SEANERGY

the Sustainability EducationAl programme for greeNER fuels and enerGY on ports

Horizon Europe Energy - HORIZON-CL5-2021-D3-02

EUROPEAN CLIMATE, INFRASTRUCTURE AND ENVIRONMENT EXECUTIVE AGENCY (CINEA)

Results of demo-ports' LCA

Lead Partner(s): Zero Emissions Engineering B.V. (ZER0-E) and World Maritime University (WMU)

Author(s): Ana Gomez, Johann Ramirez, Lorena Peña, Fabio Ballini, Peyman Ghaforian, Natalia Calderon

This document is the SEANERGY project **"Results of demo-port's LCA & ESG sustainability assessments"** (contract no. 101075710) corresponding to **D1.3 (Month 8)** led by **"Zero Emissions Engineering B.V. (ZER0-E)".**

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement number 101075710. This visual support reflects only

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

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

1.1. 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.

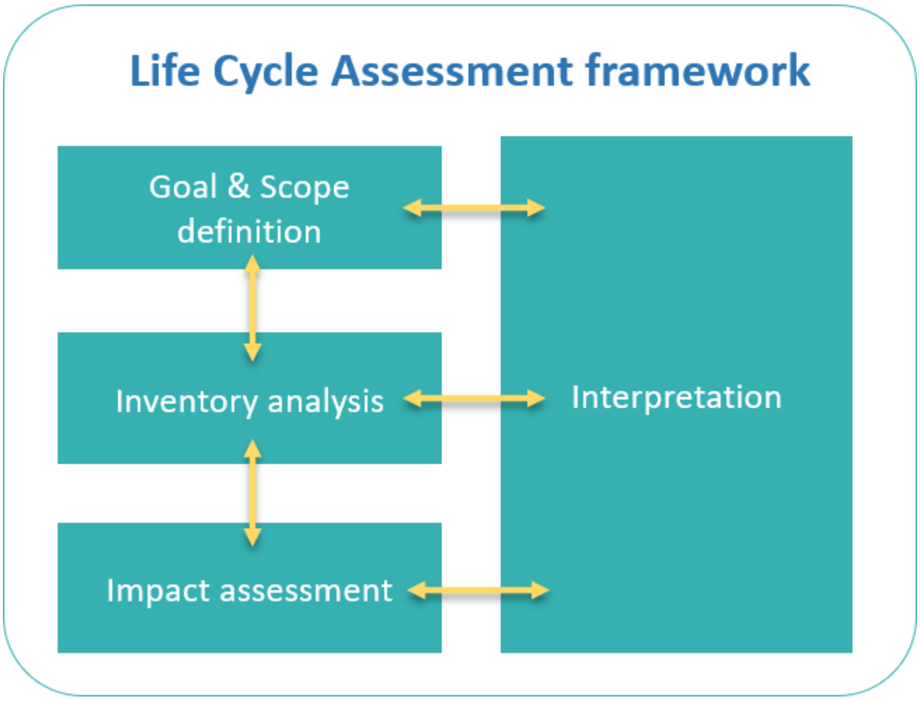


Figure 2 LCA framework

1.2. 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).

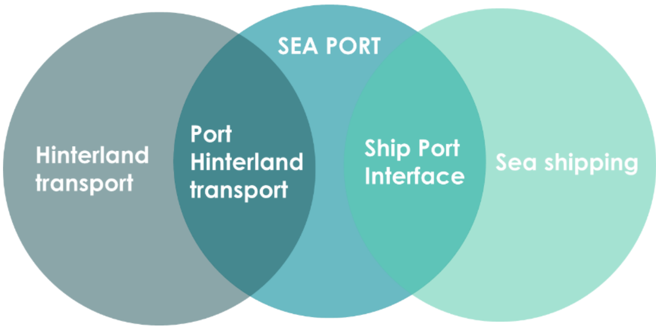


Figure 3 SEANERGY LCA scope

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 a 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 is 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.).

1.3. 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.).

1.3.1. LCI

The LCI of 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 information provided by the Fundacion Valenciaport shows that 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 provided by the port 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".*

- On the market, it is possible to find diesel or electric forklifts, where an electric forklift can achieve energy savings of 75% compared to the diesel one, based on 2,500 operating hours per year (Kalmar, s.f.). Port of Valencia has the advantage to have electric forklifts, thus it is expected that their energy consumption and environmental impacts are low. To calculate the impacts, it is used based on 2,500 operating hours per year, with a diesel consumption of 8 liters/hour and electricity consumption of 17 kWh/hour (Kalmar, s.f.). In discussions with the Port of Valencia for the calculation of 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 in the port.

Considering the information given by the Fundacion Valenciaport and the points mentioned before, Table 3 summarized the inputs enter 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

SOURCE	QUANTITY	UNIT	LCI DATASET	DATABASE
Electricity consumption port facilities	8,874,954	kWh	Electricity, medium voltage {ES}| market for electricity, medium voltage | Cut-off, S	Ecoinvent v3.9.1

1.3.2. 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.

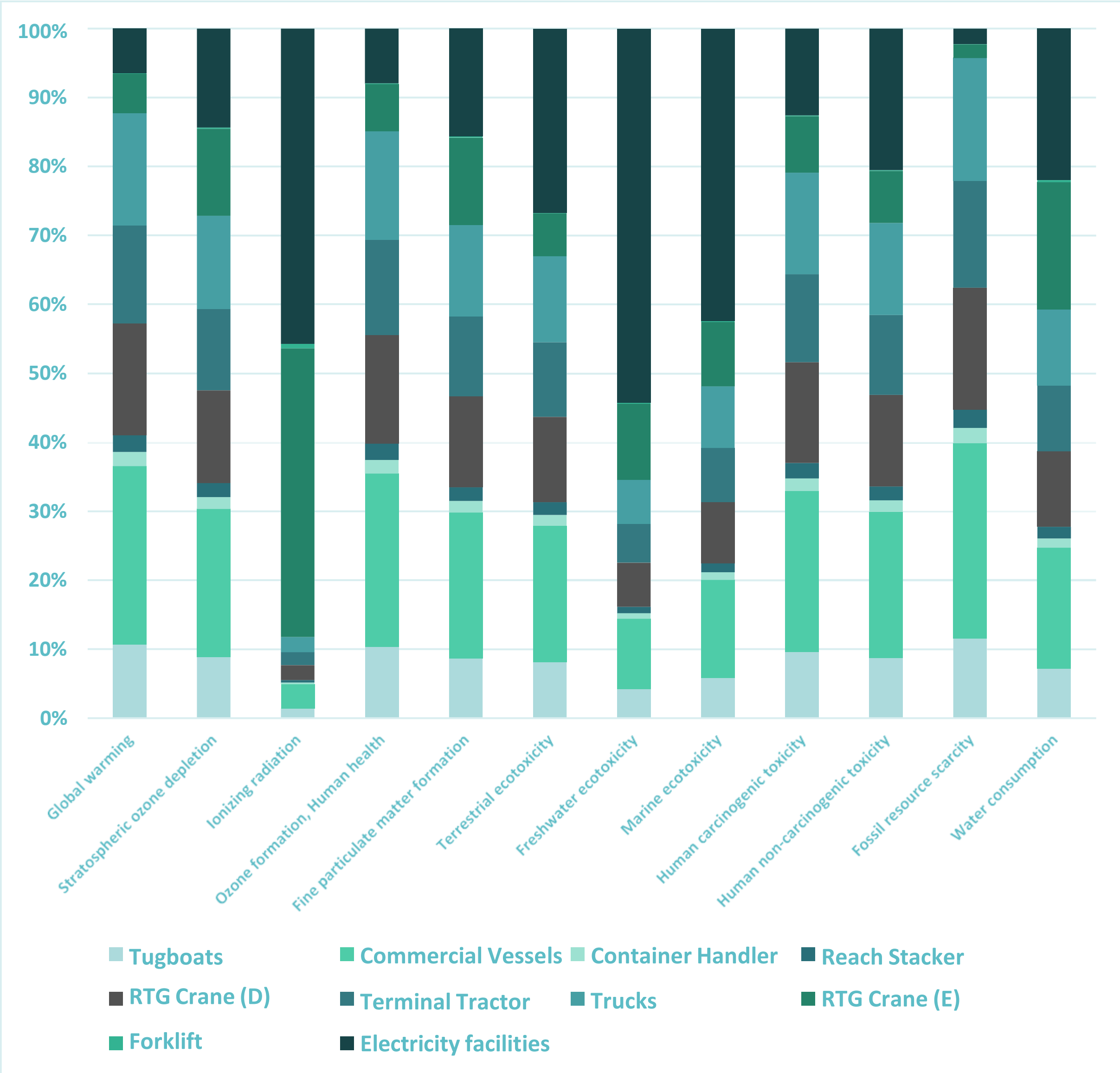
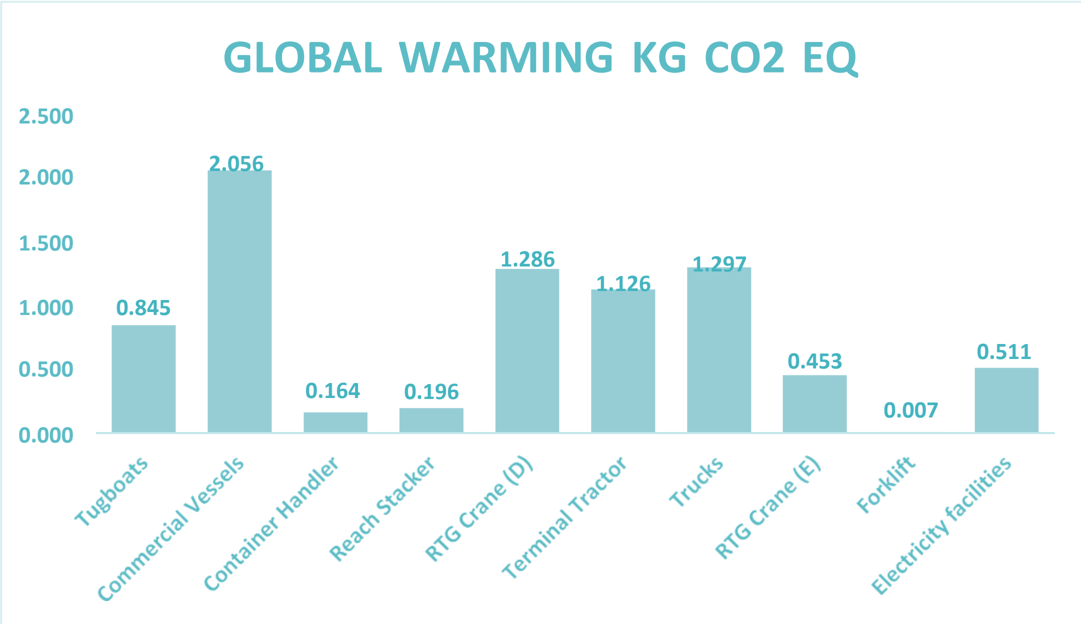
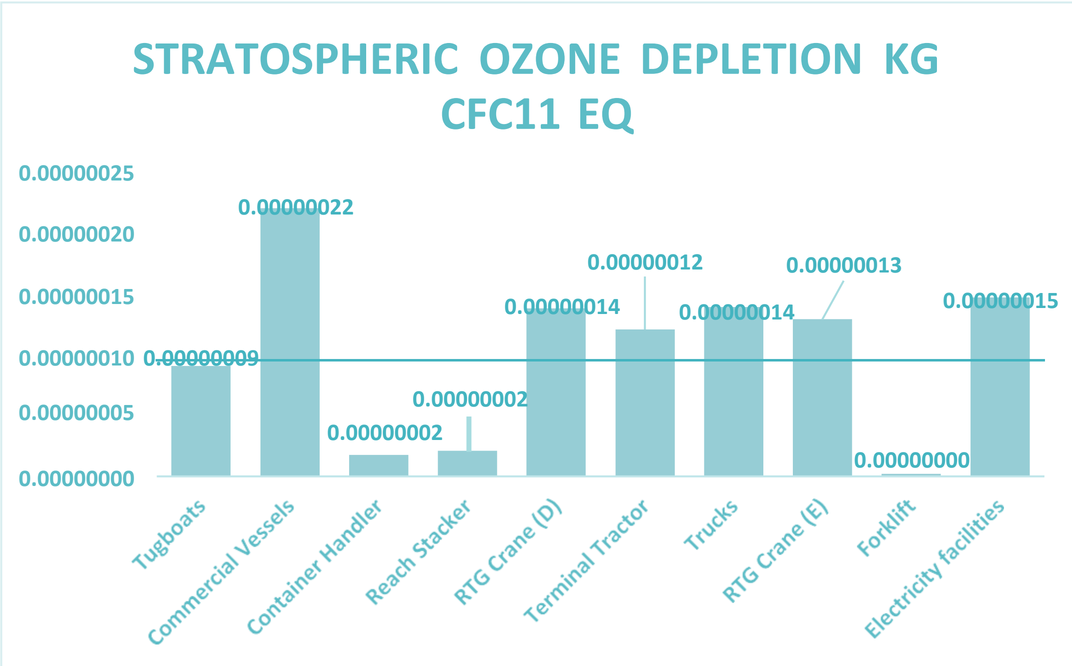
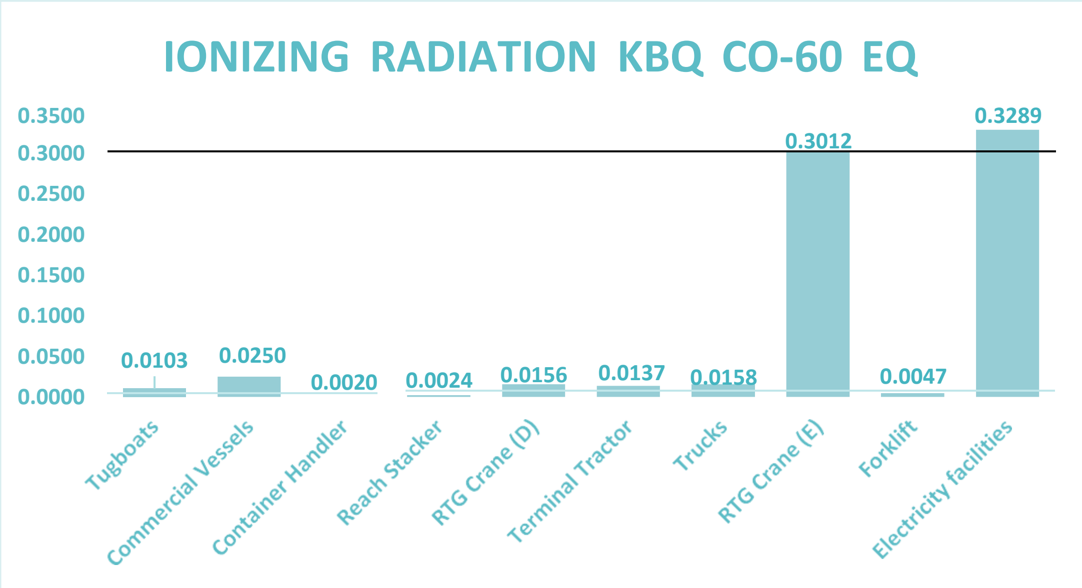


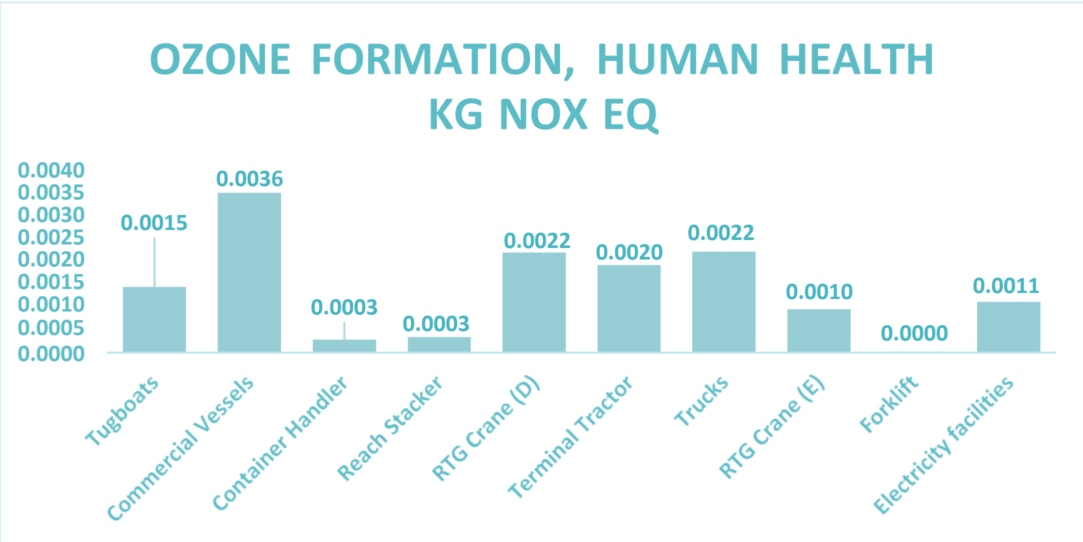
Figure 5 Port of Valencia results per environmental impact categories

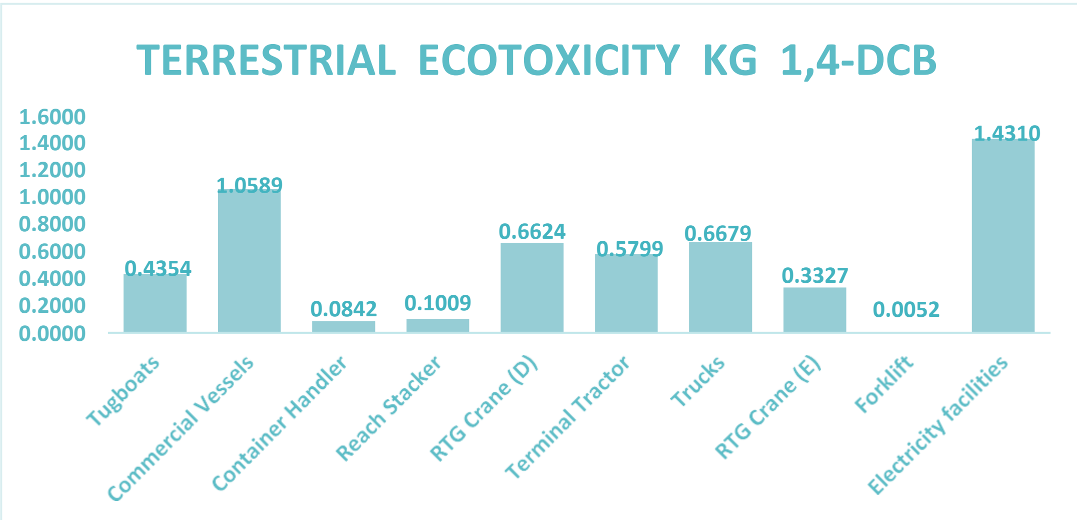
As mentioned before, the main sources of negative impact are diesel-powered sources covering about 70% of the total emissions. This result was expected since this equipment consumes diesel, a fuel derived from petroleum that significantly affects the environment. For clarity of the results, the coming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

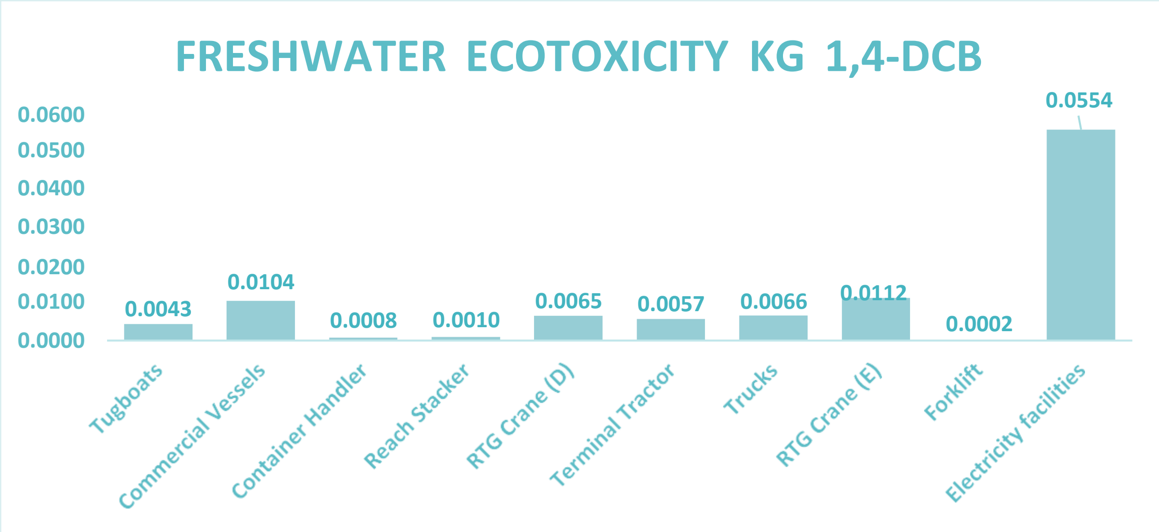

GLOBAL WARMING KG CO2 EQ
2.500
2.000
1.500
1.000
0.500
0.000
0.845
2.056
0.164
0.196
1.286
1.126
1.297
0.453
0.007
0.511
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities

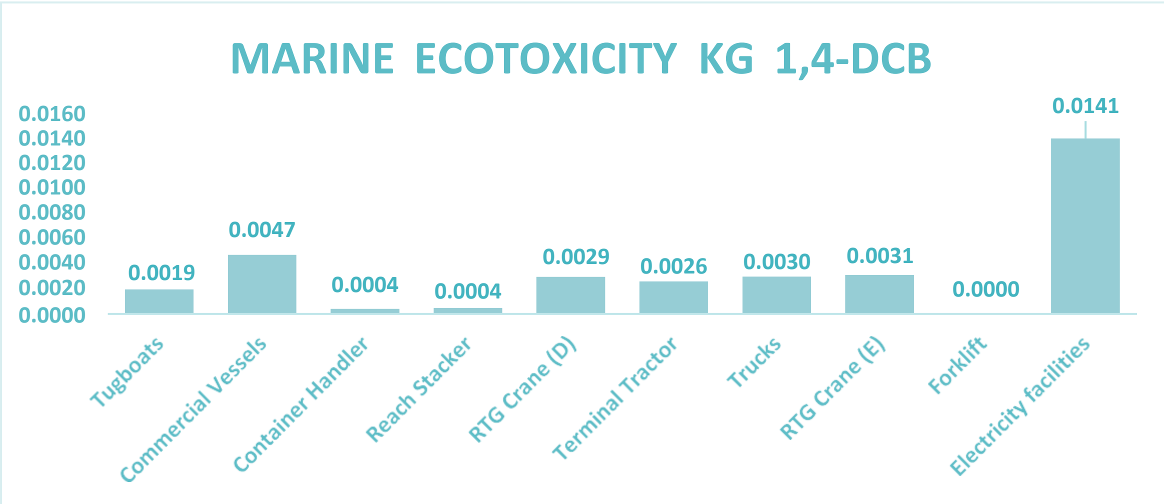

STRATOSPHERIC OZONE DEPLETION KG CFC11 EQ
0.00000025
0.00000020
0.00000015
0.00000010
0.00000005
0.00000000
0.00000009
0.00000022
0.00000002
0.00000002
0.00000014
0.00000012
0.00000014
0.00000013
0.00000000
0.00000015
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities

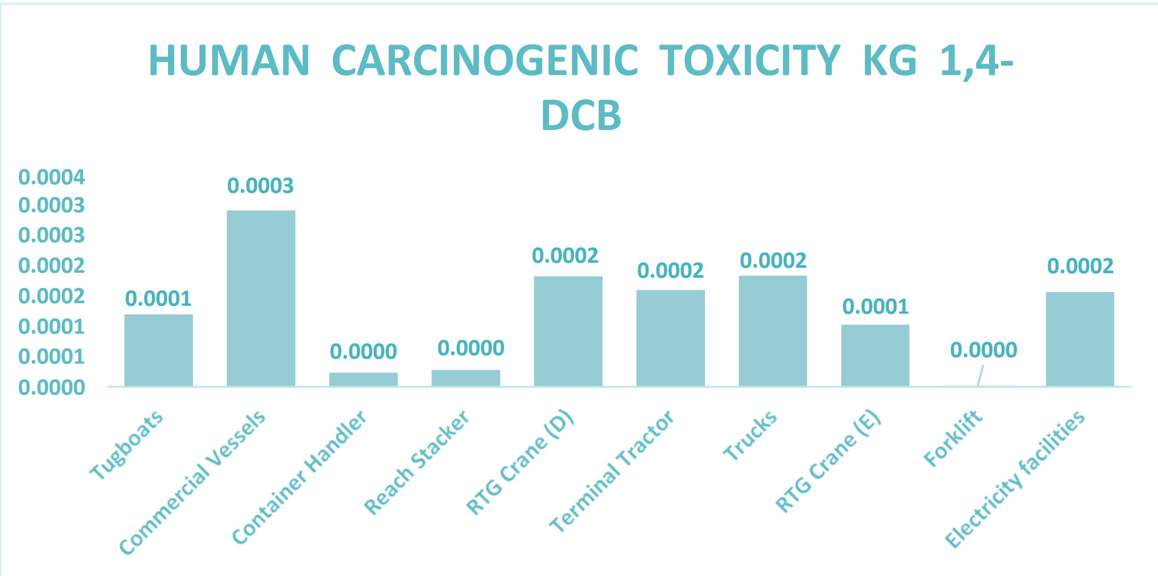

IONIZING RADIATION KBQ CO-60 EQ
0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
0.0103
0.0250
0.0020
0.0024
0.0156
0.0137
0.0158
0.3012
0.0047
0.3289
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities

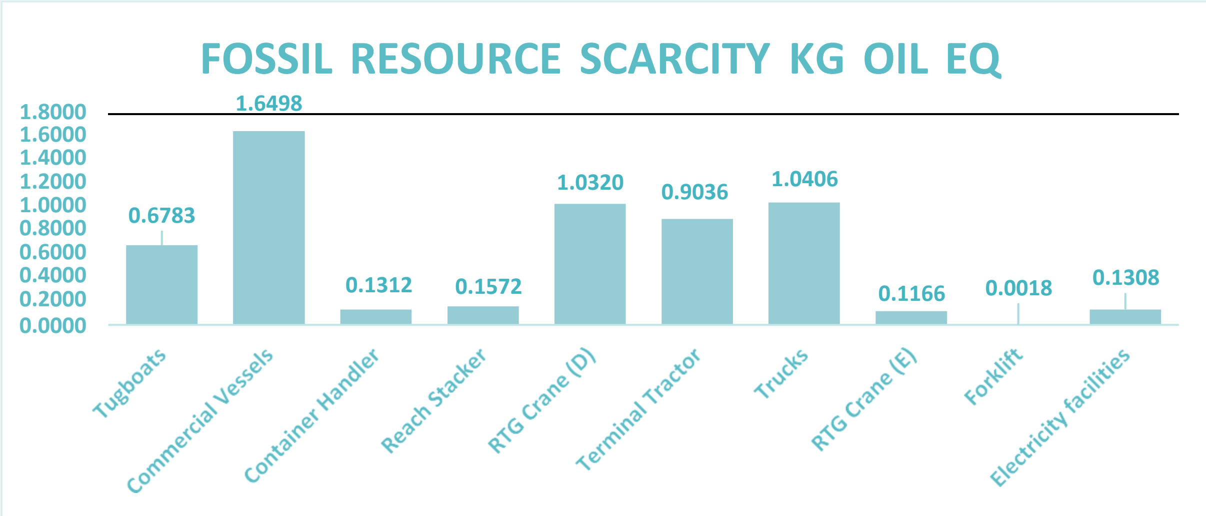

OZONE FORMATION, HUMAN HEALTH KG NOX EQ
0.0040
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0.0015
0.0036
0.0003
0.0003
0.0022
0.0020
0.0022
0.0010
0.0000
0.0011
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities

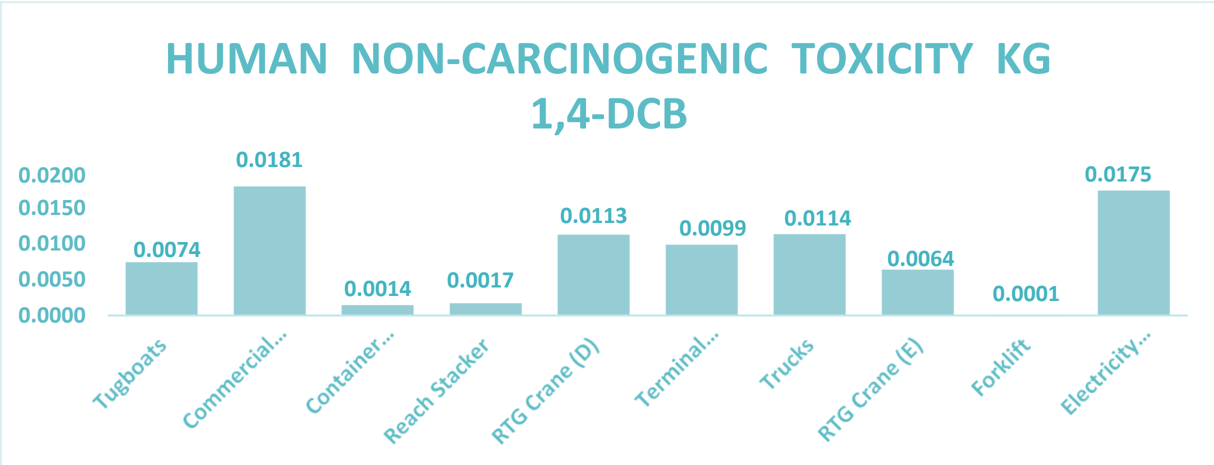

TERRESTRIAL ECOTOXICITY KG 1,4-DCB
1.6000
1.4000
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
0.4354
1.0589
0.0842
0.1009
0.6624
0.5799
0.6679
0.3327
0.0052
1.4310
Tugboats
Commercial Vessels
Container Handler
Reach Stacker
RTG Crane (D)
Terminal Tractor
Trucks
RTG Crane (E)
Forklift
Electricity facilities


FRESHWATER ECOTOXICITY KG 1,4-DCB
0.0600
0.0500
0.0400
0.0300
0.0200
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
0.0160
0.0140
0.0120
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
0.0004
0.0003
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





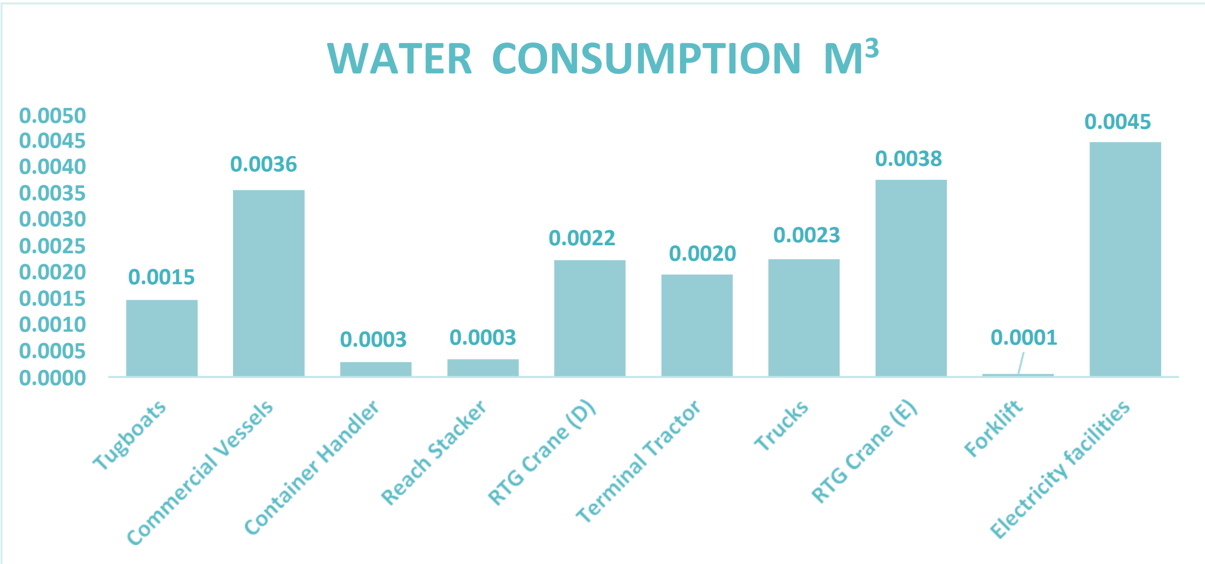


Figure 6 Port of Valencia´s impact categories in charts

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 source of energy consumption. Port of Valencia uses renewable energy as a source of supplier for electricity, this is an essential factor in the results because as it is shown in the table provided by the Port of Valencia, the equipment focused on the ship port interface is electrical (Cranes and Forklifts). By being containers the focus of Valencia Port, the movement, upload, and download of the TEUs should be one of the primary sources of energy consumption, if the cranes and forklifts were driven by fuel motors the impact from this section would be higher (like in Syros Port). Yet, the transportation of those containers on land is fuel consumers, considering this, it is evident why trucks are the primary sources of impact.

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 emission factor (Verifavia shipping, s.f.), the total emissions from each source are shown in the Table 5. As well it is 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 summarizing 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.
- In the current market, 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 in the market 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

SOURCE	TOTAL EMISSIONS (kgCO2)
RTG Crane (E)	2,540,496.7069
Forklift	39,490.8457
Electricity facilities	2,865,311.0668
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).

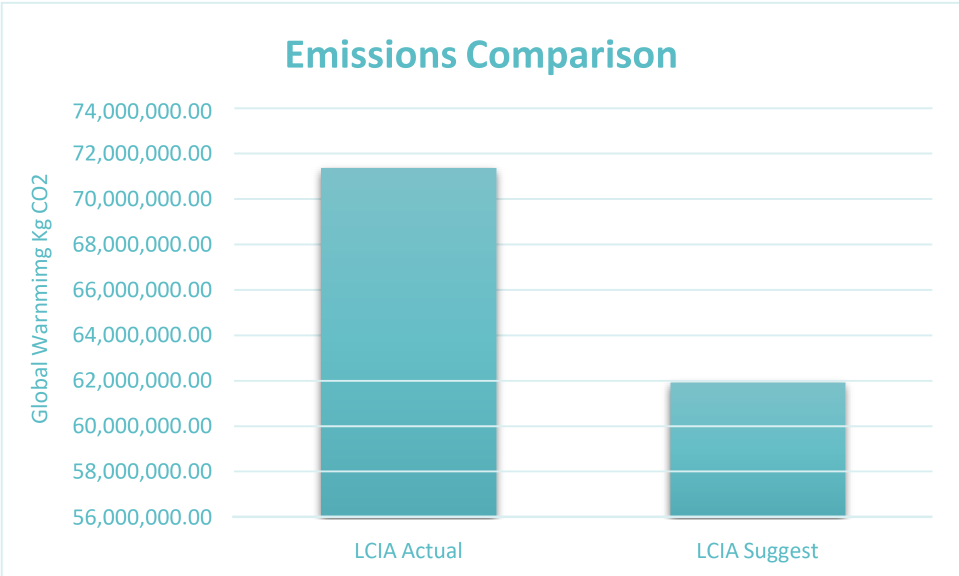


Figure 7 Comparison between actual LCIA and suggested LCIA in Valencia Port