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Local added value and environmental impacts of ship scrapping in the context of a ship's life cycle

Nathanael Ko*, Johannes Gantner

University of Stuttgart, Chair for Building Physics, Dept. Life Cycle Engineering, Germany

A R T I C L E I N F O

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A B S T R A C T

Globalization leads to an increase in goods transported by ships. Ships are scrapped once they have reached the end of their use. Over its lifetime a ship generates added value, which benefits the owner, and at the same time harms the environment through emissions. A certain imbalance in the distribution of the added value and the harm to the environment can be observed over the lifetime of a ship. The goal of this study is to depict and quantify this imbalance and give an evaluation indicator in order to transparently describe this issue. Methods used in this study are Life Cycle Assessment (LCA), for the quantification of the environmental impacts, local added value, for the quantification of economic impact and the method of eco-efficiency. A literature review was conducted in order to estimate the added value per life cycle phase. Finally these two factors were put in relation and the adjusted eco-efficiency indicator was developed. As result it can be seen, that especially the European owners of the ship during its use phase benefit the most, whereas the Asian producers and dismantlers of the ship have to suffer comparatively more environmental impacts per unit of added value.

1. Introduction and goal of the study

Within our current global economic system the majority of goods, including primary resources, intermediate goods and end-products, are transported by ships at one time or another. In order to satisfy the demand for transport there are about 170,000 cargo vessels (MarineTraffic.com, 2015) travelling the seas. The ship is a durable capital good which is built to produce the service of transport. It goes through a product life cycle including three phases: production, use and end-of-life (EoL). While the ship is providing its service in the use phase, it generates income for the owner and, at the same time, causes environmental impacts through emissions from the combustion of fuel. The other two life cycle phases also generate income and emissions to the environment. According to the previous work (Ko and Gantner, 2015) however, they appear to be not relevant, yet within the end-of-life, i.e. decommissioning and dismantling, of ships significant impacts to the environment and people involved are observed.

Goal of this study is to show a distribution of added value per impact on the environment over the life cycle of a ship. This is done through the combination of environmental impacts, which are generated from a Life Cycle Assessment (LCA), with the local added value. The applied concept in this study is similar to the eco-efficiency method and is called the adjusted eco-efficiency. This concept is applied in order to answer the following questions: How are the environmental impacts of a ship's life cycle distributed and how much money does each phase yield in return? An answer to this question might be interesting for committed ship owners, who look beyond their own business case and also politics or NGOs in order to push for new business models which take into account a more holistic view on a ship's life cycle. The presented approach might also support decisions about compensation measures, if such measures are deemed necessary.

2. Methods and data

Within this chapter the definitions for Life Cycle Assessment (LCA), local added value and eco-efficiency are provided and the data basis for this study is laid out.

2.1. Life Cycle Assessment (LCA)

The LCA is a method defined in ISO 14040 (European Committee for Standardization, 2009). LCA takes into account the inputs (material and energy) and the outputs (emission and waste) over the whole life cycle of a product, a system or a service. The results used in this study are based on a LCA study on ships (Ko and Gantner, 2015). The functional unit is 1 ship with a light displacement tonnage (LDT) of 4108.4 over the lifetime of 25 years.

* Corresponding author.
E-mail address: Nathanael.Ko@lbp.uni-stuttgart.de (N. Ko).

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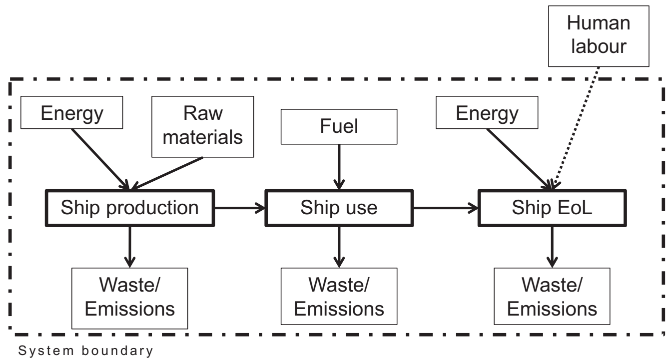

Fig. 1. System boundary for the LCA with elementary flows crossing the system boundary.

Fig. 1 depicts the system boundary which includes the three life cycle phases "ship production", "ship use" and "ship end-of-life (EoL)" and the inputs and outputs associated with each individual life cycle phase. The factor of human labour is not included in this study as its assessment poses a set of other challenges and questions, such as the quantification of damages to the human health in ship scrapping. This issue remains open for further research, as it is of great importance, especially in regions such as Bangladesh, India and Pakistan where the decommissioning and dismantling of ships is heavily relying on manual labour.

The previous LCA model (Ko and Gantner, 2015) was used and following updates were applied:

- No environmental credit is given for EoL treatment of the ship.
- More details on local emissions were added for the EoL.

In contrast to the previous study, no credits were given for the materials gained from decommissioning and dismantling of ships in order to have a distinct attribution of environmental impacts to each life cycle phase. Further, more details on energy consumption and emissions of the ship dismantling process were added to the LCA model, which was implemented in the software and database GaBi ts (thinkstep AG, 1992–2015). The data refer to the functional unit as defined above and are summarized in Table 1.

The following impact categories for the assessment in this study are chosen:

- ReCiPe 1.08 Midpoint (E) – Climate change, incl. biogenic carbon [kg CO_2-Equivalents] (ReCiPe Mid, 2012)
- USEtox, Human toxicity, non-cancer (recommended) [CTUh] (Rosenbaum et al., 2008)

A mid-point indicator, describing the potential environmental impacts on global warming in [kg CO_2-Equivalents], is taken from the egalitarian (E) perspective, which is "the most precautionary perspective, taking into account the longest time-frame impact types that are not yet fully established but for which some indication is available" (Goedkoop et al., 2012). A toxicity indicator describing potential non-cancerous effects on human health expressed in [CTUh] (comparative toxic units, human), i.e. "providing the estimated increase in morbidity in the total human population per unit mass of a chemical emitted" (Rosenbaum et al., 2008), is used to include the impacts to human health in general. Yet, the local impact on human health due to the manual labour from ship breaking cannot be covered with this indicator. These two indicators are chosen to give a broad assessment, by taking into account a global environmental problem, such as global warming. The effect on human health is addressed through the toxicity indicator, whereas the mid-point indicator gives an overall view on the potential harm resulting from the different life cycle phases. This broad assessment also allows the comparison among the life cycle phases where each phase has its specific environmental impacts.

2.2. Local added value

The local added value in this study is defined in a simplified manner. In this simplified context each life cycle phase is one "location" where material is processed or the ship is used. The production phase is mainly located in south-east Asia, including South-Korea, China and Japan (MarineTalk, 2006). The use phase is dominated by European companies as ship owners (Abendblatt, 2014), whereas most of the ship scrapping is done in south Asia (Puthucherril, 2010; Kumar, 2011). During the run-through of the value chain, "value", in the monetary unit of Euros [€], is added in every location. Fig. 2 depicts the assessment boundaries, for which the "local added value" was determined.

Within the first location, the ship production, three stages are identified where value is added through activities such as material processing, assembly, research and development: the material extraction, the production of intermediates and the final assembly of the ship. The data acquired for the individual materials in stage 1 is rather detailed, whereas no data was available for "miscellaneous" material. Stages 2 and 3, which also include the added value of research, development and design of the ship are summarized in Table 2 and are assumed to be the difference between the cost of material and the final price of 12,452,795 € (based on Täglicher Hafenbericht, 2015; Svante Domizlaff, 2013) at which the ship is sold. Based on the data, it could be possible to make a more detailed assessment of the ship production itself and the added value in each phase, but for the purpose of this study the total added value for the ship production is assumed to be the selling price of the ship.

At the second location, during the use phase of the ship, the total added value over the lifetime of 25 years amounts to 38,573,614,468 €, which includes the added value for fuel (bunkerworld.com, 2015), maintenance (Greiner, 2011), port dues (Springer Fachmedien München GmbH, 2012) and transported goods (DFS Worldwide, 2015).

The added value for the third location, the end-of-life of ships, is 156,637 €. This is calculated using the difference between the reselling value of the materials, which is assumed to be the same as described in Table 2 (sum of Stage 1:1,553,927 €) and the price at which the decommissioned ship is bought (in this study 352 €/LDT

Table 1
Data on ship dismantling process for LCA modelling.

Type of data	Description	Amount	Unit	Calculations based on
Energy	Electricity for dismantling (assumed to be comparable to ship building)	315,266	kWh	Kameyama et al. (2004)
Emission	Residue diesel oil	24,651	kg	Kumar (2011)
Waste	Polychlorinated Biphenyl (PCB) from plastics and cable	3250	µg	Kumar (2011)/Andersen et al. (2000)
Waste	Asbestos	219	kg	Kumar (2011)
Waste	Antifouling paint	8217	kg	Young Power in Social Action (2012)
Waste	Glass wool	2500	kg	Kumar (2011)