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Life Cycle Assessment on an Aluminum Patrolling Ship in Malaysia

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Abstract

The shipping sector is one of the major contributing factors to greenhouse gas emissions. As it is growing fast, shipping could produce 17% of global emissions by 2050 if it left unchecked. In this paper, we assess life cycle environmental impact of an aluminum patrol vessel of 25-meter size in Malaysia with the help of life cycle analysis (LCA) method. This paper also identifies the major hotspots of the life cycle impacts from the ship to examine the primary influential factors on environmental impact. Three main groups in the life cycle of the ship have been identified namely construction, operation, and disposal. In this analysis, this ship is considered to use the principle of cradle to grave that means this ship is built from raw materials and will be recycled after the ship is decommissioned. The results show that the operating part has given the highest value in climate change impact (GWP100) with 1.36048×10^8 kg CO_2-Eq compared to the construction value in climate change impact (GWP100) with 1.70506×10^6 kg CO_2-Eq.

Keywords
Life Cycle, Assessment, Greenhouse, Impact, Endpoint

1. Introduction
The shipping sector is one of the major contributing factors to greenhouse gases. According to International Maritime Organization (IMO), the shipping industry accounts for at least 3% of global greenhouse gas emissions, the sixth biggest in terms of total emissions share (Baldi et al. 2014). As it is growing fast, shipping could produce 17% of global emissions by 2050 if it left unchecked (Chen et al. 2019). Marine transport has been essential for international trade with about 90% of the world's trade is carried by sea (Goldsworthy et al. 2019). In recent years, we have seen the growth of the ship in the shipping industry (Ling-Chin and Roskilly 2016). The rapid increase of number merchant ship at sea causes the demand for raw material, fuel, and maintenance and also creates problem with the disposal for ship rack after ship was decommissioned (Sun et al. 2019).

The concern for environment impacts was growing among the regulators, ship designers, classification society, ship owners and other stakeholders to make ship sector environmentally friendly using a variety of methods including life cycle assessment (LCA) method (Islam et al. 2016). Life cycle assessment is a comprehensive approach in which all processes involved in product creation from raw material acquisition through the final production, use, and disposal are analyzed. The effectiveness of the life cycle assessment (LCA) comes from its ability to provide a boundary assessment of the environmental impact on the product throughout its life cycle covering all phases (Bert Metz et al. 2005). This paper evaluates life cycle impact of a 25-meter aluminum patrolling ship by using life cycle assessment (LCA) method with the help of OpenLCA software (OpenLCA 2021). This work identifies the major hotspot of the ship life cycle impact from construction to disposal.

2. Analysis procedure
2.1 OpenLCA software
The OpenLCA tool is used to analysis the life cycle impact from raw material extraction (cradle) through disposal (grave) called cradle-to-grave analysis (Figure 1). OpenLCA is a software to assess environmental impacts associated with all the stages of a ship life from raw material extraction through materials processing, manufacture, distribution, use, repair, and maintenance and lastly disposal or recycling (Blanco-Davis and Zhou 2016). The results will help to make decision-maker select processes that result in the least impact to the environment by considering an entire stage of a ship life.

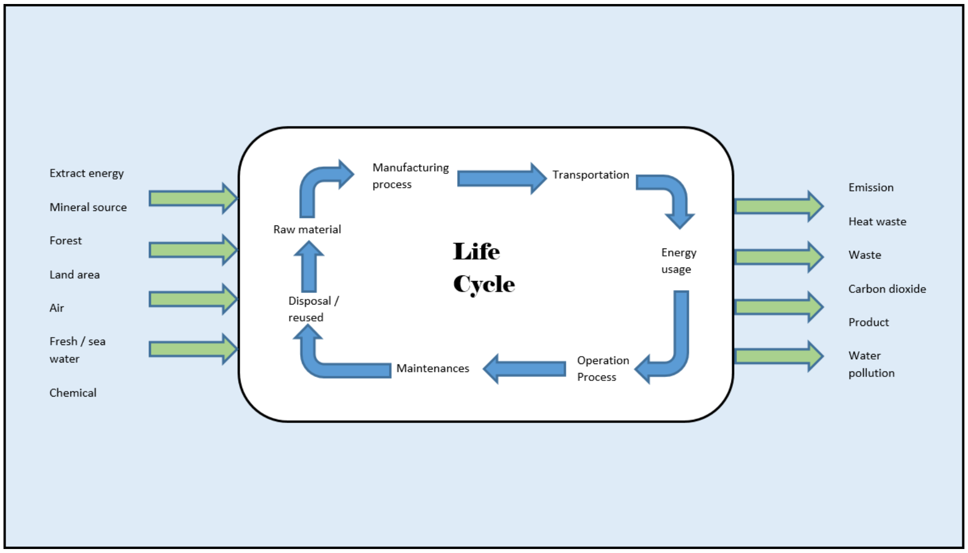

Figure 1. Life cycle Inventory (LCI)

The life cycle assessment is a process to evaluate the environmental effects associated with product process or activity by using energy, material and wastes released. Life cycle assessment also provide to evaluate and implement opportunities and best method to help stockholders to reduce affect any activity to the environment. The assessment also affects all process of entire life cycle of the product from raw material until disposal cradle to grave such as process extracting raw material, processing, energy usage, manufacturing, assemble, transportation and distribution including re-use and maintenance or final disposal. Among the things brought by life cycle assessment include as illustrated in Figure 2 (ISO 2006).

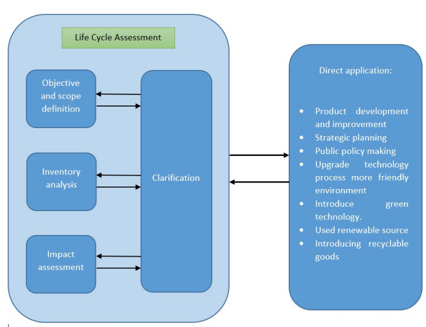

Figure 2. Conceptual framework on LCA

2.2 System boundary
The system boundary will determine which unit processes to be included in LCA during study, selection of system boundaries influences base on an objective study (U. Sonesson et al. 2010). In LCA study each input entered is directly proportional to the output of the system, the user can only select each method from the system only with the suitability

of an analysis. The suitability of the analysis depends on the place, purpose, process, and materials used. In LCA method, analysis results produce output of the effect of a process or product or service (Figure 3).

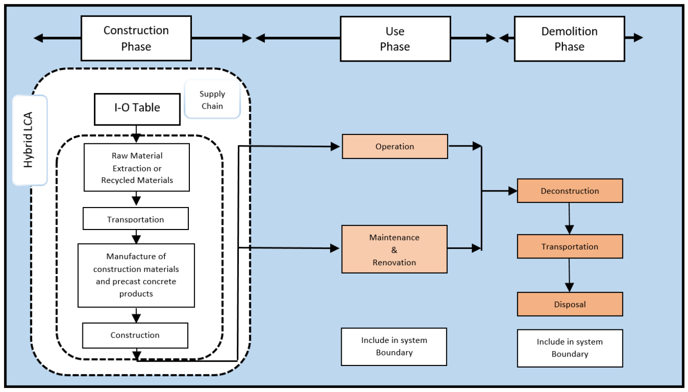

Figure 3. System boundary for LCA in construction process (Omar et al. 2014)

Figure 3 gives an example of the boundary focusing on construction chain, operation, and disposal of an analysis. For the study focusing on life cycle assessment on ship, it will be important to ensure that boundaries are established such that all related process having born on one or more of these concerns are included. For example, in the context of deforestation although there is no carbon oxide release but from the point of view of environmental damage and pollution is a contributor to natural damage (Nemecek and Gaillard 2010).

2.3 Selection method

In the analysis, there are numerous impact categories namely climate change, ozone layer, abiotic resource, human toxicity, acidification, eco toxicity, photo oxidant formation, stratospheric ozone depletion, land use, water depletion and depletion of minerals fossil fuels. Currently, many methods have been developed by the researcher with specific objectives to produce results that are appropriate to the situation and needs of the user. The selection method needs to be introduced to get each result displayed to meet the requirements and to meet the actual impact on the environment. For this work, the Recipe method is found to be suitable because this method includes chemical process and suitable for engine combustion. The Recipe method also produces endpoint results which is useful to compare the impacts on various stages that can be useful to improve the system (Jolliet et al. 2004).

3. Results and discussion

3.1 Midpoint impact category

The simulated results show a comparison between construction and operation process and there are two main comparisons to be evaluated midpoint impact category and endpoint impact category.

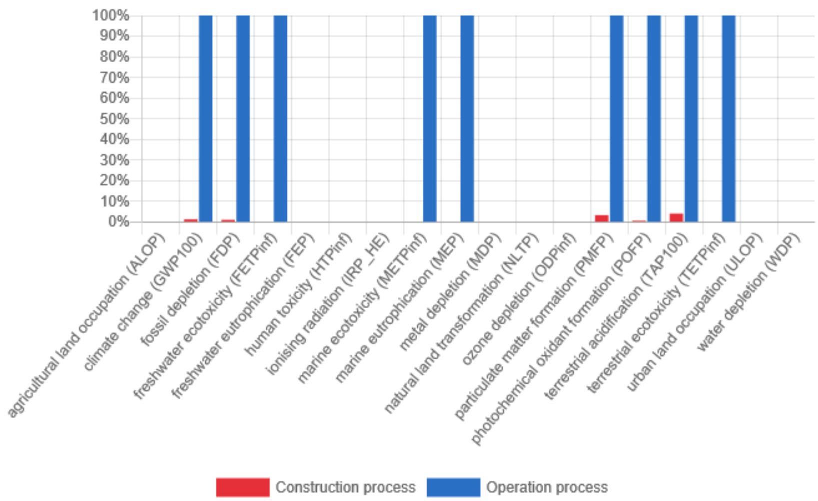

Figure 4. Result LCIA of midpoint impact category for operation and construction process

Figure 4 shows the comparison life cycle impact analysis (LCIA) relative indicator result of the respective operation and construction process. For each indicator, the maximum result is set to 100%. This figure shows, climate change (GWP 100) for operation hits 100% and for construction 1%, which represents 136,048,000 kg CO2-Eq and 1,705,060 kg CO2-Eq, respectively. For fossil depletion (FDP) impact category operation hits 100% while construction 1%, which represents 46.3426 kg oil-Eq and 0.500778 kg oil-Eq respectively. Particulate matter formation (PMFP) shows the reading 100% for operation process and 3% of construction process which represents 34361.5 kg PM10-Eq and 1140.43 kg PM10-Eq, respectively. Photochemical oxidant formation (POFP) also shows 100% reading for operation and 1% for construction represents as 1.39057 kg NMVOC and 462.667 kg NMVOC, respectively and terrestrial acidification (TAP100) indicator shows 100% of operation and 4% of construction represents as 139057 kg SO2-Eq and 5701.95 kg SO2-Eq, respectively.

3.2 Endpoint impact category

Endpoint modeling may facilitate more structured and in-formed weighting science-based aggregation across categories in terms of common parameters. The endpoint of LCIA is result of a data from midpoint**.** Endpoint covers three impact categories namely human life, ecosystem and to natural resource. Endpoint impact category results are represented by unit point (Pt) based on the weight of the results at the endpoint.

Table 1 shows LCIA endpoint impact category of operation and construction process of the whole life cycle of the ship. The results show that impacts for ecosystem quality on climate change from construction process is 29876.9 Pt and operation process is 2383900 Pt. The ecosystem quality on freshwater ecotoxicity, marine ecotoxicity, and terrestrial ecotoxicity have the impacts 46.7188 Pt, 0.00123262 Pt, and 467.679 Pt, respectively. For terrestrial acidification, 73.0857 Pt for construction and 1782.39 Pt for operation process, respectively.

Table 1. endpoint impact category for operation and construction process

Indicator	Construction process	Operation process
Ecosystem quality (agricultural land occupation)	0	0
Ecosystem quality (climate change, ecosystems)	2.98769e+4	2.38390e+6
Ecosystem quality (freshwater ecotoxicity)	0	4.67188e-1
Ecosystem quality (freshwater eutrophication)	0	0
Ecosystem quality (marine ecotoxicity)	0	1.23262e-2
Ecosystem quality (natural land transformation)	0	0
Ecosystem quality (terrestrial acidification)	7.30857e+1	1.78239e+3
Ecosystem quality (terrestrial ecotoxicity)	0	4.67679e+2
Ecosystem quality (total)	2.99500e+4	2.38615e+6
Ecosystem quality (urban land occupation)	0	0
Human health (climate change, human health)	4.72690e+4	3.77162e+6
Human health (human toxicity)	0	0
Human health (ionising radiation)	0	0
Human health (ozone depletion)	0	0
Human health (particulate matter formation)	7.39727e+3	2.05033e+5
Human health (photochemical oxidant formation)	3.57030e+3	6.58578e+4
Human health (total)	5.82366e+4	4.04251e+6
Resources (fossil depletion)	6.00504e-2	5.55714e+0
Resources (metal depletion)	0	0
Resources (total)	6.00504e-2	5.55714e+0
Total (total)	8.81867e+4	6.42866e+6

3.2.1 Endpoint impact category, ecosystem quality

Figure 5 shows the single result LCIA endpoint impact category for ecosystem quality total. From the Figure 5, it appears that impact for operation process much higher compared with construction process with data reading 2386150 Pt and 29950 Pt, respectively.

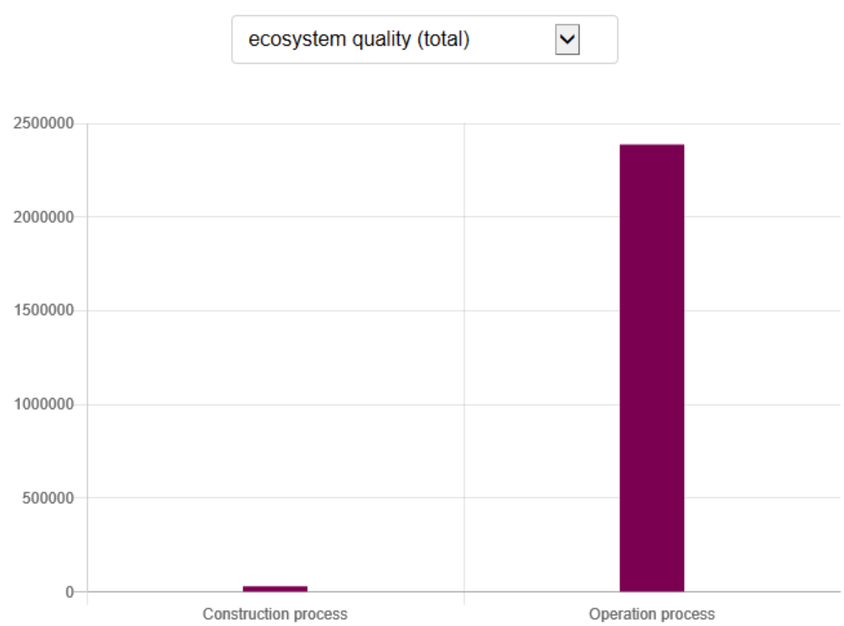

Figure 5. Single result LCIA of Endpoint impact categories, ecosystem quality

3.2.2 Endpoint impact category, human health

Figure 6 shows the single result LCIA endpoint impact category for human health. The results show that the operation process impact has 4042510 Pt and construction process impact has 58236.6 Pt, respectively.

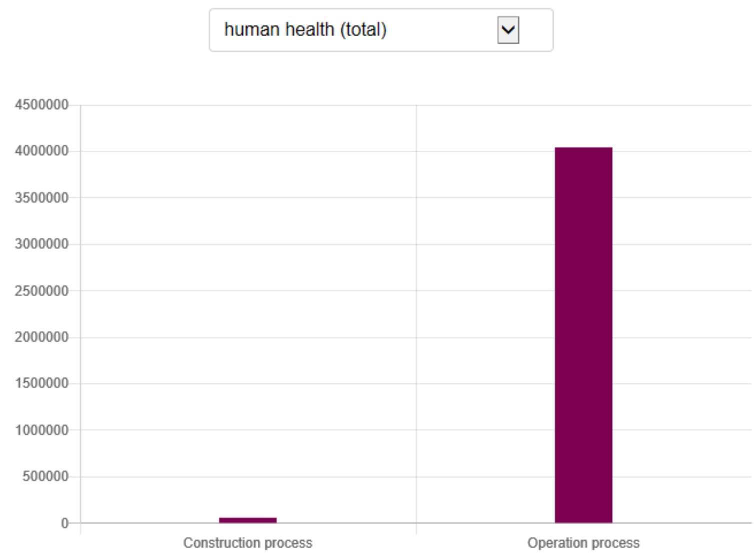

Figure 6. Single result LCIA of Endpoint impact categories, human health

3.2.3 Endpoint impact category, resources

Figure 7 shows single result LCIA endpoint impact category for resource. It shows that the operation process has impacts 0.0600504 Pt and construction process has impacts 5.55714 Pt, respectively.

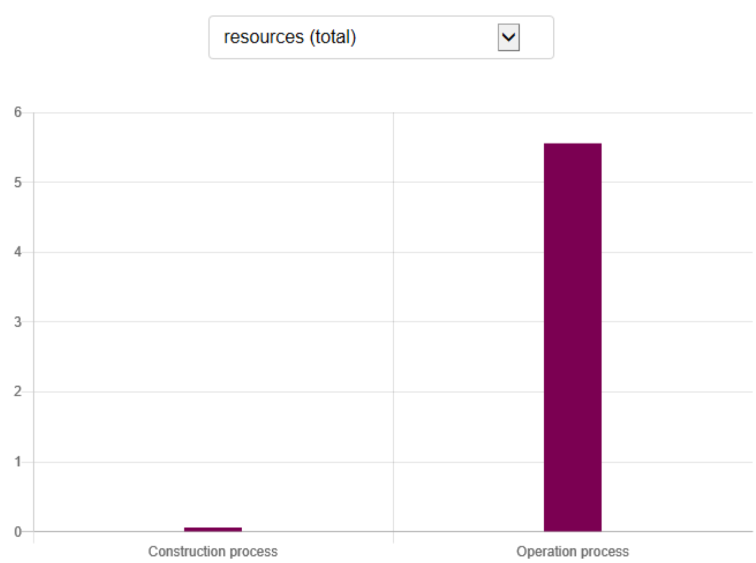

Figure 7. Single result LCIA of Endpoint impact categories, resources.

3.2.4 Endpoint impact category, total score of endpoint impact

Figure 8 shows single result LCIA endpoint impact category for total impacts. This result shows that the operation process has 0.0600504 Pt and construction process has 5.55714 Pt, respectively.

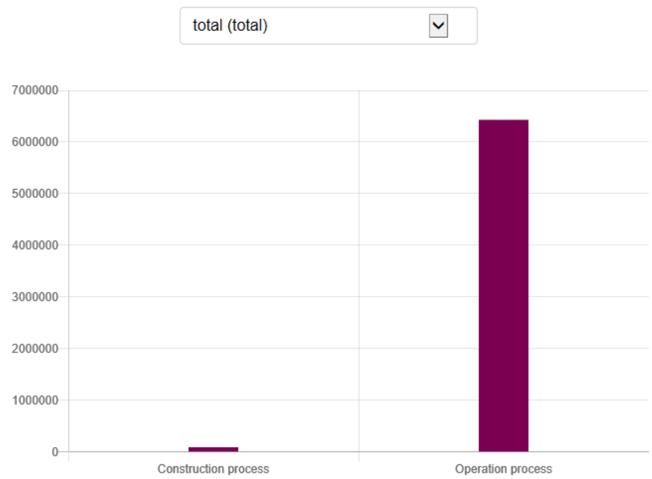

Figure 8. Single result LCIA of Endpoint impact categories

4. Conclusions

Ship industry mostly uses oil as the main fuel in generating propulsion by using combustion causes a lot of GHG emission that promotes climate change. shipping industry can cost a lot of energy and effect on environment. We can see the most problem of ship transport is associated with energy efficiency of ships. It is important to improve the ship energy efficiency and reduce the ship emissions. Various emission reduction measures have been proposed to reduce the ship emissions. Fuel efficiency also make a lot of effect to environments and management cost. From the analysis, we see that the major hotspot for environmental effect comes from the operational process. The results show that the operating part has given the highest value in climate change impact (GWP100) with 1.36048×108 kg CO2-Eq compared to the construction value in climate change impact (GWP100) with 1.70506×106 kg CO2-Eq.

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