control) of third parties and contractors in ports - Compliance with applicable rules, laws, regulations, standards (to be ensured by internal audit)

Table 16 ESG KPIs and best practices for port decarbonization and energy transition

		Environment	Social	Governance
KPIs		- Port decarbonization strategy is a major part of the port policy - Significant environmental aspects in port have been identified - Significant energy users in port have been identified - Energy baseline has been established in the port - Specific CO2 reduction target has been set - Decarbonization is a major part of the port clean air action plan - Internal audit plan is set (in the EnMS or EMS framework) - Record of the latest energy audit results - Energy intensity (e.g., grCO2/TEU) is measured at intervals - Records of annual management review is available - Set of procedures and criteria to select green contractors - Set of procedures and criteria to select green suppliers - Port has adopted the ISO 14001 or PERS framework as a guideline - Port is certified by the ISO 14001 or PERS - Port has adopted the ISO 50001 framework as a guideline - Port is certified by the ISO 50001 - Record of water consumption particularly if it is product of fresh water generators and not from natural resources	- Port has a documented training plan - Number of training courses and training hours - Number of trainees and their working position (title) - Number of certificates issued - Budget spent on learning and development - Total training hours for male and female employees - Average training hours provided per employee - Types of training including technical training, behavioural training, soft skills training, safety training, orientation/ new joiner training, leadership/ management, language training, information technology & security, HSE training. - Port has provided all or some of the following employee benefits including life insurance, health insurance, parental leave, pension contribution, and performance bonus - Lost time incident rate (LTIR) - Lost time incident frequency (LTIF)	- Port policy includes 'Quality of Services', 'Health and Safety at Workplace' and 'Environmental Protection' - Proper ESG KPIs have been defined - Proper ESG action plans have been developed - Mapping of the GHG emission (scope 1-2-3) and emission inventory is a major part of port annual ESG or sustainability report - Health, Safety and Environmental (HSE) Corrective actions are documented and implemented - Port is a member of regional associations for data exchange and sharing best practices and lesson learnt - Ethics Committee is in place with a defined line of report - Checklists for key operations have been developed - The procedure of permit to work for high-risk operations is in effect (relevant form to be filled and archived) - The procedure of risk assessment before attempting high-risk operations is in effect (relevant form to be filled and archived)
Best practices	Economy	- Green loans for decarbonization projects - Economic models (e.g., maritime energy contracting (MEC) or energy supply contracting (ESC)) to provide green technologies and green fuels in ports - R&D investment for decarbonization projects - Market consultation for decarbonization projects - Economic collaboration of shipowner-shipper-port-technology provider to invest and run the infrastructures at port	- Resource management (human resource and asset) - Recognizing and rewarding accomplishments (e.g., cost saving innovations) - Socio-economy collaboration between ports and residential areas (e.g., creation of parks and green spaces, museum, and tourist and duty-free zones)	- Tax exemption for clean operators - Incentive programs for ship and hinterland operators - Subsidies for green technology providers - Economic feasibility study for decarbonization projects - Development of the code of business ethics and conduct - Environmental assessments of suppliers - Stakeholders' engagement - Financial support by future GHG Fund of shipping
	Safety	- Developing contingency plans to handle fire and oil & chemical spills at port - Accountability: Establishment an ERT (emergency response team)	- Updated safe working practices for the port employees - Safety considerations for port visitors, and port neighbouring residents - Safety training and awareness raising	- ISO 45001: Occupational health and safety management system - ISO 31000: Enterprise Risk Management
	Technology	- Installation of advanced and accurate measuring devices for monitoring and metering of energy consumption - Port digitalization including ship-port digitalization, port-hinterland digitalization, and inside port actors' digital connectivity - Adoption of green technologies - Development of required infrastructure for alternative fuels - Development of renewable energy harvesting infrastructure - Joint research project with research institutes and universities	- Technical training and upskilling courses for port employees to adopt with new technologies - Techno-socio impact assessment studies - Technical skill audit for port operators	- Cooperation of ports in development of codes and standards for new technologies - Technical feasibility studies for decarbonization projects - Spatial planning for accommodating green technologies and circular economy infrastructure - Identifying the area and amount of reduction in energy consumption as a direct result of conservation and efficiency initiatives
	Security	- Ensured energy security/resilience in ports - Ensured cyber security for critical infrastructures in port	- Job security: Employee retention should be the priority of port managers; Port employees must be under the support of unions - Cyber security training and awareness raising - Customer privacy and data security to be ensured	- ISO 27001: Information security management system - Cyber security is embedded in the corporate governance

4.4.4. ESG analysis of the port energy transition

Port ESG material issues, KPIs and best practices relevant to port energy transition were identified in the last section and presented in Table 15 and Table 16, respectively. On the other hand, responses from three DEMO ports regarding the application of proposed decarbonization measures (technical, operational, and governance) were received and presented in appendices A, B, and C. At this stage, an ESG assessment of the adaptation of these measures in ports is conducted. This process necessitates considering the impacts of port energy transitions from an environmental, social, and governance perspective. These impacts are classified into three major categories including E-S-G ***challenges***, E-S-G ***requirements*** (prerequisites), and E-S-G ***positive features*** as a result of port energy transition. The ESG analysis comprises the following 8 categories of technical, operational, and governance measures presented in Table 17 and Table 24. At the end of each category of measures, the status of each DEMO port has been mentioned.

- Alternative fuel
  - LNG *Table 17*
  - Methanol *Table 18*
  - Ammonia *Table 19*
  - Hydrogen *Table 20*

- Renewable energies in ports and ships' electrification (OPS & battery charging) *Table 21*
- Digitalization, automation, and innovative technologies *Table 22*
- Management systems and certification *Table 23*
- Port green policies, incentive programs, and investment in hinterland *Table 24*

Technical details about alternative fuels have been inspired by Bilgili (2023) and the other details have been taken from our last report, D 1.1.1, regarding the analysis of barriers and drivers for the energy transition in ports.

Table 17 ESG impacts due to the adoption of LNG fuel bunkering infrastructure

	Environment	Social	Governance*
Alternative fuel- LNG	**CHALLENGES**		
	- It is a kind of fossil fuel - Non-renewable source of energy with high impact on resource depletion - Methane slip in IC engines - Methane leakage in the entire supply chain (life cycle) - High energy consumption in storage and transport (liquefaction) - Env. risk at the time of emptying and purging of tanks	- Safety issues for port, ship, and hinterland operators - Safety of neighbouring residents - Lack of training and skills - Social admissibility of residents living in the vicinity of the port	- Underdeveloped supply chain for LNG outside the ECA mostly due to less demand - High initial cost for establishment of LNG infrastructure in ports - High initial cost of ship building - LNG storage occupies high volume of space onboard ships - Lack of standard for LNG bunkering - Energy security vulnerabilities associated with LNG - Lack of economic motivation in all stakeholders - Lack of physical space in ports
	POSITIVE FEATURES		
	- Mitigate climate crisis as a solution in transition phase towards net zero emission - Reduction of other pollutants such as SOx, NOx, and PM -	- Improvement of society health condition (less pollutant) - Acceptability by stakeholders due to abundance and low price	- Availability of IGF and IGC codes in shipping - Well established supply chain - Acceptable technical maturity - In terms of SOx reduction, LNG use is less costly than scrubber
	REQUIREMENTS		
	- Environmental impact assessment - Environmental contingency plan	- Specialized training and certification for port operators - Techno-socio studies - Risk assessment - Information share and awareness raising	- Project funding in port - Codes and standards for LNG handling including transport, bunkering, storage, and usage - Spatial study in ports for establishment of LNG infrastructure - Economic and technical feasibility studies - Establishment an ERT (emergency response team) - Carbon tax in shipping industry
Demo port status	- **Port of Valencia:** LNG bunkering for commercial vessels and trucks is operational - **Port of Syros:** Under feasibility studies - **Port of EHOO:** LNG bunkering for trucks is operational; same could be used for cargo handling equipment		
***Governance**: environmental, social, economic, and technical policy and management			

Table 18 ESG impacts due to the adoption of Methanol fuel bunkering infrastructure

	Environment	Social	Governance*
Alternative fuel- Methanol	**CHALLENGES**		
	- Methanol is toxic and corrosive - The CO2 reduction by methanol, produced from fossil sources, is not very high - Higher CO and HC emissions in low loads due to incomplete combustion	- Safety issues for port, ship, and bunkering staff - Lack of training and skills	- Some inconsistency in IGF code in case of methanol fuelled ships - Low flash point that necessitates higher safety standard - Low calorific value necessitates higher storage space or more frequent bunkering - Necessitates modification in ship's engine due to its corrosive nature - Very limited production of bio-methanol which is very effective in CO2 reduction - High cost of production - Lack of economic motivation in all stakeholders - Lack of physical space in ports
	POSITIVE FEATURES		
	- Mitigate climate crisis (less CO2 emission) - Less env. risk in case of spillage in the seawater (methanol can dissolve in water) - It is Sulphur free - Reduction of other pollutants such as SOx, NOx, and PM	- Improvement of society health condition (less pollutant)	- Large-scale production capacity - Easy storage and bunkering (in liquid form at ambient pressure and temperature) - Well established supply chain - Acceptable technical maturity
	REQUIREMENTS		
	- Environmental impact assessment - Environmental contingency plan	- Specialized training and certification for port operators (storage and bunkering staff) - Techno-socio studies - Risk assessment - Information share and awareness raising	- Project funding in port - Modification of IGF code to be applicable consistently for methanol - Spatial study in ports for establishment of methanol infrastructure - Economic & technical feasibility studies - Carbon tax in shipping industry
Demo port status	- **Port of Valencia:** Under feasibility study through a joint project (methanol storage capacity is available) - **Port of Syros:** It is not applicable in this port - **Port of EHOO:** Under feasibility study		
***Governance**: environmental, social, economic, and technical policy and management			

Table 19 ESG impacts due to the adoption of Ammonia fuel bunkering infrastructure

		Environment	Social	Governance*
Alternative fuel- Ammonia	**CHALLENGES**			
		- An unpleasant pungent odour - Corrosive and highly toxic - Higher NOx and N2O emissions in the higher ratio of Ammonia in the fuel mixture	- Safety issues for port, ship, and bunkering staff - Lack of training and skills - Inhalation of Ammonia is harmful to health - Social admissibility of residents living in the vicinity of the port	- Ammonia supply is very less - Unstable combustion at very low and very high engine loads - Low calorific value that necessitates higher storage space or more frequent bunkering - Modification of Ammonia tanks and supply systems is necessary - High cost of production in particular in case of green Ammonia - Immature technology - Lack of economic motivation in all stakeholders - Lack of physical space in ports
	POSITIVE FEATURES			
		- High potential in CO2 reduction in case of blue and green Ammonia - It is Sulphur free - Extreme reduction of other pollutants such as SOx and PM	- Improvement of society health condition (less pollutant) - Less fire risk associated with ammonia vapour	- Ammonia can be used as a fuel and as a hydrogen carrier (as a H2 carrier, Ammonia is very promising) - Easy storage and bunkering (in liquid form at ambient pressure and temp.) - Well established supply chain - Fuel cells and internal combustion engines can use Ammonia directly
	REQUIREMENTS			
		- Environmental impact assessment - Environmental contingency plan	- Specialized training and certification for port operators (storage and bunkering staff) - Techno-socio studies - Risk assessment - Information share and awareness raising	- Project funding in port - Necessitates further work on engine and fuel cells' technology - Specific code and standard to be developed for marine use of Ammonia - Spatial study in ports for establishment of Ammonia infrastructure - Economic & technical feasibility studies - Carbon tax in shipping industry
Demo port status	- **Port of Valencia:** Under feasibility study; Ammonia storage capacity is available in vicinity of Valencia port - **Port of Syros:** It is not applicable in this port - **Port of EHOO:** Under feasibility study (according to the port manager, the probability of Ammonia adoption in inland shipping is very low)			
***Governance**: environmental, social, economic, and technical policy and management				

Table 20 ESG impacts due to the adoption of Hydrogen fuel bunkering infrastructure

	Environment	Social	Governance*
Alternative fuel- Hydrogen	**CHALLENGES**		
	- High energy consumption in liquefaction of H2	- Safety issues for port, ship, and bunkering staff (highly flammable) - Lack of training and skills - Social admissibility of residents living in the vicinity of the port	- Underdeveloped supply chain - High cost and difficulties of storage and transportation of liquefied H2 - H2 is capable to penetrate and pass through many materials - Very low energy density (high volume storage is challenging) - High cost of production - Difficulties in direct use in IC engines - Immature technology - Lack of economic motivation in all stakeholders - Lack of physical space in ports
	POSITIVE FEATURES		
	- It is non-toxic - Zero CO2 emission in case of green Hydrogen - It is Sulphur free - Reduction of other pollutants such as SOx, NOx, and PM (in case of mixture of H2 and Ammonia)	- Improvement of society health condition (less pollutant)	- Feasibility to use it with other fuels - Appropriate combustion characteristics
	REQUIREMENTS		
	- Environmental impact assessment - Environmental contingency plan	- Specialized training and certification for port operators (storage and bunkering staff) - Techno-socio studies - Risk assessment - Information share & awareness raising	- Project funding in port - Necessitates further work on engine and fuel cells' technology - Specific code and standard to be developed for marine use of H2 - Spatial study in ports for establishment of Hydrogen infrastructure - Economic and technical feasibility studies - Carbon tax in shipping industry
Demo port status	- **Port of Valencia:** Short-term strategy (very close to pilot) for cargo handling equipment and trucks; under feasibility study for commercial vessels and reefer containers - **Port of Syros:** Under feasibility study for marine diesels - **Port of EHOO:** Monitoring of the latest technology advancement to deploy H2 for cargo handling equipment, trucks, and reefer containers		
***Governance**: environmental, social, economic, and technical policy and management			

Table 21 ESG impacts due to the adoption of renewable energies and ship electrification appliances

<table>
<tr><th rowspan="7">Renewable energies in ports and ships' electrification (OPS & battery charging)</th><th>Environment</th><th>Social</th><th>Governance*</th></tr>
<tr><td colspan="3">CHALLENGES</td></tr>
<tr><td>- Electricity from national grid always and everywhere is not green
- Uncertainties in future environmental regulations</td><td>- Lack of training and skills
- Resistance by seafarers in case of battery powered ships (fear of immaturity of battery technology)</td><td>- Lack of green electricity in ports
- Possibility of stranded investment in OPS or battery charging equipment
- High retrofit cost for shipowners
- High capital cost for establishment of electrification infrastructure in ports
- Battery chargers is only applicable for ships engaged in short sea shipping
- OPS is applicable for ships with higher berthing time
- Inconsistency between port and ships' equipment</td></tr>
<tr><td colspan="3">POSITIVE FEATURES</td></tr>
<tr><td>- Mitigate climate crisis (less CO2 emission)
- No air pollutant in port area
- No noise pollution in port area</td><td>- Improvement of society health condition (less pollutant)
- Acceptance and alignment of society</td><td>- Availability of codes and standards
- Acceptable technical maturity
- Technology availability in the market
- Ensured energy security and energy self-sufficiency of ports, in case if they can produce enough renewable energy</td></tr>
<tr><td colspan="3">REQUIREMENTS</td></tr>
<tr><td>- Environmental strategic plan
- Environmental impact assessment
- Environmental commitment</td><td>- Specialized training and certification for port operators (operation and maintenance of electrification appliances, and renewable energy equipment)
- Specialized training for onboard electrical engineers
- Techno-socio studies
- Risk assessment
- Information share and awareness raising</td><td>- Financial support by future GHG Fund
- Mandatory regulations for ports as well as specific ship segments to adapt OPS
- Incentive programs such as tax exemption provided by ports and governments
- Investment and operation of port electrification infrastructures by shippers and shipping companies that use this equipment by their ships more frequently
- Technology providers can invest on electrification technologies both at ports and on ships
- Spatial planning, and feasibility studies</td></tr>
<tr><td>Demo port status</td><td colspan="3">- Port of Valencia: Detailed calculation for two OPS connecting locations is completed (short-term); Elec. charging infrastructure is under feasibility study; Renewable energy is used for buildings and facilities.
- Port of Syros: OPS is in use for touristic boats and in long-term strategy for ships; Charging appliances is in use for touristic boats, in short-term for trucks and in long-term for ships; Renewable energy is part of long-term strategy.
- Port of EHOO: OPS is in use for commercial vessels; Charging appliances is in use for ships and cargo handling equipment and soon (short-term) for trucks; Renewable energy is used for buildings and facilities.</td></tr>
<tr><td colspan="4">*Governance: environmental, social, economic, and technical policy and management</td></tr>
</table>

Table 22 ESG impacts due to the adoption of digitalization, automation, and innovative technologies

	Environment	Social	Governance*
Digitalization, automation, and innovative technologies	**CHALLENGES**		
	- Probability of environmental disasters as a result of automation failure - Fraudulent energy saving or pollution mitigation claims by technology providers	- Lack of skills and competency to adapt with new technologies - Lack of ICT skills - Inertia (resistance to change) by managers and employees in adoption of new technologies - Lack of shared information and lesson learnt - Emergence of techno-stress	- Lack of required infrastructure (e.g., ICT infrastructure) - Lack of codes and standards for new emerging technologies - Inconsistency in adaptation of new technologies between ports, ships, and hinterland transport - Maturity (reliability) of new technologies and advanced automatic systems - Cyber attacks
	POSITIVE FEATURES		
	- Mitigate climate crisis (less CO2 emission) - Less pollution	- Less human error - Less administrative burden and paper work - Less manpower	- More harmony between stakeholders - Save of time and energy - Significant reduction in idle time of ships and hinterland modes of transport - Improved monitoring and control - Improved data collection and analyse
	REQUIREMENTS		
	- Environmental strategic plan - Monitoring pilot projects to ensure materialization of the energy saving targets - Improve the reliability of the automatic systems and providing the fail-safe options in them	- Corporate social responsibility (CSR) - ICT training - Training courses by technology providers - Techno-socio studies - Risk assessment - Information share and awareness raising	- ICT infrastructure - Set of criteria for green procurement - Joint research projects to introduce pilot projects in ports - Technical feasibility studies, and project risk assessment - The framework of information security management system to be embedded in port management
Demo port status	- **Port of Valencia:** Advanced automation systems are either in operation or in short-term strategy; digitalization to connect inside port actors as well as port-hinterland connectivity are in operation. - **Port of Syros:** Advanced automation systems are in the long-term strategy; For digitalization, Syros soon will have an application for touristic boats, berth and billing. - **Port of EHOO:** EHOO has deployed highly modern and automated gantry cranes. They have port management system (software) for ship-port digital connectivity as well as a program focusing on containers to improve port- hinterland digital connectivity.		
***Governance**: environmental, social, economic, and technical policy and management			

Table 23 ESG impacts due to the adoption of management systems

	Environment	**Social**	**Governance***
Management systems and certification	**CHALLENGES**		
	- Certification as a motivation to display a green image rather than proper implementation of a management system - Challenges in CO_2 reduction target setting as a result of uncertainties in policies and technology readiness	- Extra administrative burden - Lack of managerial skills - Inertia (resistance to change) in managers	- Energy management may not be a top priority for port managers - Cost for establishment of energy management system including costs for establishment of energy management department (employing energy manager and auditors), and ICT infrastructure, as well as costs for consultancy, certification, and monitoring and measurement equipment.
	POSITIVE FEATURES		
	- Improved energy efficiency and declined CO_2 emission	- Mitigation of the negative environmental externalities on society - Systematic follow up of the training requirements	- Identification of the stakeholders and their interests - CO_2 reduction goal setting - Systematic approach for CO_2 reduction (continuous improvement for example by active PDCA cycle) - Certification can be an effective drive for establishment of management systems
	REQUIREMENTS		
	- Environmental commitment - Environmental strategic plan - Willingness to achieve a green image and high reputation	- Corporate social responsibility (CSR) - Availability of competent managers and auditors - Training plan and relevant KPIs	- Establishment of the energy management department - Establishment of ICT infrastructure and measurement and data collection systems - Designing the monitoring plan and formulating relevant KPIs - Identification of significant environmental aspects, and significant energy users - Establishment of energy baseline - Development of the port clean air action plan - Development of audit scheme - Management review and corrective action plan
Demo port status	- **Port of Valencia:** Valencia port is certified by ISO 14001, IS0 50001, and PERS. - **Port of Syros:** Environmental management system is under feasibility study and energy management system is part of long-term strategy. - **Port of EHOO:** Environmental and energy management systems have been established and their certification is part of short-term strategy.		
***Governance**: environmental, social, economic, and technical policy and management			

Table 24 ESG impacts due to the adoption of green policies and incentive schemes, and investment in hinterland transport

	Environment	Social	Governance*
Port green policies, incentive programs, and investment in hinterland	**CHALLENGES**		
	- Incentive programs have not had significant effect on CO2 reduction	- Extra administrative burden for ship and port staff in implementation of port incentive programs - Lack of managerial skills - Inertia (resistance to change) in managers - Lack of information dissemination (e.g., port sustainability or ESG reports)	- Incentive programs are not practiced by many ports - Lack of policy feedback on effectiveness of green policies - Lack of budget in port management to invest in port-hinterland connectivity - Failure of “polluter pays” principle in port incentive schemes (incentives are mostly provided from port revenue not from polluting ships) - The amount of financial incentive is not encouraging - High diversity in methods and objectives of port incentive programs
	POSITIVE FEATURES		
	- Declined CO2 emission per unit of cargo transported as a result of improved port-hinterland connectivity - Positive impacts of ports on entire green supply chain - Motivation of ship and hinterland operators to green operation	- Mitigation of the negative environmental externalities on society	- Enhanced port-hinterland connectivity - Improved modal shift from road to rail - Significant decline in ships, trucks, and trains idle time at port gates and anchorage
	REQUIREMENTS		
	- Environmental commitment - Environmental strategic plan - Willingness to achieve a green image and high reputation	- Corporate social responsibility (CSR) - Information share and awareness raising - Communication and collaboration between stakeholders	- Policy innovation (green policy making in ports e.g., green procurement, green concession contracts, green suppliers’ assessment, etc.) - Implementation of shipping MBM and financial support for ports from IMO GHG Fund - Green loans for decarbonization projects - Market consultation before joint investment projects - Feasibility studies
Demo port status	- **Port of Valencia:** Already tax exemption and port incentive program for ships are in place and for trucks is under feasibility study; Valencia port has invested in dry ports and railroad infrastructure. - **Port of Syros:** Participation in joint ventures is under feasibility study in this port. - **Port of EHOO:** EHOO has invested in railroad expansion and its connectivity to the port.		
***Governance**: environmental, social, economic, and technical policy and management			

5. Conclusions and Recommendations

Through the implementation of the Life Cycle Assessment (LCA), we were able to critically examine and identify the major sources of impact within the standard operations of the demo ports of Syros and Fundación Valencia. The LCA enabled us to pinpoint areas of opportunity that would allow us to refocus our energy and fuel technologies towards reducing both carbon footprint and greenhouse gas emissions.

Both Valencia and Syros Ports were included in our life cycle inventory, their respective mandatory elements being factored into the selection of impact categories, adhering to the guidelines set by ISO 14040-44. We employed a black-box-oriented approach to classify and characterize the environmental impacts of these life cycles. To ensure the relevance of our life cycle impact assessment (LCIA), we used ReCiPe 2016 Midpoint - the common LCIA method favored within Europe. Our findings indicated that diesel-powered sources at the Port of Valencia constitute around 70% of the total CO2-eq emissions per TEU. These sources include commercial vessels, diesel-fueled RTG cranes, terminal tractors, and trucks. In contrast, at Syros Port, the majority of CO2-eq emissions per ship are associated with marine diesel used by vessels. The use of the LCA methodology permitted us to analyze these situations, identifying not just the negative impacts of the use of natural resources such as energy and fuels, but also strategies to reduce the carbon footprint and greenhouse gas emissions in these ports.

In Valencia, though energy and fuels are integral to daily operations, mitigating environmental impact may require increased operational efficiency and potentially adopting renewable energy sources. In Syros, given the impact of marine diesel, alternatives may include route efficiency, engine maintenance, engine or vessel upgrades, or adopting renewable energy sources like hydrogen or natural gas.

Considering ports handle nearly 80% of international cargo tied to maritime transport and hinterland connections, they hold a significant role in local economies, impacting tax collection and employment (Caldeira dos Santos & Pereira, 2022). However, the industry faces mounting challenges related to water and air pollution, congestion, and stakeholder participation, all of which are critical considerations for investors concerned about their reputation (Caldeira dos Santos & Pereira, 2022).

In this light, adapting practices promoting better ESG performance becomes crucial. These include designating personnel both onshore and onboard, reducing emissions beyond CO_2, preparing for future challenges such as alternative fuels, and managing data and governance (ESG News, 2022). To aid this effort, the development of strategies to measure environmental impact, diversity, and inclusion within the industry, sustainability of financial results, and the relationship between the city and the port are of utmost importance (Caldeira dos Santos & Pereira, 2022).

While investors are wary of strategies negatively impacting the population and environment, academic evaluation of ESG in port operations and other industries such as automotive and aviation is still nascent (Caldeira dos Santos & Pereira, 2022). Thus, this report presents a series of KPIs aimed at CO_2 reduction and port decarbonization, providing measurable targets and a concrete action plan to optimize and promote energy efficiency. However, addressing CO_2 emissions is only part of a much larger scope within the port ESG. The adoption of CO2 reduction measures can give rise to significant environmental, social, and governance challenges. We examined five broad categories of CO_2 reduction measures: i) alternative fuel; ii) renewable energies in ports and ships' electrification; iii) digitalization, automation, and innovative technologies; iv) management systems and certification; and v) port green policies, incentive programs, and investment in the hinterland.

In these categories, four alternative fuels were evaluated. While the use of LNG is already established for bunkering of commercial vessels, trucks, and cargo handling equipment in two DEMO ports and is under feasibility study for the Port of Syros, the feasibility of methanol and ammonia is still under review for the Port of Valencia and EHOO. However, hydrogen usage is very close to being pilot-tested on cargo handling equipment and trucks in Valencia Port, and the other DEMO ports are closely monitoring this technology's advancements.

Renewable energies and ships' electrification are increasingly prevalent in ports, not only for OPS but also for buildings and facilities. Digitalization and automation are already in place or soon to be implemented as part of short-term strategies, promoting digital connectivity between port stakeholders. Moreover, environmental management systems are being increasingly adopted, and green policies and incentive programs are in place in DEMO ports, along with investments in hinterland connectivity.

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Appendix A: Adoption of technical and operational measures in the port of Valencia in the process of energy transition

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
TECHNICAL							
LNG bunkering infrastructure	For commercial vessels	☒	☐	☐	☐	☐	Currently, LNG is bunkered to Baleària's ferries through MTTS. SAGGAS LNG import plant is already capable of providing LNG to bunkering barges
LNG bunkering infrastructure	For tugboats	☐	☐	☐	☐	☒	The use of LNG in tugboats was studied in the framework of the CoreLNG as a hive project in which the basic engineering of an LNG-propelled tugboat was done, even though it was concluded not to be a proper option for the Port of Valencia operation.
LNG bunkering infrastructure	For cargo handling equipment	☐	☐	☐	☐	☒	CEF-funded initiative GreenCranes tested an LNG yard tractor, although finally, it has not been adapted for any of Valencia's container terminals.
LNG bunkering infrastructure	For trucks	☒	☐	☐	☐	☐	
Methanol bunkering infrastructure for commercial vessels		☐	☐	☐	☒	☐	FV is a partner of the POSEIDON project which will test methanol on marine engines. In addition, right now the port of Valencia has a

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
							methanol storage capacity in the TEPSA terminal
Ammonia bunkering infrastructure for commercial vessels		☐	☐	☐	☒	☐	In the port of Sagunto (next to the Port of Valencia, and also managed by the Port Authority of Valencia) Fertiberia's terminal has an ammonia storage capacity
Hydrogen bunkering infrastructure	For commercial vessels	☐	☐	☐	☒	☐	The current feasibility studies focus on the use of H2 for technical nautical services
	For cargo handling equipment	☐	☒	☐	☐	☐	H2PORTS is currently underway, the pilot period is about to start, and final users participating consider H2 zero-emissions
	For trucks	☐	☒	☐	☐	☐	The road transport sector is part of the H2VLC initiative, which focuses on the development of a hydrogen valley for mobility uses in the area of the city of Valencia
	For fuel cells installed on reefer containers	☐	☐	☐	☒	☐	Feasibility studies have not yet started
Shore Power	For commercial vessels	☐	☒	☐	☐	☐	Detailed engineering studies have already been carried out for two connecting locations
	For tugboats at berth	☒	☐	☐	☐	☐	
Elec. charging	For commercial vessels	☐	☐	☐	☒	☐	FV is a partner of the HE project HYPOBATT which focuses on charging

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
	For cargo handling equipment	☐	☐	☐	☒	☐	Studies being carried out by terminals
	For trucks	☐	☐	☐	☒	☐	The first pilot of an electric truck was carried out at the beginning of 2023
Renewable energy	For buildings and facilities electrical consumption	☒	☐	☐	☐	☐	The installation of 1.2 MW PV has been already started which will be followed by a 5.2 MW already awarded
	To produce Hydrogen through the electrolysis process	☐	☐	☐	☒	☐	
Higher automation level	To enhance efficiency in cargo handling equipment	☐	☒	☐	☐	☐	New terminal foreseen as partially automatized
	To enhance efficiency in buildings and facilities	☒	☐	☐	☐	☐	Automatic refrigeration and light systems, management improvement systems
Adoption of innovative technologies	For commercial vessels (e.g., foldable containers)	☐	☒	☐	☐	☐	Valencia port has offered support and follow-up to the Navlandis Zbox folding container project (they participated in the Maritime Climate Kic Accelerator program) which currently has units on the market, but on routes that do not pass through Valencia yet.
	For cargo handling equipment	☐	☒	☐	☐	☐	FV coordinates the terminals project, whose aim is to facilitate information management and achieve digital transformation of container

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
							port operations by applying technologies working towards operational efficiency as a framework of standards
	For trucks (e.g., foldable containers)	☐	☒	☐	☐	☐	It is foreseen to implement a Vehicle booking system (VBS)
OPERATIONAL AND GOVERNANCE							
Port digitalization	ship- port connectivity e.g., electronic bill of lading & advanced berth allocating mechanism (virtual arrival)	☐	☒	☐	☐	☐	
Port digitalization	port actors' connectivity e.g., port collaborative decision-making (CDM)	☒	☐	☐	☐	☐	Valencia port has participated in projects such as Monalisa and STM Validation that developed the concept of PortCDM systems and led to the creation of the spin-off Seaport Solutions and the development and implementation project of the Paula system with the help of a Ports 4.0 project.
Port digitalization	port- hinterland connectivity e.g., Truck traffic control or virtual gates	☒	☐	☐	☐	☐	The PCS has a module and mobile App for the advanced management and organization of land transport by truck and rail, integrating stakeholders (shipping companies, freight forwarders, transport operators, carriers,

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
							drivers, terminals, depots, operators and railway companies, customs, etc.). The system is complemented by automated door systems at the accesses to the port area and terminals. Within the framework of innovation projects, other TAS solutions etc., have been and continue to be developed and tested, which may end up being implemented or providing improvements in current systems and solutions.
Port incentive program	Discounts in the fairway and port dues for ships	☒	☐	☐	☐	☐	
	Incentives for trucks	☐	☐	☐	☒	☐	One of the aspects being analyzed in the Port of Valencia's net zero emissions plan
	Tax exemption	☒	☐	☐	☐	☐	
Management system	Energy management system	☒	☐	☐	☐	☐	
	Environmental management system	☒	☐	☐	☐	☐	

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
Certification	ISO 14001	☒	☐	☐	☐	☐	
	ISO 50001	☒	☐	☐	☐	☐	
	PERS	☒	☐	☐	☐	☐	
port-hinterland investment and collaboration	Investment in the development of dry ports and high connectivity between dry ports & your port	☒	☐	☐	☐	☐	
	Participation in joint ventures	☐	☐	☐	☒	☐	Highly restricted by the Spanish Ports Law in its current version
	Investment in railroad expansion and its connectivity to your port and contribution to the modal shift from road to rail mode	☒	☐	☐	☐	☐	
Green port policies and programs (e.g., green procurement)		☒	☐	☐	☐	☐	

Appendix B: Adoption of technical and operational measures in the port of Syros in the process of energy transition

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
TECHNICAL							
LNG bunkering infrastructure	For marine diesel	☐	☐	☐	☒	☐	
LNG bunkering infrastructure	For touristic boats	☐	☐	☐	☐	☒	
LNG bunkering infrastructure	For auxiliary systems	☐	☐	☐	☐	☒	
LNG bunkering infrastructure	For trucks	☐	☐	☐	☐	☒	
Methanol bunkering infrastructure for marine diesel		☐	☐	☐	☐	☒	
Ammonia bunkering infrastructure for marine diesel		☐	☐	☐	☐	☒	
Hydro	For marine diesel	☐	☐	☐	☒	☐	

	For touristic boats	☐	☐	☐	☐	☒	
	For trucks	☐	☐	☐	☐	☒	
	For fuel cells installed on reefer containers	☐	☐	☐	☐	☒	
Shore Power	For marine diesel	☐	☐	☒	☐	☐	
	For touristic boats at berth	☒	☐	☐	☐	☐	
Elec. charging infrastructure	For commercial vessels	☐	☐	☒	☐	☐	
	For touristic boats	☒	☐	☐	☐	☐	
	For trucks and vehicles	☐	☒	☐	☐	☐	
Renewable energy	For lighting	☐	☐	☒	☐	☐	Included in Masterplan
	For building & facilities	☐	☐	☒	☐	☐	Included in Masterplan
Higher automation level	To enhance efficiency in lighting	☐	☐	☒	☐	☐	
	To enhance efficiency in buildings and facilities	☐	☐	☒	☐	☐	
	To enhance efficiency in auxiliary systems	☐	☐	☒	☐	☐	

Diesel gen. set working on alternative fuels	For lighting	☐	☐	☐	☐	☒	
	For building & facilities	☐	☐	☐	☐	☒	
	For auxiliary systems	☐	☐	☐	☐	☒	
	For heating in buildings	☐	☐	☐	☐	☒	
OPERATIONAL AND GOVERNANCE							
Port digitalization	ship- port connectivity e.g., electronic bill of lading & advanced berth allocating mechanism (virtual arrival)	☐	☒	☐	☐	☐	In 6 months, available app for touristic boats, berth and billing.
	port actors' connectivity e.g., port collaborative decision-making (CDM)	☐	☐	☐	☐	☒	
	port- hinterland connectivity e.g., Truck traffic control or virtual gates	☐	☐	☐	☐	☒	
Port incentive	Discounts in the fairway and port dues for ships	☐	☐	☐	☐	☒	
	Incentives for trucks	☐	☐	☐	☐	☒	

	Tax exemption	☐	☐	☐	☐	☒	
Management system	Energy management system	☐	☐	☒	☐	☐	
	Environmental management system	☐	☐	☐	☒	☐	
Certification	ISO 14001	☐	☐	☒	☐	☐	Under evaluation
	ISO 50001	☐	☐	☒	☐	☐	Under evaluation
	PERS	☐	☐	☒	☐	☐	
port-hinterland investment and collaboration	Investment in the development of dry ports and high connectivity between dry ports & your port	☐	☐	☐	☐	☒	
	Participation in joint ventures	☐	☐	☐	☒	☐	
	Investment in railroad expansion and its connectivity to your port and contribution to the modal shift from road to rail mode	☐	☐	☐	☐	☒	
Green port policies and programs (e.g., green procurement)		☐	☒	☐	☐	☐	

Appendix C: Adoption of technical and operational measures in the port of EHOO in the process of energy transition

Mitigation measure		It (or a similar measure) is already operational in this port	It is included in the short-term strategic plan	It is included in the long-term strategic plan	It is under feasibility studies	It is not applicable in this port	Comments
TECHNICAL							
LNG bunkering infrastructure	For commercial vessels	☐	☒	☐	☐	☐	Planning for equipment is ready (truck-to-ship) resp. will be finished soon (shore-to-ship); BUT: there is no demand on inland waterway now (as there are no LNG-driven vessels on the Danube
	For tugboats	☐	☐	☐	☐	☒	Not relevant / no tugboats in the inland port
	For cargo handling equipment	☒	☐	☐	☐	☐	Our filling station for trucks is even suitable e.g. reach stackers – but no such equipment till now working on LNG-basis
	For trucks	☒	☐	☐	☐	☐	The filling station in the port area started in 2017 (the first station in Austria), good development since then

Methanol bunkering infrastructure for commercial vessels		☐	☐	☐	☒	☐	Prefeasibility considerations for possible improvement/development of existing bunkering station for future needs – most probably in the direction of fuels – even MeOH might be part of this development in the future. (depends on European developments of fuels – currently there is no sign that MeOH will come soon for inland shipping)
Ammonia bunkering infrastructure for commercial vessels		☐	☐	☐	☒	☐	See the comment above for MeOH; it is much, much, much less unlikely that NH3 will come soon for inland shipping
Hydrogen bunkering infrastructure	For commercial vessels	☐	☐	☐	☒	☐	Watching development for H2 is ongoing, but far away from detailed feasibility; more likely is that H2-derivates will come within the next years for inland ports (e.g. efuels, …)
	For cargo handling equipment	☐	☐	☐	☒	☐	See above comment
	For trucks	☐	☐	☐	☒	☐	See above comment
	For fuel cells installed on reefer containers	☐	☐	☐	☒	☐	see above comment
Shore Power	For commercial vessels	☒	☐	☐	☐	☐	Currently, infrastructure is available with 63 A and 32 A; plans are ready for upgrading to 400 A, and the investment

							may start in 2024 (depending on the next CEF-founding call)
	For tugboats at berth	☐	☐	☐	☐	☐	Not relevant for an inland port
Elec. infrastructure charging	For commercial vessels	☒	☐	☐	☐	☐	See comment above (shore power)
	For cargo handling equipment	☒	☐	☐	☐	☐	For mobile equipment: Currently available only in lower kW levels (for forklifts, ..) “stationary”: all gantry cranes are running on an electricity basis
	For trucks	☐	☒	☐	☐	☐	Plannings for high-ampere loading boxes
Renewable energy	For buildings and facilities electrical consumption	☒	☐	☐	☐	☐	Photovoltaics are installed
	To produce Hydrogen through the electrolysis process	☐	☐	☐	☐	☒	Currently no technical equipment ready to market for this application
Higher automation	To enhance efficiency in cargo handling equipment	☒	☐	☐	☐	☐	State-of-the-art gantry cranes with state-of-the-art connectivity
	To enhance efficiency in buildings and facilities	☐	☐	☐	☐	☐	
Adoption of innovative	For commercial vessels (e.g., foldable containers)	☐	☐	☐	☐	☒	
	For cargo handling equipment	☐	☐	☐	☐	☒	

	For trucks (e.g., foldable containers)	☐	☐	☐	☐	☒	
OPERATIONAL AND GOVERNANCE							
Port digitalization	ship- port connectivity e.g., electronic bill of lading & advanced berth allocating mechanism (virtual arrival)	☒	☐	☐	☐	☐	Port management system (PMS as basis, on the way to further development stages of a PCS/port community system)
	port actors’ connectivity e.g., port collaborative decision-making (CDM)	☐	☐	☐	☐	☒	Not applicable for inland ports; standard digitalised connectivity of process players
	port- hinterland connectivity e.g., Truck traffic control or virtual gates	☒	☐	☐	☐	☐	Widely installed for container business (connections with first and last mile)
Port incentive program	Discounts in the fairway and port dues for ships	☐	☐	☐	☐	☒	
	Incentives for trucks	☐	☐	☐	☐	☒	
	Tax exemption	☐	☐	☐	☐	☒	
Management system	Energy management system	☒	☐	☐	☐	☐	Work in progress, not finalised
	Environmental management system	☒	☐	☐	☐	☐	Work in progress, not finalised

Certification	ISO 14001	☐	☒	☐	☐	☐	Currently not clear, if really ISO – probably a huger ESG system due to the European sustainability standard system (ESG, EU-taxonomy)
	IS0 50001	☐	☒	☐	☐	☐	See comment above
	PERS	☐	☒	☐	☐	☐	See comment above
port-hinterland investment and collaboration	Investment in the development of dry ports and high connectivity between dry ports & your port	☐	☐	☐	☐	☒	Not relevant for inland ports in our case
	Participation in joint ventures	☐	☐	☐	☐	☒	Not relevant to us
	Investment in railroad expansion and its connectivity to your port and contribution to the modal shift from road to rail mode	☒	☐	☐	☐	☐	Permanent ongoing work, focus not only on rail-road but even trimodality (BUT: please consider this in the sense of inland port situation)
Green port policies and programs (e.g., green procurement)		☒	☐	☐	☐	☐	Own strategic documents