Life Cycle Assessment as a Prerequisite Tool in Maritime Industry

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ABSTRACT

The current state of the environmental protection awareness and the possible impacts associated with the products' manufacturing and consuming stages, has led to the need for the development of advanced environmental assessment methods and tools, in order to comprehend better the way of reducing these negative impacts. One of these techniques, in response to this demand, is Life Cycle Assessment, which can assess the environmental aspects and potential impacts associated with a product, compiling an inventory of relevant inputs and outputs of a system. Life Cycle Assessment can also interpret the results of the inventory analysis and impact assessment phases, in relation to the objectives of each study. In the current study, the environmental footprint of a barge tanker during the most stages of its life cycle has been assessed via the SimaPro 8 software. For this reason, the Ecoinvent database has been used, whileone tanker unit has been chosen as functional unit. The life cycle of the tanker concerns its construction. It is mandatory to study not only the environmental impact of the emissions due to fuel consumption, but also the materials used during the construction and maintenance of the ship, e.g. coatingsfor the external protection of the ship's hull, which may have negative effects on the aquatic environment. For this reason, particular emphasis has been given on the antifouling coatings that consist of a variety of substances, including cuprous oxide and several organic biocides; these may be dissolved in seawater and cause severe effects on flora and fauna, due to their ability to bio-accumulate. The identification and quantification of the environmental impact of all raw materials and the assessment of the production processes can lead to the development of advanced coatings with minimal environmental impact to marine ecosystem and people; towards this, Life Cycle Assessment assists in identifying opportunities to improve the environmental aspects of products or processes at various points in their life cycle, as decision making (e.g. design or redesign) for instance. However, the information developed in a Life Cycle Assessment study should be used as a part of a much more comprehensive decision process or for understanding the broad of general trade-offs about the environmental impacts.

INTRODUCTION

The transportation sector is an important contributor among industrial activities. Maritime transport of goods is currently gaining relative weight with respect to air and road transport due to the fact that is a relatively clean form of transportation per kilogram of material (Grewal and Haugstetter 2007, Micco and Perez 2001). This form of transportation has also been increased (expected to continue increasing in the future) due to the globalization of manufacturing processes and the growth of global-scale trade. As a result, certain types of emissions have been

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increased; causing severe impacts on human health, climate and ecosystems.Therefore, the assessment of shipping emissions on the global and regional scales is of great interest.

The emissions from maritime industry can be categorized to those that are related to fuel consumption and those that are relevant to the coatings used for the protection and maintenance of the ships' structure. In recent decades the paint systems used in shipbuilding have undergone enormous development in correspondence with emerging regulations and legislation, especially those related with protection of the environment and of human health. The reduction of VOCs and the elimination of the toxic andcarcinogenic components from traditional paint products were attempted (Almeida, Diamantino and de Sousa 2007). However, the antifouling coatings that are used for the hulls'protection still have a detrimental impact on the ecosystem.

Due to the increased awareness for the environmental protection from all the possible impacts associated with products manufactured and consumed, a demand for the development of methods to better comprehend how to reduce these negative impactshas arised. One of the techniques developed in response to this demand is Life Cycle Assessment (LCA). LCA is a method that became popular in the early nineties. By this method it is possible to determine and quantify the environmental impacts of a process or a material. In the current study, emphasis will be given on the impacts that are related to coatings used for the hull protection of a barge tanker.

COATING SYSTEM FOR SHIP PAINTING

The subsequent painting of ships during and after construction is a highly complex technology; each surface requires unique treatment. It is hard to combine all the requirements for any surface within one paint; thus, multi-coat systems are essential. (Lambourne 1987, Weismantel 1981). Modern paint systems for the ship hulls, typically include a two-pack epoxy primer (Almeida, Diamantino and de Sousa 2007). Primer coatings are used mainly to provide an adhensive bond between the substrate and the complete coating system. If inhibitive pigments, such as zinc oxide, are present, it is also possible to obtain anticorrosion properties. Epoxy resins are good candidates since they have excellent physicochemical properties and are compatible with the wide range of topcoat vehicles. Anticorrosive or barrier coatings present a physical barrier between moisture and metal. Their effectiveness is related to film thickness (Weismantel 1981). As a barrier coat, usually a chlorinated rubber anticorrosive primer is used which contains anticorrosive pigments such as aluminium and also extender pigments (e.g. TiO_2) and talc (Lambourne 1987, Weismantel 1981). Finally, the topcoat in this case, is an antifouling paint with soluble matrix. These coatings act by simultaneous removal of both toxicant and matrix (which is a resinous vehicle) and especially gum rosin with main substance the abietic acid (Weismantel 1981). For all the other parts of the ship e.g. topsides and superstructures, a variety of coatings can be used. The simplest system however, comprises of an alkyd primer and an alkyd enamel over it (Lambourne 1987).

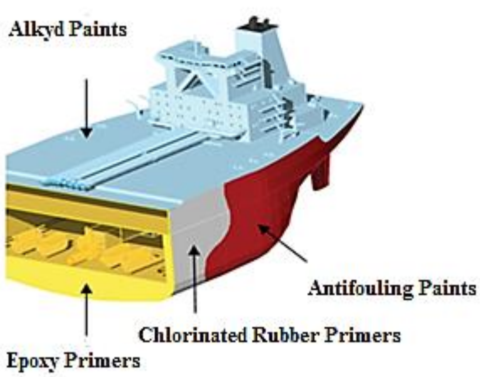

Figure 1 Different coatings used for the ship structure painting.

LIFE CYCLE ASSESSMENT METHODOLOGY

Life Cycle Assessment is a technique for assessing the environmental aspects associated with a product over its life cycle, i.e. from raw material extraction over production, distribution and use to waste management. It sets out to cover all environmental aspects relevant for a specific production system; it includes. The analysis of the contribution of the life cycle stages to the overall environmental load and the comparison between products for internal or external communications by compiling an inventory of relevant inputs and outputs of a system is rather critical. Life Cycle Assessment provides quantitative and scientific basis for all the new concepts, concerning products and business processes by interpreting the results of the inventory analysis and impact assessmentphases in relation to the objectives of the study. Moreover, LCA is an internationally standardized methodology. It evaluates the potential environmental impacts associated with those inputs and outputs according to two ISO standards; the ISO 14040: Principles and Framework, and the ISO 14044: Requirements and Guidelines (ISO 2006).

First of all, in order to conduct the LCA, the unit of assessment, termed the functional unit, shall be specified and shall reflect the function of the product. Secondly, the following stages should be incuded:

1. Goal and Scope definition
2. Inventory
3. Impact assessment
4. Interpretation

Life Cycle Assessment is an iterative process because early steps often need to be revisited after the first results are obtained. Goal and scope means framing the study in terms of setting the boundaries and defining the product to be studied as well as the types of environmental impacts to be covered. Data inventory means collecting data on inputs and outputs of every activity involved in the production system. Impact assessment translates the aggregated resource use into emissions which are weighted together into impact categories to which they contribute (e.g. Global warming, Eutrophication, Acidification, Aquatic ecotoxicity etc.). Various impact assessment methods are used to calculate impact assessment results. In the current study, ReCiPe method (Goedkoop, et al. 2013) was used due to the most appropriate impact categories that includes. Interpretation involves drawing conclusions from the results in relation to e.g. data quality and performing a sensitivity analysis, possibly resulting in a second iteration of refining important data used. Life Cycle Assessment is a tool used for product development, policy-making and as a basis for certification both by companies and by public organizations on a voluntary basis (CHANGE 2014).

GOAL AND SCOPE

Goal

The goal of this study was the environmental impact evaluation of the water soluble compounds existing in the used marine coatings and especially the antifouling coating that are released during the operation of a barge tanker.

Scope

The scope of the study describes below the most important methodological choices, assumptions and limitations.

ReCiPe Method. ReCiPe is the successor of the methods Eco-indicator 99 and CML-IA that integrates the 'problem oriented approach' of the former and the 'damage oriented approach' of the latter. The 'problem oriented approach' defines the impact categories at a midpoint level with a relatively low rate of results' uncertainty. However, this solution leads to many different impact categories, which makes the drawing of conclusions much more complex. On the other hand, the damage oriented approach of Eco-indicator 99 results in only three impact categories, which makes the interpretation of the results easier, yet with higher uncertainty. ReCiPe implements both strategies and with the multiplication by damage factors from midpoint, one could obtain the endpoint characterization values and vice versa.Generally, at the midpoint level, eighteen (18) impact categories are included but in our case only ten (10) of them will be anylized due to their importance to the marine environment. At the endpoint level, most of these midpoint impact categories are multiplied by damage factors and summarized into three endpoint categories that are normalized, weighted, and aggregated into a single score:

1. Human health, expressed as the number of year life lost and the number of years lived disabled. These arecombined as Disability Adjusted Life Years (DALYs), an index that is also used by the World Bank and WHO. The unit is years.
2. Ecosystems, expressed as the loss of species over a certain area, during a certain time and the unit is also years.
3. Resource surplus costs, expressed as the surplus costs of future resource production over an infinitive timeframe (assuming constant annual production), considering a 3% discount rate. The unit is 2000US$.

The impact categories above, as shown in Figure 2, along with their correlation to the endpoint categories are climate change (human health and ecosystems), human toxicity, ozon depletion, marine ecotoxicity, sources depletion, photochemical oxidant formation and freshwater contamination.

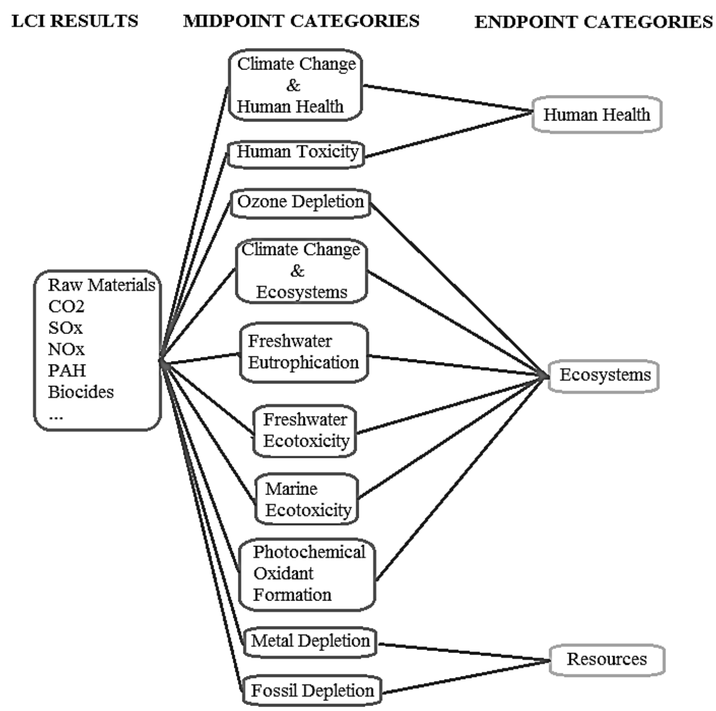

Figure 2 Representation of the relations between the inventory, the midpoint categories and the endpoint categories (Goedkoop, et al. 2013).

To ease the doubts arising from the relations governing the midpoints and the endpoints, different sources of uncertainty and different (value) choices were grouped into a limited number of perspectives or scenarios (Thompson 1990). Three perspectives are discerned, namely, the individualist (I), the hierarchist (H), and the egalitarian (E) that are merely used to group similar types of assumptions and choices. The perspective I is based on the short-term interest. The perspective H is based on the most common policy principles concerning the timeframe and other issues and the perspective E is the most precautionary perspective, taking into account the longest timeframe, impact types that are not yet fully established but for which some indication is available.

Functional Unit. The functional unit of this study is one barge tanker, with total capacity of 1200000 kg (1322.77 ton) (DWT). For paints, the functional unit could be a liter of paint or the coverage of a certain area over a certain period of time (m^2year or ft^2 year). The functional unit could also be related to the purpose of using the paint, like keeping the boat free from fouling in the example of antifouling paints. In this study, the functional unit for the paints' LCA was chosen to be the 100kg (220.5 lb), as the formulations are known in % percentages.

System Boundaries. In this study, the environmental footprint of a barge tanker was investigated during the construction and the operation. The maintenance and the final disposal are excluded as the barge tanker operates for two years. It is considered that the tanker operates in the time horizon of two years. The port facilities, the canal in which the barge tanker transports and the production stage of the used marine coatings, are not taken into account. Also, energy consumption during production of the paints, their packaging and the transportation to the shipyard are excluded.

Assumptions and Limitations. It was assumed that the barge tanker has specific dimensions, as shown in Table 1 and Figure 3. For the painting of the hulls of this barge tanker, it was assumed that three layers of coating were necessary with DFT 250 10^{-6}m (0.0098 in), 50 10^{-6} m (0.0019 in) and 200 10^{-6}m (0.0079 in) for the epoxy primer, anticorrosive primer and antifouling paint, respectively. For simplification purposes, the calculation of the coatings' quantity needed for the painting of the barge tanker followed flat geometry in shape of a rectangle. The fuel consumption is exluded due to the lack of data for the operation period. Correction factors were taken into account according to literature (HEMPEL 2010). Some of the paints' substances did not exist in the software databases and as a result, similar ones replaced them. Moreover, it was conjectured that every one of the water - soluble compounds of the coatings were released in seawater for the operating time period, especially for the external layer (antifouling coating). Finally, weighting factors for the inventory analysis were not taken into account.

Table 1.Barge Tanker Characteristics

Dimensions	SI units	I – P units
Length overall	60.00 m	2362.21 in
Breadth moulded	15.60 m	614.17 in
Depth	6.00 m	236.22 in
Draft	4.50 m	177.17 in
Deadweight	1200000kg	1322.77 ton

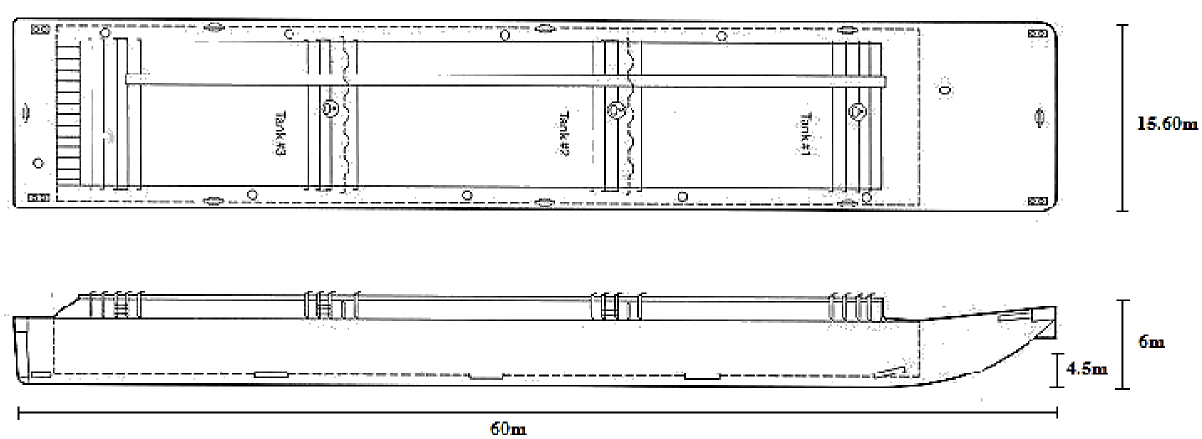

Figure 3 Schematic representation of the main dimensions of a barge tanker (Maritime Reporter 2012).

LIFE CYCLE INVENTORY

SimaPro 8 commercial software was used for LCA. Transport starts with the production of one barge tanker and the service of the energy used. A 2-year time frame is considered, assuming that the ship is painted once during that time. Data of the energy use and combustion emissions are excluded. As shown in Figure 4, emphasis is given to the coatings used for the painting of the barge tanker. For each of the coatings, resins and solvents are the main factors that are taken into account for the impact assessment.

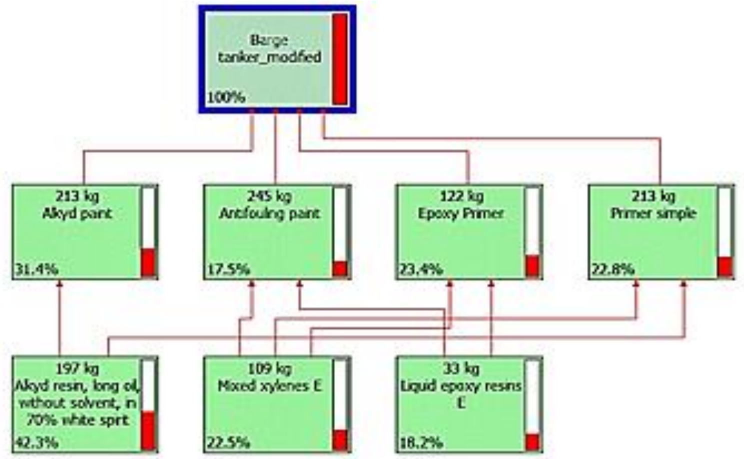

Figure 4 Flow diagram of the different processes and materials used for the painting of a barge tanker.

After the Life Cycle Inventory (LCI) analysis, the endpoint results arise. Three main impact categories are taken into account (human health, ecosystems and resources), as shown in Figure 5. Antifouling coating contributes in all categories, with special emphasis in human health and resources. On the other hand, alkyd coatings (primer and paint) exhibit higher impact in ecosystems. The impact of the other two primers (epoxy and chlorinated rubber) is lower, as they do not contact seawater directly (inner layers).

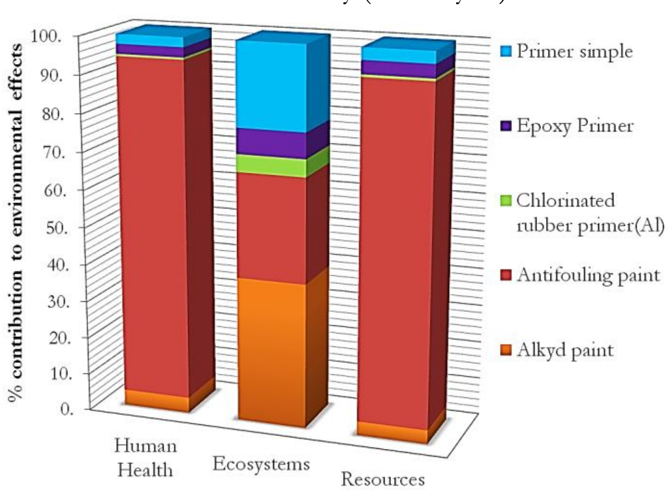

Figure 5 LCA assessment results, calculated by the method ReCiPe Endpoint (H) V1.11 / Europe ReCiPe H/H-Damage Assessment.

The midpoint results of the impact assessment are shown in Figure 6. As it obvious, antifouling coating has a crucial role in the marine ecotoxicity impact; its contribution is represented with the red colour in the column diagram and it almost reaches the 100% of the cumulative column. Furthermore, its effect is evident in all impact categories. Specifically, the cuprous oxide (Cu_2O) included in the antifouling coating, is toxic both for humans and flora-fauna of the marine environment (Turner 2010). Moreover, for the production of Cu_2O, metallic copper should be used; for this reason metal depletion occurs. All the other metals used both for construction of the barge tanker and the production of the coating, contribute in this impact category. Fresh water eutrophication is caused due to the zinc phosphate of antifouling coating. All the other coatings used have lower impact to the environment.

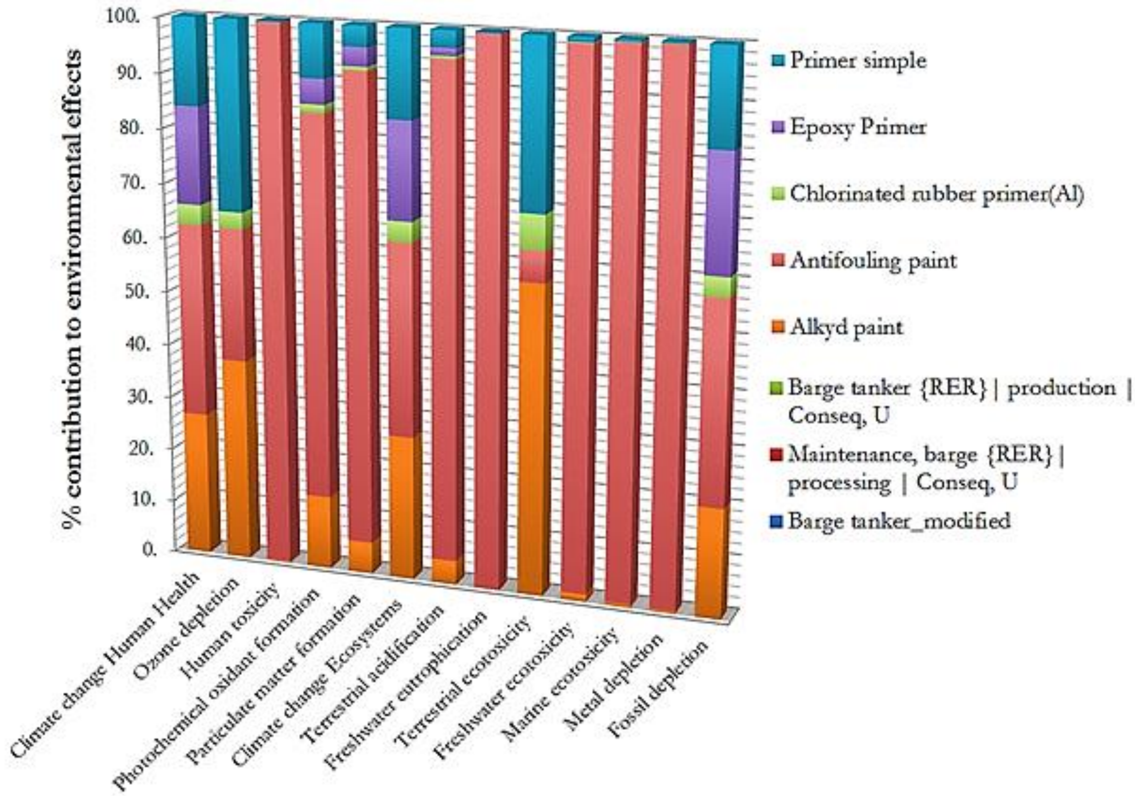

Figure 6 LCA assessment results, calculated by the method ReCiPe Midpoint (H) V1.11 / Europe ReCiPe H/H-Damage Assessment.

CONCLUSIONS AND FUTURE RECOMMENDATIONS

The results that came from this study indicate the need for replacing the toxic compounds that are included in marine paints. Especially, the antifouling coating contains both biocides and metal oxides that are harmful for humans and the marine environment. Regarding human toxicity, this could affect not only the maritime workers, but also all the involved individuals in the coating production industry. As far as the ecosystem toxicity, it is important to develop innovative coating systems with antifouling activity, but with fewer bioaccumulative effects in higher organisms. Then, it is interesting to investigate the alteration to fuel consumption, assuming that by using an ideal antifouling system, fewer fouling would take place so the fuel consumption and the emissions due to the compustion would be lower.

Life Cycle Assessment is one of several environmental management techniques and may not be the most appropriate technique to use in all situations. It is recommented to use the information developed in an LCA study as part of a much more comprehensive decision process or to understand the broad of generaltrade-offs. Comparing results of different LCA studies is only possible if the assumption and context of each study are the same. However, LCA may contribute to decision making, comparing different production routes and materials. It is a prerequisite tool in every industry and it could be an integral part of safe-by-design management.

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NOMENCLATURE

LCA	=	Life Cycle Assessment
LCI	=	Life Cycle Inventory
DALY	=	Disability Adjusted Life Years
I	=	Individualist
H	=	Hierarchist
E	=	Egalitarian
DWT	=	Deadweight tonnage
VOC	=	Volatile Organic Compound
DFT	=	Dry Film Thickness

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