Comparative Life cycle assessment of a sailboat, a yacht and a rigid inflatable boat

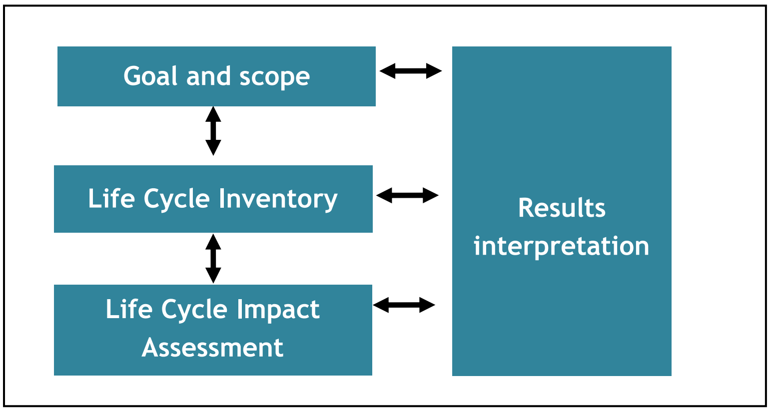
Introduction and methodology

A Life Cycle Assessment study of three kinds of recreational boats: a sailboat, a rigid inflatable boat and a yacht, has been done in the framework of the Life European project “BoatCycle” in order to assess the potential environmental impact of this kind of boats.

Life cycle assessment is a methodology for assessing quantitative environmental analysis of products and services, which allow quantifying the potential environmental impacts of a product or service generated in all its life cycle.

The methodology followed is based in ISO standards UNE-EN ISO 14040:2006 and UNE-EN ISO 14044:2006, as well as the standards of International Reference Life Cycle Data System (ILCD) Handbook. The software used to perform the LCA study is SimaPro and the Database used for the majority of cases in this study is Ecoinvent v2.2.

Figure 1. Steps of the Life Cycle Assessment, according to UNE-EN ISO 14040:2006



Goal of the study

The goal of this LCA study is to identify the potential environmental impacts of three recreational boats: a sailboat, a rigid inflatable boat and a yacht, and to compare the environmental performance of the different boats studied.

The study would provide information on the main environmental concern issues of the studied system, identifying the hot spots of the processes. This information will be analysed in order to propose good practices to the nautical sector.

Scope of the study

The study is a cradle to grave LCA, since it includes all stages of boats, from raw materials extraction and transformation boat manufacturing, distribution, use stage (including mooring, maintenance operation and sailing) to the end of life. The boats analysed and compared are:

- A sailboat of 40 ft (12 meters) for recreational sailing use.
- A yacht of 5,57 meters for recreational sailing use.
- A rigid inflatable boat of 5 meters length for recreational sailing use.

Functional unit

The "functional unit", describes qualitatively and quantitatively the function(s) or the service(s) provided by the product. The functional unit has been defined with the purpose of representing a recreational boat, using the average processes and European current technologies.

For the comparative LCA of the three kinds of boats; the functional unit should be common for the three boats analysed because the three boats have different life length and different levels of use. The common functional unit is defined for a common use as follows:

One hour of navigation (sailing action) in a recreational boat with leisure purposes

For each kind of boat, impacts are calculated also for a unit (a boat) to know the impact of the whole boat (in sections 5, 6 and 7). In order to relate the boat with the functional unit, the life length of each boat and the average hours of navigation have been considered.

Table 1. Parameters of each kind of studied boats

	Length of boat (years)	Hours navigation /year	Hours navigation /boat
RIB	15	201	2350
Yacht	25	248	6208
Sailboat	25	603	15083

System definition and boundaries

The system studied is the process of a boat production and can be divided into these main sub-systems:

- Materials production. The main components of the boat will be quantified and analysed. The removal of raw materials, energy and resources used in production process and transports process are included in this stage.
- Design. The initial phase of the productive process of a boat is the design of a concrete model. As this is a unique process for all the boats of that model that will be manufactured and it is a low environmental loaded activity, the design phase has been not considered into the system.

- Manufacturing. The production contains all stages from materials to the final product. In this stage are included: auxiliary materials, inputs process (energy, water,..), outputs process (wastes, emissions, etc.).
- Distribution. In this case, distribution from the manufacturer to the final user has been considered.
- Use. In this stage all lifetime of the boat has been considered, taking into account the life time of each boat. During this phase users' profile and its behaviour is highly determinant, so that different scenarios has been compared depending on the user's expertise and intensity of use. In this stage, different activities are analysed: sailing, storage in mooring, and maintenance activities.
- End of life. This stage includes the disposal as a waste at the end of life of the boat. Once the owner decides to get rid of the boat, different possibilities exist actually for the final treatment. The most usual treatment is controlled disposal after decontamination where only some metal components are separated and valorised. However, some sailboats are abandoned in the repairs shops, seaports or in countryside. Another scenario, less common, is the scraping and posterior components valorisation, which has been carried out during BoatCycle project.

Impact assessment method

The impact assessment method selected for this study is CML. Impact category selected are those with more scientific consensus and recommended by *ILCD Handbook: Recommendations for Life Cycle Impact Assessment in the European context*[1]. It has been used the method CML 2001 baseline for characterization categories:

Table 2. Impact categories selected for the study

Impact categories selected	Units
1. Global warming (GWP100)	kg CO_2 eq
2. Ozone depletion (OD)	kg CFC-11 eq
3. Acidification (A)	kg SO_2 eq
4. Photochemical oxidant formation	kg C_2H_4
5. Eutrophication	kg PO_4--- eq
6. Human toxicity (HT)	kg 1,4-DB eq
7. Freshwater ecotoxicity (FET)	kg 1,4-DB eq
8. Marine ecotoxicity (MET)	kg 1,4-DB eq
9. Terrestrial ecotoxicity (TE)	kg 1,4-DB eq
10. Abiotic depletion	kg Sb eq

In order to facilitate comparability of the solutions studied and reported the results in a more synthesized, the **ReCiPe**[2] calculation method has been used, which

[1] *Recommendations for Life Cycle Impact Assessment in the European context based on existing environmental impact assessment models and factors.* EUR 24571 EN – 2011. JRC European Commission. Joint Research Centre Institute for Environment and Sustainability.
[2] http://www.lcia-recipe.net/

allows adding indicators of different categories of environmental impact (or endpoints) into a single score, using the processes of normalization and aggregation.

Comparative impact assessment of studied boats

In table 45 the different indicators in terms of emission and resources are summarize. When they are calculated expressed by a boat (unit) it can be seen that the yacht is the boat which has major impacts during the 25 years of its useful life *(in red)* and the sailboat is the second boat with major impacts during the 25 years of its life *(in orange)*. Finally the RIB, with a lower amount of materials used a lower weight and a shorter useful life, has minor impacts comparing to the other two boats *(in green)*.

Nevertheless, if these environmental impacts indicators are expressed by one hour navigated with each kind of boat (as it is defined in our functional unit) it can be seen that the yacht have major impacts *(in red)* followed by the RIB *(in orange)*, whereas the sailboat *(in green)* is the less impacting navigation, in part due to a lower used of the engine during sailing (which is the most impacting phase for the three kinds of boats).

Table 3. Summary of environment data for the three boats

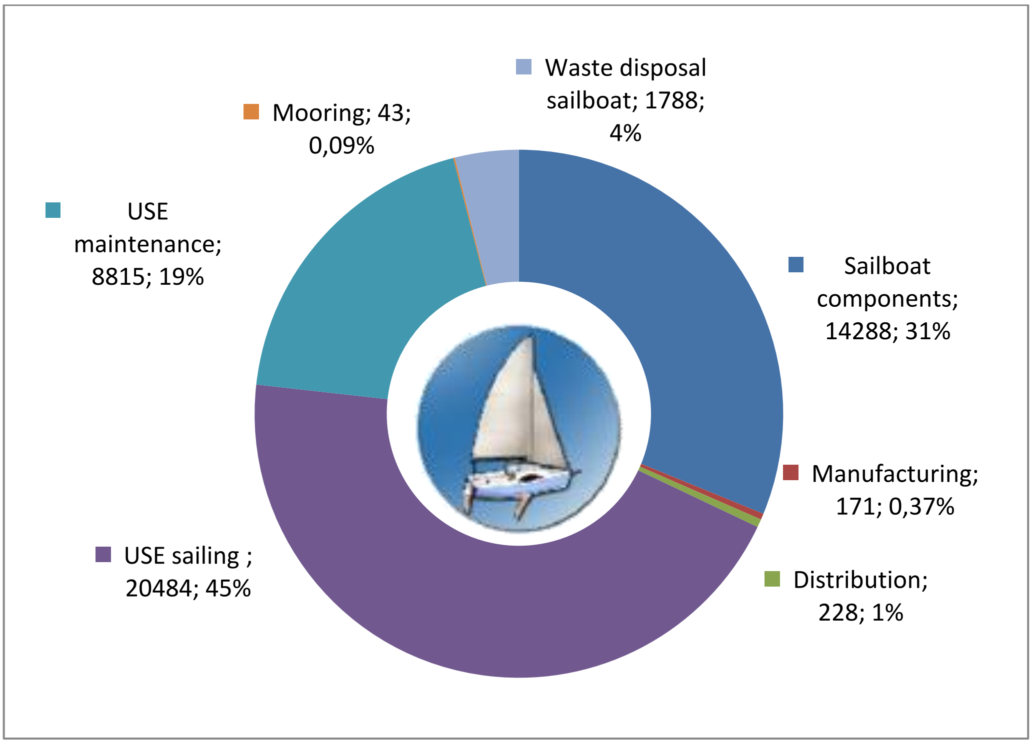
	BOAT (UNIT)				HOUR NAVIGATED			
	Energy demand (GJ eq)	**Water demand (m^3)**	**CO_2 emissions (t CO_2)**	**Global env. Impact (pt.)**	**Energy demand (MJ eq)**	**Water demand (m^3)**	**CO_2 emissions (kg CO_2)**	**Global env. Impact (pt.)**
Sailboat	710	951	46	4709	47	0,06	3,04	0,31
Yacht	2808	2230	158	16575	362	0,35	25,47	2,67
RIB	410	259	31	3124	175	0,11	13,44	1,33

If the carbon footprint of the three boats is calculated it has found the following distribution of greenhouse gas emission for different stages:

Carbon footprint of a sailboat

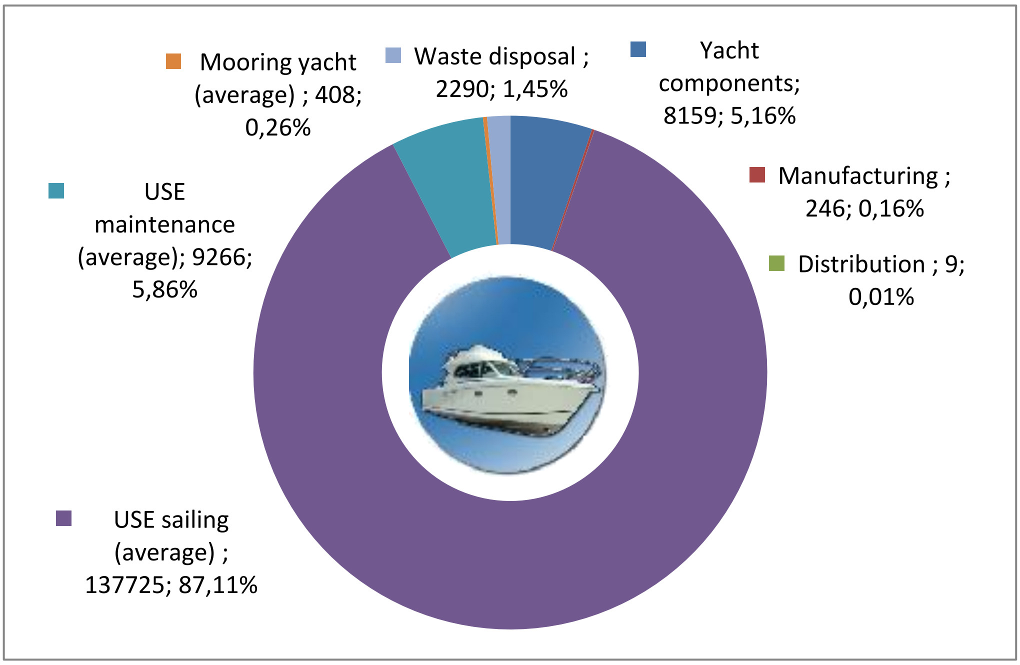
As seen above, a sailboat generates an emission to atmosphere of **45,82 tonnes of CO_2 equivalent**. These emissions are due to consumption of energy and resources that a sailboat does during all its life and it is distributed among life stages as following (See Figure 2):

Figure 2. Emission of CO_2 eq of a sailboat during all life stages (kg CO_2 eq/%)



As seen above, a yacht generates an emission to atmosphere of **158 tonnes of CO_2 equivalent**. These emissions are due to consumption of energy and resources that a yacht does during all its life and it is distributed among life stages as following (See Figure 3):

Figure 3. Emission of CO_2 eq of a yacht during all life stages (kg CO_2 eq / %)

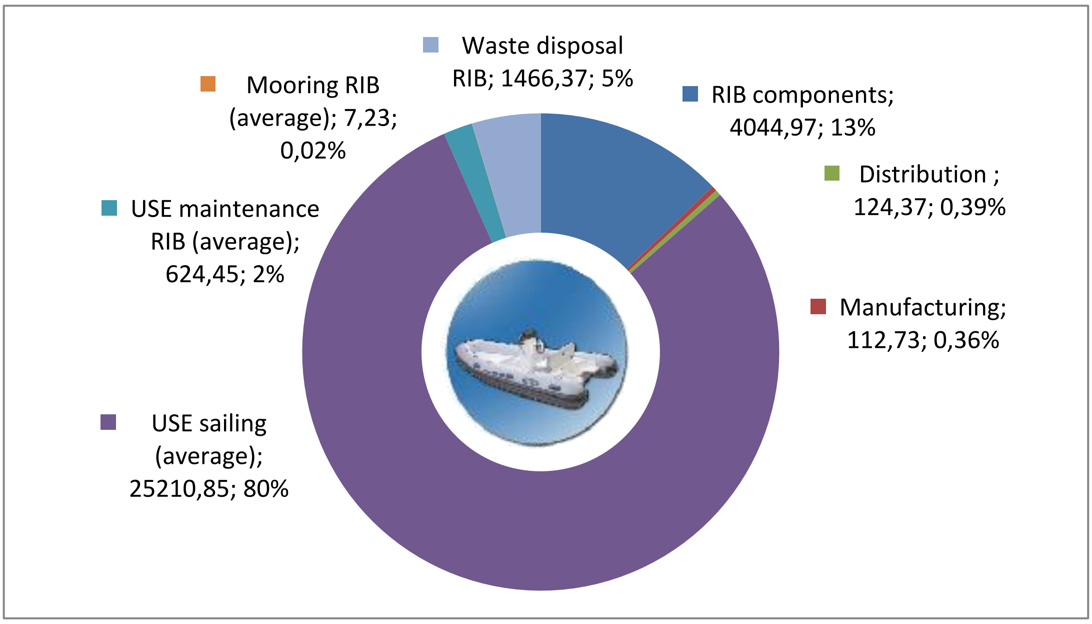


Differently to sailboats, the biggest part of CO_2 emissions generated by a yacht is due almost in a 90% (87%) to sailing activity, followed by far by maintenance operations (5,86%). Yacht components have also relevant emissions values (5,16%) and waste disposal have 1.46% of emission contributions. The rest of the stages: manufacturing, distribution and mooring have lower CO_2 emissions values.

Carbon footprint of a RIB

As seen above, a RIB generates an emission to atmosphere of **31,6 tonnes of CO_2 equivalent** during its useful life. These emissions are due to consumption of energy and resources that a RIB does during all its life and it is distributed among life stages as following (See Figure 3):

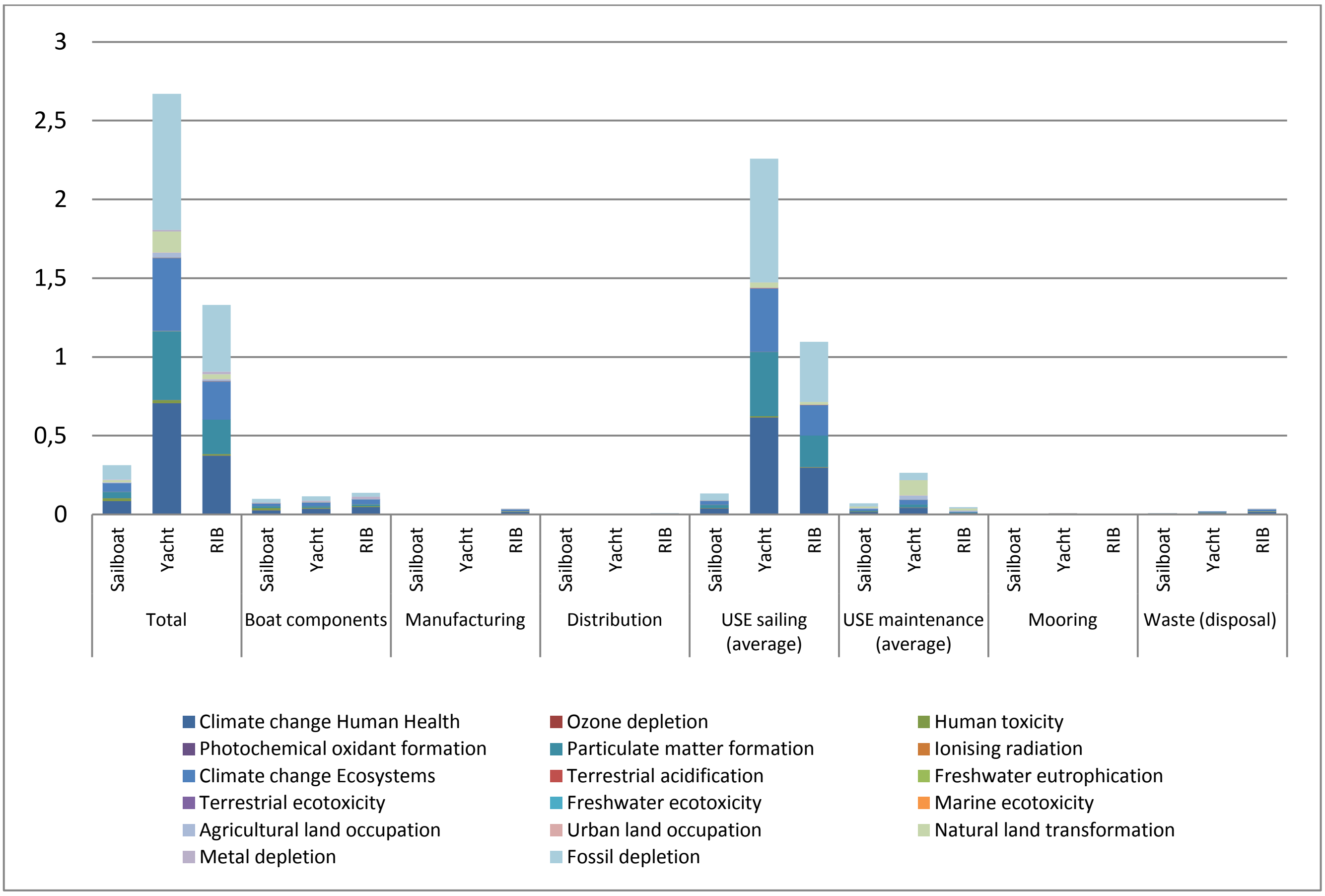
Figure 4. Emission of CO_2 eq of a RIB during all life stages (kg CO_2 eq / %)



In order to better compare the global environmental impact of each kind of boat, it has been used the method calculation **ReCiPe** to normalize and aggregate all impacts at damage level (endpoint indicators) and to obtain a unique punctuation expressing the global environmental impact where different categories are included. If impacts are calculated per hour navigated, the boat with a higher impact is the yacht, followed by RIB whereas sailboat is the boat typology with lower global impact.

In the three kinds of boats, sailing activity has the major impacts, but the components of the boats and maintenance operations have also important values. Sailboat is the boat with minor impacts during the use phase, in part because the sails allow a lower use of the engine, which is the source of a big part of impacts.

Figure 5. Comparison of global impact of three boats studied (by hour navigated)



Conclusions and improvement measures on recreational boats

As general conclusion it can be said that sailboat is the boat with minor impacts per hour navigated. This boat has a long life and is the boat with a more intensive use in hours of navigation. Impacts of sailboats are due in a big part for the sailing activity and components. Environmental savings in sailing activity are due thanks to the use of sails which allows a minor use of the engine which causes an important part of the global impact in the three types of boats. RIBs have higher impacts than sailboat, although yachts are the kind of boat with the highest impacts.

The distribution of impacts among life stages is quite similar for the three boats studied, being by order sailing, components and maintenance operations, together to the waste treatment the stages with higher contributions. Other stages such as manufacturing, distribution or mooring have far less environmental impacts.

Regarding impact categories, the three boats have high impacts on fossil depletion, climate change. Other impact categories studied present lower values when all impacts are normalized.

Relevant impacts of the stage of boats components and the stage of waste treatment prove the importance of valorising waste materials once the boat has finished its useful life as well as the use of recycled materials in boats components, which is one of the objectives of BoatCycle project.

From results and conclusions obtained in the LCA study, the following improvement measures are proposed as they are considered to have a big improvement potential in saving environmental impacts of boats:

- Improve fuel **consumption efficiency during use**. It should be done by improving efficiency of boat and engine, but also by training users, as it has been demonstrated that user's behaviour has a huge impact on fuel consumption during use (mainly in sailboats but also for the other boats).
- Increase the amount of **recycled materials** to manufacture the different **components** of the boat. This will allow decreasing notably the environmental impact of a boat.
- Foment **good environmental practices during maintenance operations and mooring**. Maintenance and cleaning operation of a boat have big environmental impacts so that these good practices will contribute to minimize those impacts.
- **Enlarge useful life of boats**, as important environmental impacts are coming from production of components. In some kind of boats with a shorter life, for instance the RIBs, substitution of the more problematic parts as the float can enlarge boat life and minimize its environmental impact.
- Increase **recyclability and reuse of all elements of the boat**. Once the boat is at the end of its life, it is recommend to **scrap it and to recover** all elements when possible. This practice has several environmental impact savings comparing to landfill in the three kinds of boats.