Annex A

LP – CORILA – Ecolabel

D.5.3.2

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Table of Contents

1. Introduction

This study, performed by Corila with the support of the University of Padova, was carried out in the period June 2021 – June 2022 and was conducted according to the principles and requirements of the following International Standards:

• ISO 14040: 2006 Environmental management - Life cycle assessment - Principles and framework

• ISO 14044: 2006 Environmental management - Life cycle assessment - Requirements and guidelines

This LCA study aims to enhance the knowledge related to potential environmental impacts of small ports and their activities. This study made possible to identify the main hotspots of the system investigated, in order to define strategies for reducing environmental impacts.

2. General Information

2.1. General information of the study

Small ports are valuable actors in the transportation and hospitality industries. Moreover, they play an active role in the socio-economic development of the Adriatic basin. However, their activities have significant environmental impacts. For this reason, developing requirements and guidelines for a sustainable management of their operations is of strategic importance in order to make small ports work in a more environmental performant manner. One of the possible ways to do so is developing a European Ecolabel. This study was performed to collect quantitative data about small ports environmental impacts and to create a solid background for the development of an Ecolabel proposal.

2.2. Small port definition

In this context, a "small port" is defined as any European maritime port that is not identified in EU Reg. 1315 as part of the core and comprehensive network. It can include direct boating services (e.g., mooring and boat repair) and other functions (e.g., housing and recreation) as well. “Users” are defined as berth holders and visitors.

2.3. Information on the small ports under analysis

The study analyzes the potential environmental impacts of small ports activities from a life cycle perspective.

4 small ports have been involved in this study:

• Marina Fiorita – Cavallino Treporti (VE), Italy

• Marina Uno – Lignano Sabbiadoro (UD), Italy

• Port of Rabac – Rabac, Croatia

• Port of Rovinj – Rovinj, Croatia

The following paragraphs provide a brief description of the small ports.

Marina Fiorita is a touristic small port that is adopting modern an innovative solution to provide high quality services to its customers. It can host up to 160 boats and it offers them the possibility to dock and take advantage of the services of the marina (e.g., showers, toilettes, boat waste management, boat storage, maintenance and repairing, and bar). Furthermore, it uses both electricity from the grid and hydroelectric energy to run the activities of the marina, provide energy to the boats and illuminate the area using LED lights. It also uses fuels to power the boat that are used to provide services to its customers, and it has a small green area treated with little amounts of fertilizers.

Marina Uno is a touristic small ports and it was the first Italian one of the Adriatic basin. The marina can host up to 400 boats. The small port offers showers, toilettes, boat waste management, and boat storage, maintenance and repairing. It also has a bar and a swimming pool that uses chemicals to maintain the health and safety standards. In addition, it uses only electricity from hydroelectric sources for all its activities and to provide energy to the boats. Furthermore, it performs gardening activities with the adoption of pesticides and fertilizers, and it uses fuel for its boat to provide services to its clients.

The Port of Rabac is a small port situated on the eastern side of Istrian peninsula. It has a communal part for local residents, fishing part for fishing boats, moorings for overnight or longer stays and operational parts for tourist ships and rent-a-boats that use the port as their base. The port hosts a variety of activities, and it is located in the central part of Rabac which is a fairly active touristic area. Parts of the port are regularly used for tourist activities, organized by different entities, such are concerts, local products fairs, regattas, etc. Users can use electricity and water while a public toilet and waste management facilities are also available.

Rovinj port is a regional port located on the west Istrian coast. The port has a variety of purposes and is suitable for touristic excursions, international maritime connections with Italy and Slovenia, port of call for cruise ships and mega yachts, fishing vessels and for berths for residents. Services available in the port are mooring and unmooring, pilotage, fuel supply, water supply, electric power, and disposal of solid and liquid waste. The port has 900 berths for residents and 164 berths for transit vessels.

3. Objective of the study

The objective of the study is to evaluate the potential environmental impacts, from a life cycle perspective, associated to the 4 aforementioned small ports.

Based on the integration of internationally recognized models for managing environmental impact aspects, this study analyzes and quantifies the environmental impacts of a system to define strategies for their reduction. The results are used to draft an Ecolabel proposal for small ports.

Furthermore, the results presented in this report uniquely refer to the practices and assumptions of the small ports. Consequently, the results cannot be used for comparisons with other organizations because differences in methodological choices, data quality and choices of databases can produce results that are not comparable.

4. Scope of the study

4.1. Functional unit

The functional unit is a single person that is coming to the small port.

4.2. System boundaries

The system boundaries include the entire life cycle of the analyzed small ports and their activities, according to the "from cradle to gate" logic.

Infrastructure, buildings and equipment construction, maintenance and decommissioning are not considered as well as the occupation of land since their contribution to the environmental impact relating to the declared unit is negligible.

The study refers to the activities of the aforementioned small ports performed in 2021.

The following environmental aspects related to the activities of the small ports are included in this study:

1. Energy. Usage of resources to produce heat (e.g., methane for heating) and the electricity used for small ports daily activities.

2. Fuels. Consumption of petrol and diesel for the boats used by the small ports.

3. Water. Usage of water for the various activities (e.g., swimming pool, toilets, showers) and management of the wastewater.

4. Waste. Management of the waste produced by the small ports and their activities.

5. Chemical use. Consumption of fertilizers, pesticides, and other substances for gardening purposes. This category includes also the chemicals used for maintaining the pool within the health and safety thresholds.

4.3. Methodology and impact categories

The methodology chosen to evaluate the potential environmental impacts of the products subject of this study is the EPD 2015 which includes the following categories of impact:

Acidification (kg SO2 equiv). This impact category concerns substances acidifiers that cause a wide range of impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). The acidification potential (AP) for emissions to air it is calculated with the adapted RAINS 10 model, which describes the fate and deposition of substances acidifiers is expressed in kg SO equivalent / kg of emissions. The method was extended for acid nitric, soil, water and air; Sulfuric acid, water; Sulfur trioxide, air; Hydrogen chloride, water, soil; Hydrofluoric acid, water, soil; Phosphoric acid, water, soil; Hydrogen sulphide, soil.

Eutrophication (kg PO43- equiv). Eutrophication includes all impacts due to levels excesses of macronutrients in the environment caused by emissions of nutrients into the air, in water and soil. The nitrification potential (NP) is expressed in kg PO4 --- equivalents per kg of emissions.

Global Warming (kg CO2 equiv). Climate change can cause negative effects on ecosystem health, human health and material well-being. Climate change is linked to greenhouse gas emissions in the air. The characterization model used is the one developed by the Intergovernmental Panel on Climate Change (IPCC). Characterization factors are expressed as global warming potential for 100 years (GWP100), in kg of carbon dioxide / kg of emissions. The geographic scope of this indicator is on a global scale.

Photochemical oxidation (kg ethene equiv). Photo-oxidant formation is formation of reactive substances (mainly ozone) which are harmful to human health and ecosystems e which can also damage crops. This problem is also referred to as "summer smog". Winter smog does not fall within this category. The potential for creating ozone photochemical (POCP) for the emission of substances into the air is calculated with the model of UNECE, expressed in equivalent kg of ethylene / kg of emissions. The time interval is 5 days and the scale geographical range varies between local and continental scales (Prè, 2016).

Ozone layer depletion (kg CFC 11 equiv). This category is about ozone depletion stratospheric, which can have harmful effects on human health, on animal health, on terrestrial and aquatic ecosystems, on biochemical cycles and on materials. The characterization model used is the one developed by the Meteorological Organization (WMO) which defines the potential ozone depletion of different gases (kg CFC-11 equivalent / kg of emission). The geographical scope of this indicator is on a global scale.

Depletion of abiotic resources-elements (kg Sb equiv) and Depletion of abiotic resources-fossil fuels (MJ). These impact categories concern the protection of human well-being, health human and ecosystem health and the extraction of minerals and fossil fuels. The factor of abiotic exhaustion is determined for each extraction of minerals and fossil fuels (kg of antimony equivalents / kg of extraction) on the basis of reserves and the rate of de-accumulation. The geographical scope of this indicator is on a global scale.

4.4. Assumptions and limitations

For this study, primary data were adopted where available. When access to this type of data was not possible, secondary data obtained through the consultation of internationally recognized databases and/or relevant publications in the field, favoring the use of those most updated. The reference dataset is the Ecoinvent v3.4 database (Frischknecht R. 2005) and/or other studies published in trade journals.

For the consumption of fuels from the boats used by the small ports, it was assumed that these boats have the emission factor of a car of small dimensions because there is no dataset for these small boats. This choice was made also because it prevents any underestimations of the environmental impacts.

In the present study, the following contribution to environmental impact were excluded: equipment, buildings and infrastructures construction, maintenance and decommissioning as well as the occupation of land (if this information does not were already present in the dataset used).

4.5. Data quality requirements

The data necessary for the study were collected in compliance with the following requirements:

• Time coverage. Data used for the LCA study refers to the activities of the 4 small ports over a period of 12-month (January 2021 - December 2021). If no primary data or models were available, secondary data obtained by consulting internationally recognized databases in their most recent available version were used.

• Geographical coverage. The geographical area of data origin relates to the Italian, Croatian, European or global situation based on the place of origin of the raw materials. Process data refer to the geographical are where the smalls ports are located.

• Technological coverage. The data collected refer to the state of the art of the technologies used for small ports activities.

• Accuracy. The data collected refer to actual resource and energy consumption and measurements for the period considered.

• Completeness. The percentage of mass flow measured or estimated can be considered equal to 99%.

• Representativeness. Data sets reflect the population precisely, since the data is collected directly on the sites of interest.

• Consistency. The study methodology is applied uniformly to the whole analysis.

• Reproducibility. The data were collected via data collection sheets. They contain all the necessary information that allows even an independent performer to reproduce the results reported in the study report.

• Sources of data. As previously explained, the data comes from a primary source (if not possible to find primary data, secondary data from internationally recognized databases were used).

• Information uncertainty. The uncertainty related to data and hypotheses was tested through a uncertainty analysis.

• Estimated data, coming from specific sites or averages, are highlighted in the inventory description phase.

5. Life cycle inventory analysis

The inventory analysis phase includes the data collection and the calculation procedures that allow to quantify the input and output of resources and energy related to the analyzed small ports' activities. The elements considered in the inventory analysis with respect to ISO 14040 series standard (ISO 2006) are presented in the following sections.

5.1. Data collection process

For the purpose of the study, data gathering sheets were provided to small ports to collect data on their inputs and outputs in terms of resources and energy consumption, and emissions and pollution production.

The data collection form was verified and checked according to mass balances and all the reporting inconsistencies have been clarified and resolved.

5.2. Description of unitary processes

This paragraph provides a description of the process units that allow the small ports to perform their daily activities.

The following process units were considered within the study:

• Energy supply from the grid or renewable sources.

• Heat production using gas burnt in boilers.

• Fuel consumption of the boats used to provide the various services to the customers.

• Water usage for the various activities of the small port, e.g., toilets, showers, swimming-pool.

• Waste management activities, both from the small port infrastructures and from the boats that stop there.

• Chemical usage related to maintain the green areas and to keep the pool under acceptable health and safety conditions.

5.3. Modelling of the various small ports

This section is presenting the way the activities performed by the various small ports have been modelled using the Simapro software v.9.1.1.1 and the Ecoinvent v3.4 dataset for the various inputs and outputs.

5.3.1. Marina Fiorita

Marina Fiorita (MF) is using 94.506kWh of electricity from the grid, that was modelled using the dataset Electricity, medium voltage {IT}| market for | Cut-off, U, and 25.488kWh of hydroelectric energy, modelled using the dataset Electricity, high voltage {IT}| electricity production, hydro, reservoir, alpine region | Cut-off, U because the small port is close to the alpine region.

The heat of the marina is burning 3.550m3 of methane that were modelled using the dataset Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler modulating <100kW | Cut-off, U adopting 35.3m3/MJ as the PCI of methane.

For modelling the fuel consumption for the boats, it was assumed that the petrol and diesel are burnt in small EURO3 cars. In fact, there are no dataset that can support the modelling of small boats. Therefore, the dataset of a car was adopted because it is the closes proxy offered by the available datasets that allows preventing underestimations of the environmental impacts. However, this dataset requires to have kilometers as unit of measurement. Therefore, the liters of fuels, 227L of petrol and 285L of diesel, needed to be converted in kilometers. In order to do that, the kg/km were retrieved form the Ecoinvent v3.4 dataset of the small cars (i.e., Transport, passenger car, small size, petrol, EURO 3 {RER}| transport, passenger car, small size, petrol, EURO 3 | Cut-off, U and Transport, passenger car, small size, diesel, EURO 3 {RER}| transport, passenger car, small size, diesel, EURO 3 | Cut-off, U). The petrol car uses 0,058kg of fuel for covering 1km, while the diesel one 0,045kg. Then the following values for the density of petrol and diesel, 0,74kg/L and 0,835kg/L, were used to convert the liters into kilograms of fuels. The result of the operation "L of fuel * density of fuel" provided the valor of 168kg of petrol and 238kg of diesel. These last two values were divided by the kg/km of the two fuels to calculate the total amount of kilometers made, and the valor of 2.896km for the petrol, and 5.288km for the diesel were obtained. These distances were used to calculate the environmental impacts of the petrol using the datasets Transport, passenger car, small size, petrol, EURO 3 {RER}| transport, passenger car, small size, petrol, EURO 3 | Cut-off, U and Transport, passenger car, small size, diesel, EURO 3 {RER}| transport, passenger car, small size, diesel, EURO 3 | Cut-off, U.

MF is using 1.998.000L of water for its activities and it has been modelled using the dataset Tap water {Europe without Switzerland}| market for | Cut-off, U. It is also producing 13m3 of wastewater that was modeled using the dataset Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | Cut-off, U. The amount of wastewater was calculated considering that each person produces 2L of excrement per day (ISPRA, 2012) and that 6.500 people were at the port during 2021 (data calculated by summing the number of people who were at the port each day of the year).

The municipal waste of the marina was calculated considering that each person is producing an average of 1,12kg of municipal solid waste per day (ISPRA, 2015; ISPRA, 2021) and that 6.500 people were at the port in 2021. Then, the data about how the waste is disposed were retrieved from a Eurostat study that explains that 31% is recycled, 17% is composted, 27% is incinerated and 24% is landfilled (Eurostat, 2021). For the waste management activities, the following dataset were used: Biowaste {CH}| treatment of biowaste, industrial composting | Cut-off, U; Municipal solid waste {IT}| treatment of, incineration | Cut-off, U and Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U. The recycling process was modelled without any dataset because its environmental impact is zero according to the Ecoinvent dataset.

Marina Fiorita uses a very small amount (i.e., 9kg) of fertilizer for its gardening activities. Therefore, this material was not modelled because its impact is not significant.

5.3.2. Marina Uno

Marina Uno (MU) is using only hydroelectric energy for its activities. Therefore, the 192.122kWh of electricity usage was modelled using the dataset Electricity, high voltage {IT}| electricity production, hydro, reservoir, alpine region | Cut-off, U because the small port is close to the alpine region.

For the heat production the marina is burning 3.796m3 of methane that were modelled using the dataset Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler modulating <100kW | Cut-off, U adopting 35,3m3/MJ as the PCI of methane.

For modelling the fuel consumption for the boats, it was assumed that the petrol and diesel are burnt in small EURO3 cars. In fact, there are no dataset that can support the modelling of small boats. Therefore, the dataset of a car was adopted because it is the closes proxy offered by the available datasets that allows preventing underestimations of the environmental impacts. However, this dataset requires to have kilometers as unit of measurement. Consequently, the liters of fuels, 200L of petrol, needed to be converted in kilometers. In order to do that, the kg/km were retrieved form the Ecoinvent v3.4 dataset of the small car (i.e., Transport, passenger car, small size, petrol, EURO 3 {RER}| transport, passenger car, small size, petrol, EURO 3 | Cut-off, U). The petrol car uses 0,058kg of fuel for covering 1km. Then the following value for the density of petrol, 0,74kg/L was used, to convert the liters into kilograms of fuels. The result of the operation "L of fuel * density of fuel" provided the valor of 148kg of petrol. Theis last value was divided by the kg/km of the fuels to calculate the total amount of kilometers made, and the valor of 2.552km was obtained. These distances were used to calculate the environmental impacts of the fuels using the datasets Transport, passenger car, small size, petrol, EURO 3 {RER}| transport, passenger car, small size, petrol, EURO 3 | Cut-off, U.

MU is using 7.381.000L of water for its activities (including offices, sanitary usage, gardening and swimming-pool) and was modelled using the dataset Tap water {Europe without Switzerland}| market for | Cut-off, U. It is also producing 4.424L of wastewater that was modeled using the dataset Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | Cut-off, U. The amount of wastewater was calculated considering that each person produces 2L of excrement per day (ISPRA, 2012) and that 2.212 people were at the port during 2021 (data calculated by summing the number of people who were at the port each day of the year). The small port is also using 7.000kg of liquid chlorine at 15% concentration and 75kg of solid chlorine (for a total of 1.125kg of equivalent solid chlorine) for purifying the swimming-pool water and these substances were modelled adopting the dataset Sodium hypochlorite, without water, in 15%

solution state {GLO}| market for | Cut-off, S. In addition, MU is using 625kg of acid to control water pH and keep the safety standards of the pool within its thresholds; the acid was modelled using the dataset Sulfuric acid {GLO}| market for | Cut-off, S.

The municipal waste of MU was calculated considering that each person is producing an average of 1,12kg of municipal solid waste per day (ISPRA, 2015; ISPRA, 2021) and that 2.212 people were at the port in 2021. Then, the data about how the waste is disposed were retrieved from a Eurostat study that explains that 31% is recycled, 17% is composted, 27% is incinerated and 24% is landfilled (Eurostat, 2021). For the waste management activities, the following dataset were used: Biowaste {CH}| treatment of biowaste, industrial composting | Cut-off, U; Municipal solid waste {IT}| treatment of, incineration | Cut-off, U and Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U. The recycling process was modelled without any dataset because its environmental impact is zero according to the Ecoinvent dataset.

For the gardening activities MU is using 100kg of fertilizer and 10kg of pesticide. The former is made of Nitrogen, Phosphorus Pentoxide, Sulfur and Potassium. These elements were modelled according to the percentage relative to the composition of the fertilizers using respectively the following datasets in the emissions to water, air and land section of Simapro: Nitrogen, atmospheric; Phosphorus pentoxide; Sulfur and Potassium. The pesticide used was modelled according to the percentage of their composition using the following datasets in the emissions to water, air and land sections of Simapro: Copper oxide; Hydrocarbons, aromatic, styrenes, C9; Zinc oxide; Hydrocarbons, aromatic; Zinc. In addition, according to the PEFCR of Wine, 9% of the emissions produced by pesticides are on air, 1% on water and 90% on soil (European Commission, 2021).

5.3.3. Port of Rabac

The port of Rabac (PR) is using 3.385kWh of electricity from the grid, that was modelled using the dataset Electricity, medium voltage {HR}| market for | Cut-off, U.

PR is using 584.000L of water for its activities and it has been modelled using the dataset Tap water {Europe without Switzerland}| market for | Cut-off, U. It is also producing 5.760L of wastewater that was modeled using the dataset Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | Cut-off, U. The amount of wastewater was calculated considering that each person produces 2L of excrement per day (ISPRA, 2012) and that 2.880 people were at the port during 2021 (data calculated by summing the number of people who were at the port each day of the year).

The municipal waste of the marina was calculated considering that each person is producing an average of 1,12kg of municipal solid waste per day (ISPRA, 2015; ISPRA, 2021) and that 2.880 people were at the port in 2021. Then, the data about how the waste is disposed were retrieved from a Eurostat study that explains that 31% is recycled, 17% is composted, 27% is incinerated and 24% is landfilled (Eurostat, 2021). For the waste management activities, the following dataset were used: Biowaste {CH}| treatment of biowaste, industrial composting | Cut-off, U; Municipal solid waste {IT}| treatment of, incineration | Cut-off, U and Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U. The recycling process was modelled without any dataset because its environmental impact is zero according to the Ecoinvent dataset.

5.3.4. Port of Rovinj

The port of Rovinj (RR) is using 30.000kWh of electricity from the grid, that was modelled using the dataset Electricity, medium voltage {HR}| market for | Cut-off, U.

For modelling the fuel consumption for the boats, it was assumed that the petrol and diesel are burnt in small EURO3 cars. In fact, there are no dataset that can support the modelling of small boats. Therefore, the dataset of a car was adopted because it is the closes proxy offered by the available datasets that allows preventing underestimations of the environmental impacts. However, this dataset require have kilometers as unit of measurement. Therefore, the liters of fuels, 3.300L of petrol, needed to be converted in kilometers. In order to do that, the kg/km were retrieved form the Ecoinvent v3.4 dataset of the small cars (i.e., Transport, passenger car, small size, petrol, EURO 3 {RER}| transport, passenger car, small size, petrol, EURO 3 | Cut-off, U). The petrol car uses 0,058kg of fuel for covering 1km. Then the value 0,74kg/L for the density of petrol was used to convert the liters into kilograms of fuels. The result of the operation "L of fuel * density of fuel" provided the valor of 2.442kg of petrol. This value was divided by the kg/km of the two fuels to calculate the total amount of kilometers made, and the valor of 2.896km was obtained. This distance was used to calculate the environmental impacts of the petrol using the datasets Transport, passenger car, small size, petrol, EURO 3 {RER}| transport, passenger car, small size, petrol, EURO 3 | Cut-off, U.

RR is using 6.700.000L of water for its activities and it has been modelled using the dataset Tap water {Europe without Switzerland}| market for | Cut-off, U. It is also producing 222.000L of wastewater that was modeled using the dataset Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, capacity 1E9l/year | Cut-off, U. The amount of wastewater was calculated considering that each person produces 2L of excrement per day (ISPRA, 2012) and that 111.000 people were at the port during 2021 (data calculated by summing the number of people who were at the port each day of the year).

The municipal waste produced in one year by the port is 20.000kg. The data about how the waste is disposed were retrieved from a Eurostat study that explains that 31% is recycled, 17% is composted, 27% is incinerated and 24% is landfilled (Eurostat, 2021). For the waste management activities, the following dataset were used: Biowaste {CH}| treatment of biowaste, industrial composting | Cut-off, U; Municipal solid waste {IT}| treatment of, incineration | Cut-off, U and Municipal solid waste {CH}| treatment of, sanitary landfill | Cut-off, U. The recycling process was modelled without any dataset because its environmental impact is zero according to the Ecoinvent dataset.

6. Evaluation of the impacts and interpretation of the results

The evaluation of the impacts uses the results obtained in the previous inventory analysis phase to define the potential impacts that the investigated systems has on the environment. In compliance with ISO 14040 and ISO 14044 Standards, the evaluation phase is limited to mandatory elements, i.e., the definition of impact categories, classification, and characterization. Specifically, the evaluation refers to the EPD 2015 method indicator present in SimaPro v9.1.1.1. Finally, according to what required by the Reference Standards for conducting LCA studies (ISO 2006a, b), the results of the impact assessment are relative expressions and do not include any considerations on exceeding thresholds, safety margins or risks.

To allow a complete view of the main sources of impact, the results are presented into the following aspects:

1. Electricity. Electricity used for small ports daily activities.

2. Fuels. Consumption of petrol and diesel for the small boats used by the small ports.

3. Heat. Usage of resources to produce heat (e.g., methane).

4. Water. Usage of water for the various activities (e.g., swimming pool, toilets, showers)

5. Wastewater. Management of the wastewater.

6. Waste. Management of the waste produced by the small ports and their activities.

7. Gardening. Consumption of fertilizers, pesticides, other substances for gardening purposes, and chemicals for the swimming-pool.

The results of the environmental impact assessment are shown in the following sections.

Furthermore, in relation to the standards definitions, a life cycle interpretation phase should be performed. It consists in the analysis of the results of the inventory analysis (LCI) and impact assessment (LCA) phases including the following elements:

• Identification of the most relevant life cycle stages.

• Assessment.

• Conclusions, limitations, recommendations.

Importantly, the LCA results are based on a relative approach and refer to potential environmental impacts. The study was carried out in order to enabling the identification of the operations and specific activities with the greatest environmental impact for the product system studied.

In addition, as required by the reference standards, it must be specified that in relation to the objective of the study the unit chosen proved to be appropriate for the system studied, since it made it possible to identify the activities with the greatest environmental impact for the system under analysis. The criteria defined for the evaluation of data quality were consistently met. In the light of these considerations, the different elements of the interpretation phase are scrutinized below.

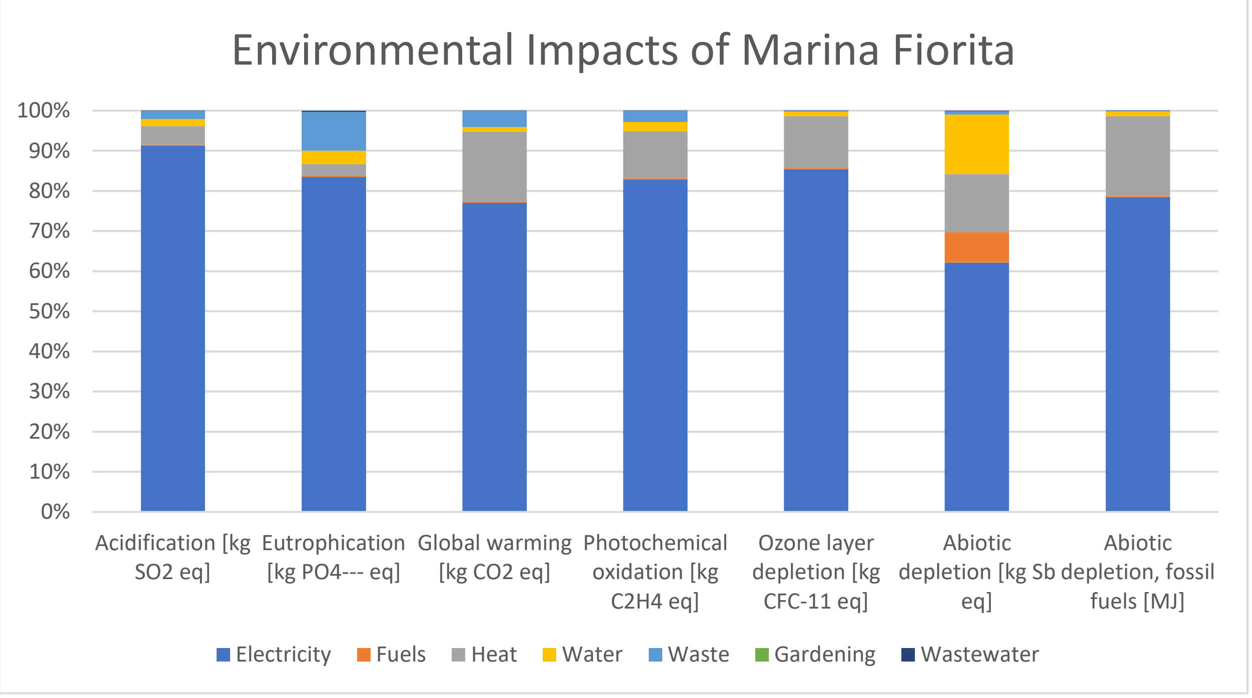
6.1. Results for Marina Fiorita

In Table 1 the characterized values are reported, divided according to the life cycle stage and the relative functional unit. The same results are reported as a graph in Figure 1.

Table 1 Impact assessment for Marina Fiorita

Impact category	Electricity	Fuels	Heat	Water	Wastewater	Waste	Gardening
Acidification [kg SO2 eq]	2.71E-02	8.30E-05	1.38E-03	5.17E-04	9.17E-06	6.13E-04	0.00E+00
Eutrophication [kg PO4--- eq]	7.16E-03	2.16E-05	2.54E-04	2.89E-04	2.69E-05	8.27E-04	0.00E+00
Global warming [kg CO2 eq]	6.38E+00	2.08E-02	1.44E+00	1.04E-01	9.66E-04	3.33E-01	0.00E+00
Photochemical oxidation [kg C2H4 eq]	1.20E-03	5.27E-06	1.71E-04	3.36E-05	3.27E-07	3.97E-05	0.00E+00
Ozone layer depletion [kg CFC-11 eq]	8.24E-07	3.20E-09	1.24E-07	1.09E-08	8.39E-11	2.46E-09	0.00E+00
Abiotic depletion [kg Sb eq]	1.24E-05	1.51E-06	2.88E-06	2.95E-06	3.02E-08	1.63E-07	0.00E+00
Abiotic depletion, fossil fuels [MJ]	8.12E+01	2.82E-01	2.07E+01	1.17E+00	9.05E-03	2.01E-01	0.00E+00

Figure 1 Graphic results for the impact assessment of Marina Fiorita



The most relevant results for each category are illustrated below, highlighting the main responsible processes.

For what concern Acidification, the main impact comes from the electricity usage. The electricity purchased from the grid is very impactful and it contributes to about the 90% of the overall impact. The production of heat via burning methane has also a relevant environmental impact. About 7% of the overall impact is caused by this process.

For what concern Eutrophication, the main impact is caused by the electricity usage at the small port. About 85% of the impact is related to this environmental aspect. 10% of the impact is caused by the waste management activities, and only a small fraction of the impact comes from heat production and water usage, while the impacts of the other aspects are not substantial.

For the impact category Global Warming the main contributor is the waste management. More than 90% of the impact comes from this environmental aspect. A lower contribution is caused by electricity and heat production via the combustion of methane. The impact of the other aspects is negligible.

For what concerns Photochemical Oxidation, about 82% of the overall impact is caused by electricity usage. About 14% of the impact is caused by heat production, and about 4% from water usage and waste management. The impact of the other environmental aspects is negligible.

For what concern Ozone layer depletion, 85% of the impact is caused by electricity usage. About 12% of the overall environmental impacts is caused by burning gas to produce heat. While the other aspects have a small impact.

For what concern the Abiotic Depletion, electricity usage is contributing to the 62% of the overall environmental impact. The 13% of the impact is caused by the heat production and about the same percentage by water usage. The usage of fuels accounts of 7% of the overall impact, while the other aspects are negligible.

For what concern Abiotic Depletion, fossil fuels, the main impact comes from electricity production (78%) because non-renewable sources are adopted. The heat production process contributes to about 19% to the overall impact. While the other environmental aspects have not a substantial impact.

The impact of the gardening activities of this marina are negligible. Therefore, there are no data about this process.

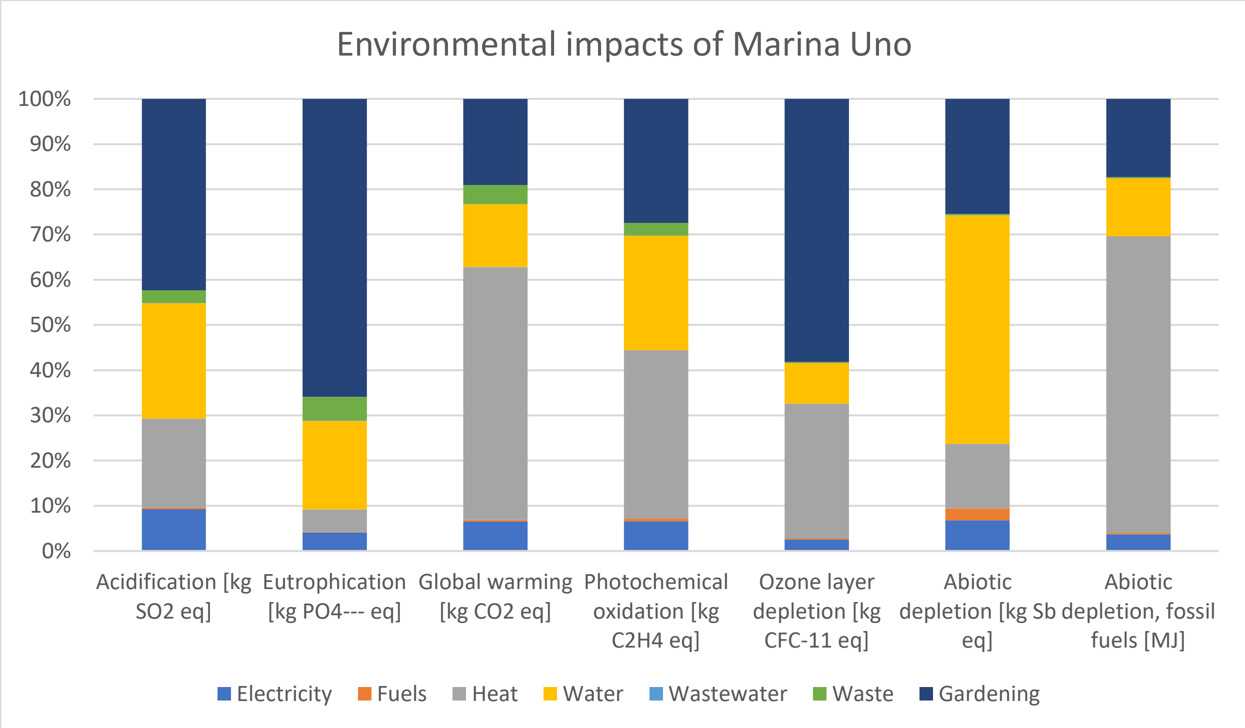
6.2. Results for Marina Uno

In Table 2 the characterized values are reported, divided according to the life cycle stage and the relative functional unit. The same results are reported as a graph in Figure 2.

Table 2 Impact assessment for Marina Uno

Impact category	Electricity	Fuels	Heat	Water	Wastewater	Waste	Gardening
Acidification [kg SO2 eq]	2.04E-03	7.52E-05	4.32E-03	5.61E-03	9.17E-06	6.13E-04	9.30E-03
Eutrophication [kg PO4--- eq]	6.56E-04	2.07E-05	7.98E-04	3.14E-03	2.69E-05	8.27E-04	1.06E-02
Global warming [kg CO2 eq]	5.29E-01	2.67E-02	4.52E+00	1.13E+00	9.66E-04	3.33E-01	1.54E+00
Photochemical oxidation [kg C2H4 eq]	9.43E-05	8.84E-06	5.36E-04	3.65E-04	3.27E-07	3.97E-05	3.95E-04
Ozone layer depletion [kg CFC-11 eq]	3.31E-08	4.03E-09	3.90E-07	1.18E-07	8.39E-11	2.46E-09	7.64E-07
Abiotic depletion [kg Sb eq]	4.31E-06	1.68E-06	9.05E-06	3.20E-05	3.02E-08	1.63E-07	1.61E-05
Abiotic depletion, fossil fuels [MJ]	3.65E+00	3.52E-01	6.50E+01	1.27E+01	9.05E-03	2.01E-01	1.72E+01

Figure 2 Graphic results for the impact assessment of Marina Uno



The most relevant results for each category are illustrated below, highlighting the main responsible processes.

For what concern Acidification, the main impact comes from the chemicals used for gardening and the pool with about 42% of the overall contribution. The water usage and the heat have also significant impacts with a contribution of 26% and 19% respectively. Electricity has only an impact of 9% because it comes from renewable sources, while the other environmental aspects are negligible.

For what concerns Eutrophication, the main impact is caused by the gardening activities of the small port. More than 65% of the impact is related to this environmental aspect. Water has also a relevant impact on this category with about 20% of the overall impact. Waste, heat, and electricity have an impact of respectively 5%, 6%, and 4%. The other aspects have a negligible impact.

For the impact category Global Warming the main contributor is the heat production. About 54% of the impact comes from this environmental aspect. A lower contribution is caused by gardening and water usage with respectively 18% and 13% of the impact. Electricity has a small contribution (7%) because it is generated by an hydroelectric source. Finally, waste has a contribution of about 4% while the impact of the other aspects is negligible.

For what concerns Photochemical Oxidation, about 35% of the overall impact is caused by heat production. Other relevant impacts come from the chemical usage (27%) and water consumption (25%). Electricity contributes only to 7%, since it comes from renewable source, and water contributes to 3%. The impact of the other environmental aspects is negligible.

For what concern Ozone layer depletion, 58% of the impact is caused by the chemical usage for the gardening and swimming-pool activities. The heat production and water usage are other aspects that cause a significant impact. Respectively 29% and 9% of the overall environmental impacts occur because of these activities. Electricity contributes to about 2% and the other aspects have a negligible impact.

For what concern the Abiotic Depletion, the 48% of the impact is caused by the water used for the small port activities. Other significant contributions come from gardening activities (25%), heat production (15%), fuels (2%), and electricity (7%). The other environmental aspects have a not substantial impact.

For what concern Abiotic Depletion, fossil fuels, the main impact comes from heat production, it contributes to about 68% to the overall impact. Furthermore, the chemicals usage and water consumption are causing respectively 18% and 12% of the overall impact. Electricity has also a relevant contribution with about 3% of the entire impact, while the other environmental aspects have not a substantial impact.

6.3. Results for Port of Rabac

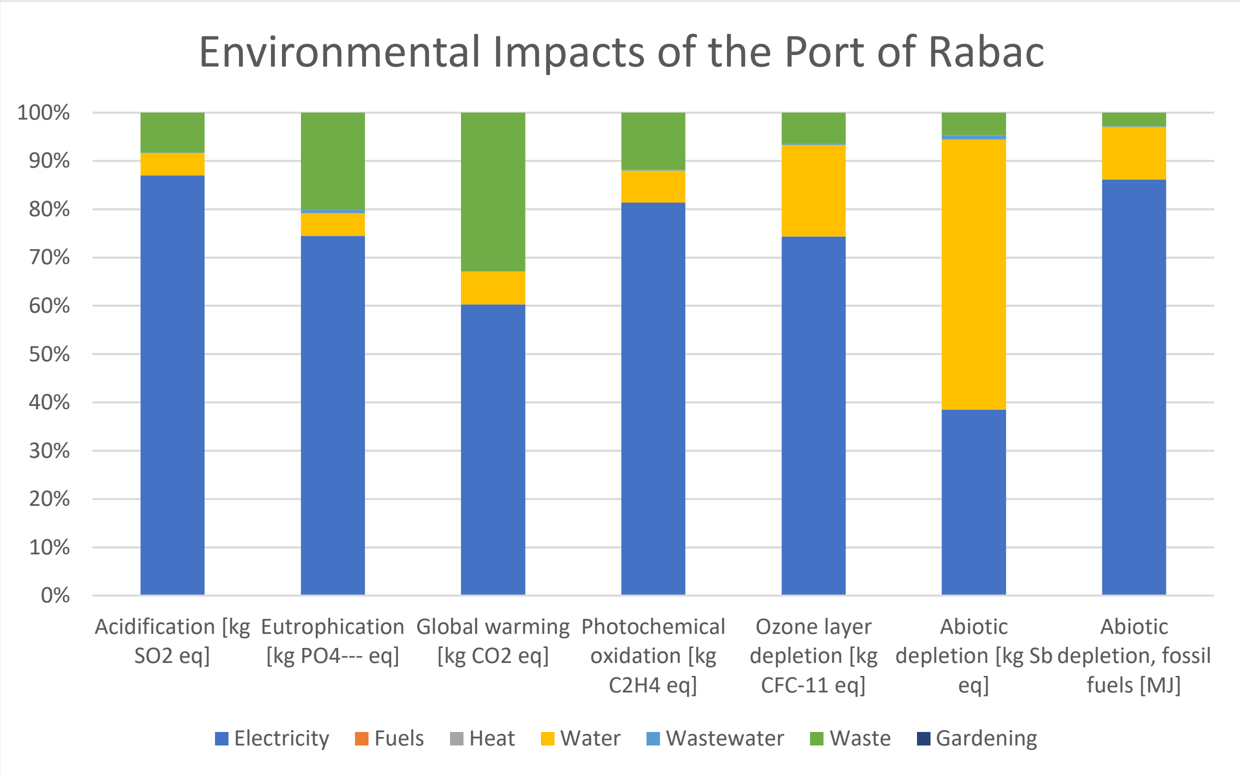
In Table 3 the characterized values are reported, divided according to the life cycle stage and the relative functional unit. The same results are reported as a graph in Figure 3.

Table 3 Impact assessment for the port of Rabac

Impact category	Electricity	Fuels	Heat	Water	Wastewater	Waste	Gardening
Acidification [kg SO2 eq]	6.47E-03	0.00E+00	0.00E+00	3.41E-04	9.17E-06	6.13E-04	0.00E+00
Eutrophication [kg PO4--- eq]	3.05E-03	0.00E+00	0.00E+00	1.91E-04	2.69E-05	8.27E-04	0.00E+00
Global warming [kg CO2 eq]	6.11E-01	0.00E+00	0.00E+00	6.84E-02	9.66E-04	3.33E-01	0.00E+00
Photochemical oxidation [kg C2H4 eq]	2.72E-04	0.00E+00	0.00E+00	2.22E-05	3.27E-07	3.97E-05	0.00E+00
Ozone layer depletion [kg CFC-11 eq]	2.82E-08	0.00E+00	0.00E+00	7.18E-09	8.39E-11	2.46E-09	0.00E+00
Abiotic depletion [kg Sb eq]	1.34E-06	0.00E+00	0.00E+00	1.94E-06	3.02E-08	1.63E-07	0.00E+00

Impact category	Electricity	Fuels	Heat	Water	Wastewater	Waste	Gardening
Abiotic depletion, fossil fuels [MJ]	6.12E+00	0.00E+00	0.00E+00	7.72E-01	9.05E-03	2.01E-01	0.00E+00

Figure 3 Graphic results for the impact assessment of Port of Rabac



The most relevant results for each category are illustrated below, highlighting the main responsible processes.

For what concern Acidification, the main impact is caused by the electricity purchased from the grid. More than 85% of the impact is related to this environmental aspect. Only a small fraction of the impact (5%) comes from water usage and 8% of the impact comes from waste management activities, while the impacts of the other aspects are not substantial.

For what concern Eutrophication, 75% of impact comes from the waste management process. 5% of the impact comes from water usage. Managing the waste produced by people at the small port is the very impactful and it contributes to 20% of the overall environmental impacts. The impacts of rest of the aspects are negligible.

For the impact category Global Warming the main contributor is electricity with about 61% of the overall impact. A small contribution is provided by water usage (7%) while the impact of waste management is about 32%.

For what concerns Photochemical Oxidation, about 82% of the environmental impact is caused by electricity usage. 7% of the impact is caused by water and 11% by the waste management activities. The impact of the other environmental aspects is negligible.

For what concern Ozone layer depletion, 74% of the impact is caused by electricity usage. The water usage and waste are responsible for the rest of the impact with respectively about 20% and 6% of the overall impact.

For the Abiotic Depletion category, water usage is contributing to the 55% of the overall environmental impact. About 38% of the impact is caused by the electricity used at the small port. The waste management activities contribute to 5% of the overall impact. The impact of wastewater is negligible.

For what concern Abiotic Depletion, fossil fuels, the main impact comes from electricity usage (87%). Water is responsible for 10% of the impact while waste only for about 3%. The impact of wastewater is not substantial.

The data about fuel, heat and gardening were not available. Therefore, their impact was not calculated.

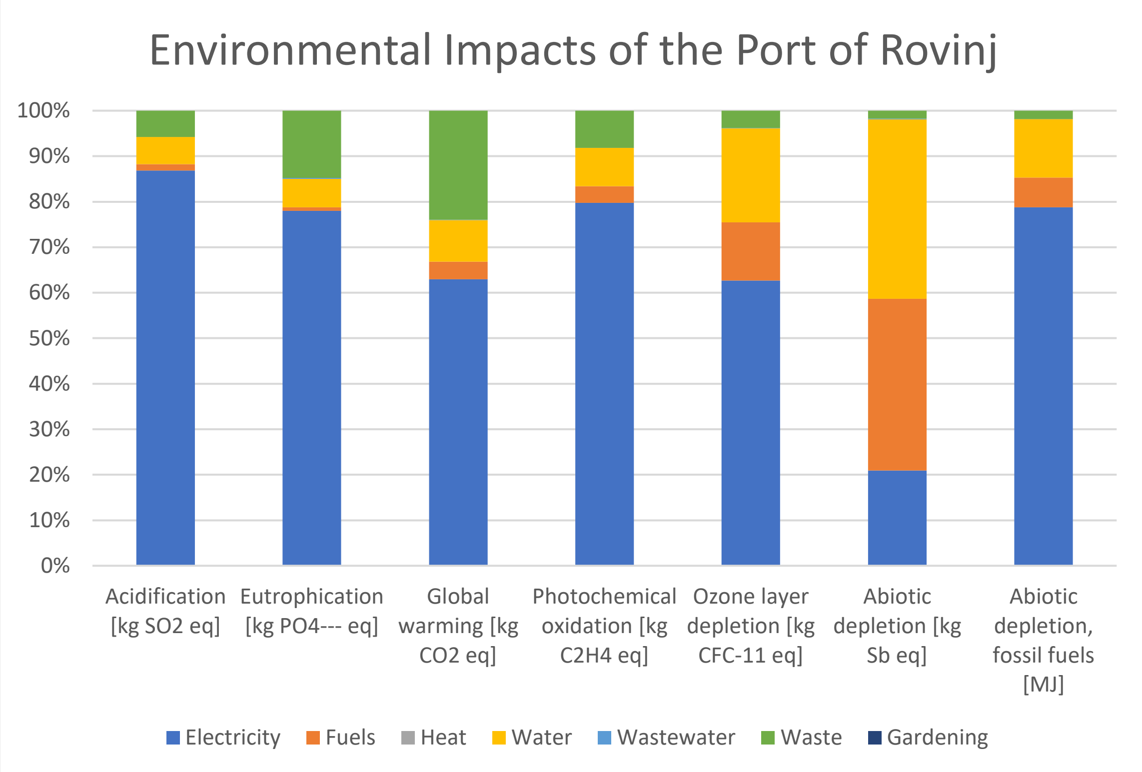
6.4. Results for Port of Rovinj

In Table 4 the characterized values are reported, divided according to the life cycle stage and the relative functional unit. The same results are reported as a graph in Figure 4.

Table 4 Impact assessment for the port of Rovinj

Impact category	Electricity	Fuels	Heat	Water	Wastewater	Waste	Gardening
Acidification [kg SO2 eq]	1.49E-03	2.47E-05	0.00E+00	1.02E-04	5.37E-07	9.86E-05	0.00E+00
Eutrophication [kg PO4--- eq]	7.02E-04	6.81E-06	0.00E+00	5.68E-05	1.57E-06	1.33E-04	0.00E+00
Global warming [kg CO2 eq]	1.41E-01	8.78E-03	0.00E+00	2.04E-02	5.66E-05	5.36E-02	0.00E+00
Photochemical oxidation [kg C2H4 eq]	6.26E-05	2.91E-06	0.00E+00	6.60E-06	1.91E-08	6.39E-06	0.00E+00
Ozone layer depletion [kg CFC-11 eq]	6.49E-09	1.33E-09	0.00E+00	2.14E-09	4.91E-12	3.96E-10	0.00E+00
Abiotic depletion [kg Sb eq]	3.07E-07	5.53E-07	0.00E+00	5.79E-07	1.77E-09	2.62E-08	0.00E+00
Abiotic depletion, fossil fuels [MJ]	1.41E+00	1.16E-01	0.00E+00	2.30E-01	5.30E-04	3.23E-02	0.00E+00

Figure 4 Graphic results for the impact assessment of the port of Rovinj



The most relevant results for each category are illustrated below, highlighting the main responsible processes.

For what concern Acidification, the main impact comes from the electricity usage because it contributes to about 86% of the overall impact. The water usage and waste management are also relevant to this environmental impact category with about 7% each of the impact. The remaining environmental aspects have a negligible impact.

For what concern Eutrophication, the main impact comes from electricity (77%). Managing the waste produced by people at the small port is also very impactful and it contributes to about 15% of the environmental impacts. The water usage is about 7% and the rest of the aspects is not substantial.

For the impact category Global Warming the main contributor is the electricity with about 63% of the impact. A small contribution is provided by fuel usage with about 4%. Water usage and waste management contribute respectively to 10% and 23% of the overall impact.

For what concerns Photochemical Oxidation, about 79% of the environmental impact is caused by electricity. A small part of the impact is produced by fuels usage (4%). Water and waste management have an impact of respectively 10% and 6%.

For what concern Ozone layer depletion, 62% of the impact is caused by electricity. Fuels are responsible for about 11% of the overall impact. 20% of the impact is caused by water usage and 3% by the waste management activities.

For the Abiotic Depletion category, fuel consumption is contributing to about 38% to the overall environmental impact. Water usage is responsible for the 39% of the environmental impact. About 21% of the impact is caused by the electricity used at the small port. The waste management activities contribute to remining impact. The impact of wastewater is negligible.

For what concern Abiotic Depletion, fossil fuels, the main impact comes from electricity with about 78% of the overall impact. Fuels usage is responsible for 7% of the impact while water about 12%. The impact of wastewater and waste is not substantial.

The data about heat and gardening were not available. Therefore, their impact was not calculated.

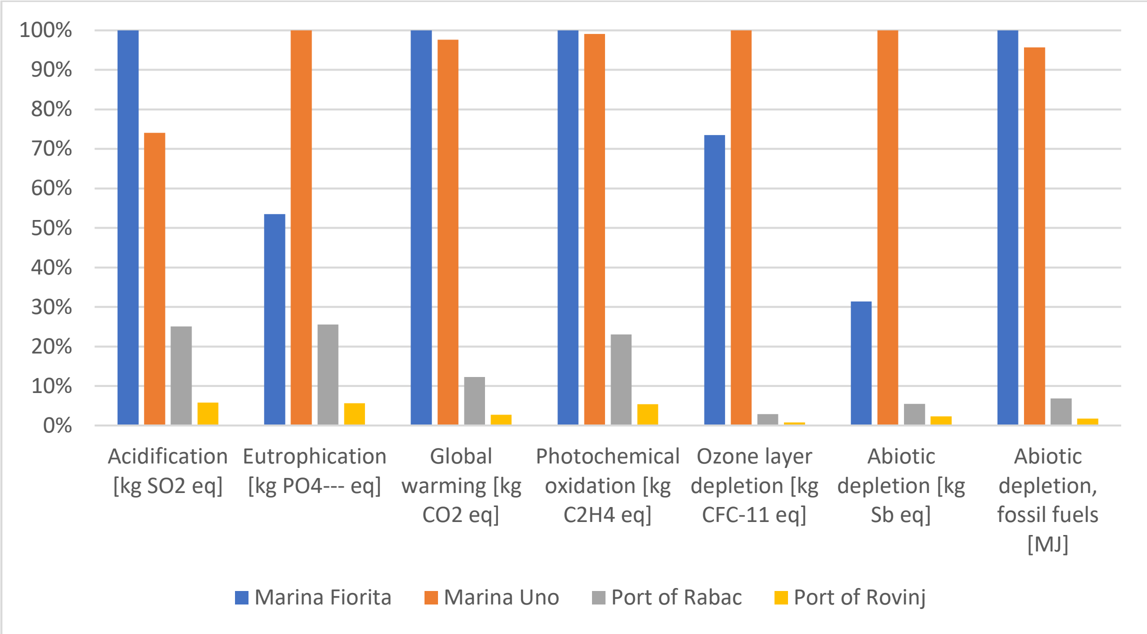
Impact comparison

Table 5 shows the environmental impacts comparison between the various small ports with reference to 1 person. The same results are expressed graphically in Figure 5.

Table 5 Comparison of the impacts of the various small ports

Impact category	Marina Fiorita	Marina Uno	Port of Rabac	Port of Rovinj
Acidification [kg SO2 eq]	2.97E-02	2.20E-02	7.43E-03	1.71E-03
Eutrophication [kg PO4--- eq]	8.58E-03	1.60E-02	4.10E-03	9.00E-04
Global warming [kg CO2 eq]	8.27E+00	8.08E+00	1.01E+00	2.23E-01
Photochemical oxidation [kg C2H4 eq]	1.45E-03	1.44E-03	3.34E-04	7.85E-05
Ozone layer depletion [kg CFC-11 eq]	9.65E-07	1.31E-06	3.80E-08	1.04E-08
Abiotic depletion [kg Sb eq]	1.99E-05	6.34E-05	3.47E-06	1.47E-06
Abiotic depletion, fossil fuels [MJ]	1.04E+02	9.91E+01	7.10E+00	1.78E+00

Figure 5 Comparison in graphic form between the various small ports



7. Sensitivity and uncertainty analysis

While conducting this LCA study, estimates and assumptions were made. This fact can potentially introduce uncertainty into the final results. The types of uncertainties associated with the results of this study are:

- Lack of information in the data collection sheets.
- Inappropriate modelling of inputs and outputs due to limited data in the databases.

When interpreting the results of an LCA study, it is necessary to consider the presence of these types of uncertainties to understand their effects. The result of these analysis are presented in the sections below.

7.1. Sensitivity analysis

In order to consolidate the results and conclusions of the LCA study, the following sensitivity analysis were carried out.

7.1.1 Variation of the quantity of waste

This analysis consists on validating the assumption related to the quantity of waste produced per person per day. In the baseline scenario, it was assumed that an average guest of the small port produces an amount of 1,12kg of waste per day (ISPRA, 2015; ISPRA, 2021). However, this data does not consider the bulky waste that normally constitutes a significant part of the waste produced by an average person in its daily life (ISPRA, 2015; ISPRA, 2021). For this reason, this sensitivity analysis studies how the impact of this additional amount of waste is influencing the overall impact of the small port. Consequently, the amount of waste per person per day has been increased to 1,34kg according to ISPRA (2015) and ISPRA (2021).

The port of Rovinj has not been analysed since primary data on waste are available.

Table 6 Sensitivity analysis about waste quantity for Marina Fiorita

Impact category	Baseline	Sensitivity scenario	Differerence in %
Acidification [kg SO2 eq]	2.97E-02	2.98E-02	0.41

Impact category	Baseline	Sensitivity scenario	Differerence in %
Eutrophication [kg PO4--- eq]	8.58E-03	8.74E-03	1.89
Global warming [kg CO2 eq]	8.27E+00	8.34E+00	0.79
Photochemical oxidation [kg C2H4 eq]	1.45E-03	1.46E-03	0.54
Ozone layer depletion [kg CFC-11 eq]	9.65E-07	9.65E-07	0.05
Abiotic depletion [kg Sb eq]	1.99E-05	1.99E-05	0.16
Abiotic depletion, fossil fuels [MJ]	1.04E+02	1.04E+02	0.04

Table 7 Sensitivity analysis about waste quantity for Marina Uno

Impact category	Baseline	Sensitivity scenario	Differerence in %
Acidification [kg SO2 eq]	2.20E-02	2.21E-02	0.55
Eutrophication [kg PO4--- eq]	1.60E-02	1.62E-02	1.01
Global warming [kg CO2 eq]	8.08E+00	8.15E+00	0.81
Photochemical oxidation [kg C2H4 eq]	1.44E-03	1.45E-03	0.54
Ozone layer depletion [kg CFC-11 eq]	1.31E-06	1.31E-06	0.04

Impact category	Baseline	Sensitivity scenario	Differerence in %
Abiotic depletion [kg Sb eq]	6.34E-05	6.34E-05	0.05
Abiotic depletion, fossil fuels [MJ]	9.91E+01	9.91E+01	0.04

Table 8 Sensitivity analysis about waste quantity for the Port of Rabac

Impact category	Baseline	Sensitivity scenario	Differerence in %
Acidification [kg SO2 eq]	7.43E-03	7.55E-03	1.62
Eutrophication [kg PO4--- eq]	4.10E-03	4.26E-03	3.96
Global warming [kg CO2 eq]	1.01E+00	1.08E+00	6.46
Photochemical oxidation [kg C2H4 eq]	3.34E-04	3.42E-04	2.33
Ozone layer depletion [kg CFC-11 eq]	3.80E-08	3.84E-08	1.27
Abiotic depletion [kg Sb eq]	3.47E-06	3.51E-06	0.92
Abiotic depletion, fossil fuels [MJ]	7.10E+00	7.14E+00	0.56

The result of this analysis highlights that there are not significant differences in the environmental performances of the small ports if they need to handle a higher amount of waste. Therefore, we can assume that managing the waste in a more sustainable manner, by for instance favoring recycling over incineration and landfill, can have a beneficial impact on this environmental aspect.

7.1.2 Variation of the source of electricity

This analysis studies the impact that using only renewable energy for electricity production has on the environmental impacts of the small ports. It was assumed that all the small ports are using renewable energy produced with photovoltaic panels instead of the one from the grid. The following datasets were adopted to model the electricity usage respectively for the Italian and Croatian small ports Electricity, low voltage {IT}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U and Electricity, low voltage {HR}| electricity production, photovoltaic, 3kWp slanted-roof installation, multi-Si, panel, mounted | Cut-off, U.

Marina Uno has not been analysed because it already uses renewable energy only.

Table 9 Sensitivity analysis about the source of electricity for Marina Fiorita

Impact category	Baseline	Sensitivity scenario	Differerence in %
Acidification [kg SO2 eq]	2.97E-02	1.19E-02	-59.90
Eutrophication [kg PO4--- eq]	8.58E-03	5.45E-03	-36.46
Global warming [kg CO2 eq]	8.27E+00	3.18E+00	-61.52
Photochemical oxidation [kg C2H4 eq]	1.45E-03	7.22E-04	-50.32
Ozone layer depletion [kg CFC-11 eq]	9.65E-07	2.77E-07	-71.27

Impact category	Baseline	Sensitivity scenario	Differerence in %
Abiotic depletion [kg Sb eq]	1.99E-05	1.88E-04	846.02
Abiotic depletion, fossil fuels [MJ]	1.04E+02	3.68E+01	-64.41

Table 10 Sensitivity analysis about the source of electricity for Port of Rabac

Impact category	Baseline	Sensitivity scenario	Differerence in %
Acidification [kg SO2 eq]	7.43E-03	1.47E-03	-80.21
Eutrophication [kg PO4--- eq]	4.10E-03	1.26E-03	-69.14
Global warming [kg CO2 eq]	1.01E+00	4.73E-01	-53.36
Photochemical oxidation [kg C2H4 eq]	3.34E-04	8.80E-05	-73.68
Ozone layer depletion [kg CFC-11 eq]	3.80E-08	1.72E-08	-54.77
Abiotic depletion [kg Sb eq]	3.47E-06	1.20E-05	245.09
Abiotic depletion, fossil fuels [MJ]	7.10E+00	1.77E+00	-75.02

Table 11 Sensitivity analysis about the source of electricity for Port of Rovinj

Impact category	Baseline	Sensitivity scenario	Differerence in %
Acidification [kg SO2 eq]	1.71E-03	3.42E-04	-80.03
Eutrophication [kg PO4--- eq]	9.00E-04	2.49E-04	-72.37
Global warming [kg CO2 eq]	2.23E-01	9.90E-02	-55.70
Photochemical oxidation [kg C2H4 eq]	7.85E-05	2.18E-05	-72.17
Ozone layer depletion [kg CFC-11 eq]	1.04E-08	5.57E-09	-46.17
Abiotic depletion [kg Sb eq]	1.47E-06	3.43E-06	133.48
Abiotic depletion, fossil fuels [MJ]	1.78E+00	5.60E-01	-68.61

The result of the sensitivity analysis demonstrates that adoption photovoltaic panels for the electricity production brings significant improvements to all the impact categories except for Abiotic depletion. For this impact category, the adoption of this renewable energy does not provide improvement, but a severe negative impact. However, the adoption of this method for energy production seems to be preferable compared to purchasing electricity from the grid according to the fact that it delivers benefit to several environmental impacts.

7.2. Uncertainty analysis

Uncertainty analysis was conducted to identify the impact of uncertainty in the input data on the results of the study. Uncertainty analysis is in fact understood as the systematic study of the propagation of input uncertainty on output uncertainty. If the uncertainty of the process data is specified, e.g., in the form of a Gaussian distribution with a certain standard deviation, which may differ for different sections of the process data, then the uncertainty analysis will produce standard deviations or confidence intervals for the inventory results.

In an LCA study there are at least two types of uncertainty involved: one is the normal uncertainty associated with the determination of a parameter in a given system, and the other refers to the choice of the value of that parameter to represent a value in another similar system.

Very often, the uncertainty about the quantity of a specific input or output cannot be derived from the available data, since there is only one source of information that provides the average value, without any indication of the uncertainty of that value. Therefore, with reference to the Ecoinvent database, a simplified procedure was developed to quantify the uncertainty of these data: this simplified approach involves a qualitative assessment of data quality indicators, based on a pedigree matrix. This matrix the so called (pedigree matrix), since the data quality indicators refer to the history or origin of the data, as a family tree reports the genealogy (pedigree) of an individual.

Basic uncertainty factors are used for the types of inputs and outputs considered; for example, it is assumed that CO2 emissions in general have a much smaller uncertainty when compared to CO, whereas the former can be calculated from fuel input data, the latter depends more closely on boiler characteristics, engine maintenance, load factors, etc. These uncertainty factors are given in the table below, as derived from expert judgements.

Data sources are evaluated according to the six characteristics "reliability", "completeness", "temporal correlation", "geographical correlation", "further technological correlation", "sample size", shown in the following table. Each characteristic is divided into five quality levels with a score between 1 and 5. Consequently, a set of six indicators is attributed to each input and output flow: five referring to the pedigree matrix (Ui) and one to the basic uncertainty (Ub).

The indicators thus identified are transformed into an uncertainty factor, expressed as the square of the geometric standard deviation, according to the correspondence shown in the table below.

Table 12 Uncertainty factors (contributing to the square of the geometric standard deviation) applied in combination with the pedigree matrix

Indicator Score	1	2	3	4	5
Reliability	1,00	1,05	1,10	1,20	1,50
Completeness	1,00	1,02	1,05	1,10	1,20
Temporal correlation	1,00	1,03	1,10	1,20	1,50
Geographical correlation	1,00	1,01	1,02		1,10
Technological correlation	1,00		1,20	1,50	2,00
Sample size	1,00	1,02	1,05	1,10	1,20

The square of the geometric standard deviation (equal to 95% of the interval) is calculated according to the formula presented by Weidema et al, (1996) which considers the following parameters:

• U1: reliability uncertainty factor (R, reliability), referring to the sources, acquisition methods and verification procedures used to obtain the data.

• U2: uncertainty factor of completeness (C), which refers to the statistical properties of the data, how representative they are, whether the sample includes a sufficient number of data and whether the period is adequate to account for fluctuations.

• U3: uncertainty factor of temporal correlation (TC), representing the temporal correlation between the year of the study (as specified in the target definition) and the year to which the data refer.

• U4: uncertainty factor of geographic correlation (G, geographic correlation), referring to the geographic correlation between the defined area and the data obtained.

• U5: uncertainty factor of other technological correlation (T, other technological correlation), referring to all other aspects than geographical and temporal correlation, e.g., it may be necessary to refer to data of similar processes or enterprises.

• U6: sample size uncertainty factor (S, sample size).

• Ub: basic uncertainty factor.

Once the score values for the six categories have been obtained, the square of the standard deviation is calculated. After having identified the most significant data, it is appropriate to proceed with the quantitative uncertainty analysis, essentially distinguishing two different ways of conducting the uncertainty analysis: through statistical sampling or through analytical formulas based on error propagation. A well-known method of random sampling is Monte Carlo analysis, the basic procedure of which is as follows:

Each input parameter is considered as a stochastic variable with a specified probability distribution:

• The LCA model is constructed with a particular configuration of each stochastic parameter.

• The LCA results are calculated with this configuration.

• The previous two steps are repeated a number of times.

• The sample of LCA results is investigated with respect to its statistical properties (such as mean, standard deviation, confidence intervals).

The selection of the most significant data was made by analyzing the contributions to the assessment of the environmental impacts of the individual sub-processes present in each process unit, with reference to all the impact categories identified by the impact assessment method.

A probability distribution had to be attributed to each of the items thus obtained. Since the inventory items found to be significant all came from the Ecoinvent database, the log normal probability distribution was assumed.

A Monte Carlo simulation was then carried out using a number of runs equal to 1000 as a stopping criterion. In this way a series of values are randomly sampled on the basis of the distribution and the LCA results are recalculated for each parameter. The following tables (present the mean, median, standard deviation (SD) and coefficient of variation (CV) for each category analyzed with a 95% confidence interval.

Table 13 Results of the uncertainty analysis for Marina Fiorita

Impact category	Average	Median	SD	CV	2,5%	97,5%	SEM
Acidification [kg SO2 eq]	1.97E-05	1.96E-05	2.39E-06	1.21E+01	1.63E-05	2.42E-05	7.56E-08
Eutrophication [kg PO4--- eq]	1.03E+02	1.01E+02	1.49E+01	1.44E+01	8.17E+01	1.31E+02	4.72E-01
Global warming [kg CO2 eq]	2.96E-02	2.95E-02	3.06E-03	1.03E+01	2.47E-02	3.54E-02	9.67E-05
Photochemical oxidation [kg C2H4 eq]	8.62E-03	7.71E-03	3.52E-03	4.08E+01	4.95E-03	1.54E-02	1.11E-04
Ozone layer depletion [kg CFC-11 eq]	8.27E+00	8.27E+00	7.18E-01	8.68E+00	7.10E+00	9.46E+00	2.27E-02
Abiotic depletion [kg Sb eq]	9.61E-07	9.37E-07	1.87E-07	1.95E+01	6.99E-07	1.28E-06	5.91E-09
Abiotic depletion, fossil fuels [MJ]	1.45E-03	1.44E-03	1.47E-04	1.01E+01	1.23E-03	1.71E-03	4.64E-06

Table 14 Results of the uncertainty analysis for Marina Uno

Impact category	Average	Median	SD	CV	2,5%	97,5%	SEM
Acidification [kg SO2 eq]	6.34E-05	6.31E-05	4.40E-06	6.94E+00	5.71E-05	7.12E-05	1.39E-07
Eutrophication [kg PO4--- eq]	9.86E+01	9.85E+01	7.66E+00	7.77E+00	8.63E+01	1.11E+02	2.42E-01
Global warming [kg CO2 eq]	2.20E-02	2.19E-02	8.87E-04	4.04E+00	2.06E-02	2.35E-02	2.80E-05

Impact category	Average	Median	SD	CV	2,5%	97,5%	SEM
Photochemical oxidation [kg C2H4 eq]	1.61E-02	1.56E-02	1.90E-03	1.19E+01	1.39E-02	1.97E-02	6.02E-05
Ozone layer depletion [kg CFC-11 eq]	8.04E+00	7.99E+00	7.61E-01	9.46E+00	6.92E+00	9.45E+00	2.41E-02
Abiotic depletion [kg Sb eq]	1.31E-06	1.28E-06	1.37E-07	1.04E+01	1.16E-06	1.57E-06	4.32E-09
Abiotic depletion, fossil fuels [MJ]	1.45E-03	1.43E-03	1.45E-04	1.00E+01	1.26E-03	1.70E-03	4.60E-06

Table 15 Results of the uncertainty analysis for the Port of Rabac

Impact category	Average	Median	SD	CV	2,5%	97,5%	SEM
Acidification [kg SO2 eq]	3.47E-06	3.44E-06	2.97E-07	8.56E+00	3.00E-06	4.00E-06	9.39E-09
Eutrophication [kg PO4--- eq]	7.14E+00	7.00E+00	1.21E+00	1.70E+01	5.44E+00	9.44E+00	3.83E-02
Global warming [kg CO2 eq]	7.44E-03	7.40E-03	7.00E-04	9.40E+00	6.35E-03	8.61E-03	2.21E-05
Photochemical oxidation [kg C2H4 eq]	4.05E-03	3.49E-03	2.40E-03	5.92E+01	1.94E-03	7.75E-03	7.59E-05
Ozone layer depletion [kg CFC-11 eq]	1.01E+00	1.00E+00	9.43E-02	9.34E+00	8.70E-01	1.18E+00	2.98E-03

Impact category	Average	Median	SD	CV	2,5%	97,5%	SEM
Abiotic depletion [kg Sb eq]	3.82E-08	3.74E-08	6.61E-09	1.73E+01	2.89E-08	5.08E-08	2.09E-10
Abiotic depletion, fossil fuels [MJ]	3.34E-04	3.33E-04	3.30E-05	9.87E+00	2.84E-04	3.91E-04	1.04E-06

Table 16 Results of the uncertainty analysis for the Port of Rovinj

Impact category	Average	Median	SD	CV	2,5%	97,5%	SEM
Acidification [kg SO2 eq]	1.46E-06	1.46E-06	9.19E-08	6.27E+00	1.32E-06	1.63E-06	2.90E-09
Eutrophication [kg PO4--- eq]	1.79E+00	1.76E+00	2.77E-01	1.54E+01	1.39E+00	2.29E+00	8.76E-03
Global warming [kg CO2 eq]	1.72E-03	1.72E-03	1.62E-04	9.41E+00	1.48E-03	1.99E-03	5.13E-06
Photochemical oxidation [kg C2H4 eq]	8.95E-04	7.81E-04	5.13E-04	5.73E+01	4.30E-04	1.79E-03	1.62E-05
Ozone layer depletion [kg CFC-11 eq]	2.25E-01	2.24E-01	1.87E-02	8.32E+00	1.95E-01	2.57E-01	5.92E-04
Abiotic depletion [kg Sb eq]	1.04E-08	1.02E-08	1.77E-09	1.70E+01	8.01E-09	1.38E-08	5.61E-11
Abiotic depletion, fossil fuels [MJ]	7.90E-05	7.86E-05	7.37E-06	9.32E+00	6.77E-05	9.10E-05	2.33E-07

8. LCA Conclusion

The study was performed in accordance with International Standards ISO 14040 and ISO 14044 to assess the environmental impacts associated to the following small ports:

• Marina Fiorita – Cavallino Treporti (VE), Italy

• Marina Uno – Lignano Sabbiadoro (UD), Italy

• Port of Rabac – Rabac, Croatia

• Port of Rovinj – Rovinj Croatia

This assessment not only allowed identifying the main hotspots of the investigated system, but also allowed defining strategies to reduce the environmental impacts. The results are used to build a solid background for developing an Ecolabel proposal for small ports.

The boundaries of the system studied include the entire life cycle of the small ports activities, adopting a "from cradle to grave" approach, considering the following aspects:

1. Energy. Usage of resources to produce energy (e.g., methane for heating) and the electricity used for small ports daily activities.

2. Fuels. Consumption of petrol and diesel for the small boats used by the small ports.

3. Water. Usage of water for the various activities (e.g., swimming pool, toilets, showers) and management of the wastewater.

4. Waste. Management of the waste produced by the small ports and their activities.

5. Gardening. Consumption of fertilizers, pesticides, and other substances for gardening purposes, aw well as chemical used for swimming-pool maintenance.

Primary data was collected for the product systems analyzed. Where these were not available, internationally recognized databases and relevant publications were used.

The results demonstrate that electricity is the most impactful environmental aspect. Therefore, the electricity usage needs to be managed in a more sustainable to decrease the impacts of the small ports. The sensitivity analysis demonstrates that the adoption of photovoltaic panels can provide significant benefits and can drastically reduce several environmental impacts. As an alternative, as shown by the Marina Uno case, the adoption of other renewable sources of energy, such as hydroelectric, can drastically decrease the impact on the environment.

Consequently, a small port that uses renewable energy only can address its efforts to a proper management of heat, water usage and chemical products' use for maintenance and gardening activities, in order to lower its impact.

The uncertainty analysis carried out using the Monte Carlo method and relating to the application of the CML-IA baseline method (v.3.05) with the addition of the water scarcity indicator (AWARE) made it possible to identify the categories for which the results more uncertain.

It should be noted that the results of the study have a relative value and validity in relation to the assumptions made and the choice of system.

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