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From LCC to LCA using a hybrid Input Output model - a maritime case study

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Abstract

As companies try to embrace life cycle thinking, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) have proven to be powerful tools. In this paper, an Environmental Input-Output model is used for analysis as it enables an LCA using the same economic input data as LCC. This approach helps align LCA and LCC while avoiding cut-offs in the LCA. The efficacy of the method is illustrated by a real case study of a tanker ship.

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Keywords: LCC; LCA; shipping; Environmental Input Output, Life cycle thinking;

1. Introduction

It is of paramount importance for modern businesses to stay competitive through efficient and responsible resource management. Taking a life cycle perspective can support sustainable decision-making, with Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) being the dominant tools for addressing costs and environmental burdens, respectively. Previous research on combining LCC and LCA has primarily focused on how the *results* of the two studies can be combined to support sustainable decision-making. This research has its origin within the LCA community, with a strong focus on adding LCC as the missing economic pillar in an LCA [1],[2]. However, what is the potential of using LCC as an offset for conducting LCA? In many contexts, an LCC is performed to evaluate options identified as part of an assessment for more sustainable decision-making support [3]. Offering a setup, where an LCC relatively easy can be translated into an LCA might help include environmental considerations into the framework.

Furthermore, LCC and LCA are traditionally performed in parallel with LCC focusing on cost and benefits, and LCA focusing on use of physical resources such as mass and energy [1]. In this paper, we investigate how LCC and LCA can be integrated by using the same - financial - inventory data. LCA and LCC usually require a great commitment of resources to collect and analyze data and the proposed methodology helps run the joint economic and environmental analysis faster, whilst at the same time aligning the two analyses and avoid cut-offs in the LCA.

The method used to translate LCC into an LCA is based on environmental input-output (EIO) LCA, where sector-specific economic inputs are used to estimate the environmental impacts, including the global supply chain impacts. The EIO model used is a so called hybrid database, meaning that for material and energy uses, the model translates the economic inputs into physical units. Therefore, wherever data on physical quantities are important and available, such as fuel, energy and some material consumption, these are used directly in the model.

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The aim is to provide a relatively quick screening of environmental hotspots, which might be used for a) including environmental performance in decision making without having to conduct a full, traditional LCA and/or b) as a starting point for further analysis of the identified hotspots. The method is demonstrated on the analysis of a group of tanker ships and results are shown for one case ship. The result of the LCA is expressed in CO_2 equivalents, thus only the contribution to global warming is presented in this paper.

LCA has previously been used as a decision making tool for ship design [4,5][6], evaluation of retrofit technologies [7], and comparison between fuel types [8]. EIO analyses in the maritime sector can also be found in the literature [6][9], however none of these studies are fully integrated with LCC of a ship as presented in this paper.

The outline of the paper is as follows: section 2 describes the case under study including the key facts and assumptions on which the study was based. Section 3 explains LCA and LCC modelling and the case results are presented in section 4. Finally, section 5 discusses the method and gives an outlook to future work.

2. Case introduction

The focus of the analysis is on a group of 5 Medium Range (MR) tankers carrying clean petroleum products such as naphtha, gas oil, jet fuel and biofuels. The ships under study are “sister vessels” since they share the same design and were built by the same shipyard. They do not have a fixed itinerary and are operated worldwide, depending on where they can find cargo in a market segment known as tramp shipping [10].

The shipping industry is capital intensive industry characterized by long term investments [10]. It is particularly sensitive to fuel prices which increased by nearly threefold between 2005 and 2012 [11]. At the same time it is subject to ever tightening local and global environmental regulations [11].

For shipping, greenhouse gas (GHG) emissions account for approximately 3.1 % of global emissions contributing to global warming [12]. Other emissions of importance are sulphur and nitrous oxides from burning fuel oils [11].

Other environmental aspects not included in this study but worth mentioning are: ballast water exchanges affecting the maritime environment, release of biocides from antifouling paints, oil spills, waste and sewage handling and hazardous materials released in ship scrapping [13]. Various IMO regulations address all these issues [11], but with the shipping industry continuing to be absent from international climate conventions, GHG can be considered the least regulated area. Based on this argumentation and for the sake of simplicity, only GHG emissions are presented and discussed in this paper.

For a tanker ship, the functionality is the transport service, which can be expressed in tkm (amount of cargo transported over a distance). In the case study, the functional unit is one average year of ship transport service, and the reference flow is therefore the total amount of tkm per average year, with the subsequent option of expressing the results per tkm.

The operational lifetime of a tanker vessel can be divided into 4 consecutive periods of five years. At the end of each period the ship is put into a dry dock for repaint, inspection and hull repairs. At the end of the 20 years and before the last dry docking the vessel is usually sold for scrap as it becomes difficult to find customers who will trade with the vessel.

Our assessment is based on data from the first five years of the vessels’ operational life, including the first dry docking of the vessels. We have assumed that the first five years are representative for the next 3 cycles of operation before the ship is scrapped. This is due to the fact that within this 20 year period the ship has the same operational profile, which does not depend on the age of the vessel and the ship is maintained continuously according to the makers’ specifications. Table 1 summarizes the key facts on which the LCA and LCC is performed.

Table 1. Ship specification

Life cycle attributes	
Production site	China
Production year	2008
Suppliers’ location	Worldwide
Purchase price	47,000,000 USD (2008)
Capital costs	None, ship was financed on cash reserves
Estimated life time	20 years
Tkm supplied in one average year (reference flow)	2.87 E+09
Ship flag	Danish International Registry
Ship size	Lightship weight equal to 11,146 tons, Net Registered Tonnage equal to 15,937, Deadweight tonnage equal to 49,999
Scrapping location	India

3. Method

3.1. EIO modelling and database used

An economic IO table states, in average monetary terms, how much a sector buys from all the other sectors, for each unit produced in the sector [14]. The IO table can be extended with direct emission data and average resources for each sector. This Environmental extended IO table (EIO) makes it possible to calculate the life cycle impacts per monetary unit spent for each sector output.

In contrast to the “Bottom Up” approach of traditional process-based LCA, which entail potential cut off errors and time-consuming data collection [15], an EIO analysis offers a “Top Down” approach capable of capturing impacts from the entire supply chain. However, the method is also criticized, mainly due to the aggregated nature of many of the IO table’s sectors, thus creating the need to hybridize with “bottom up” data where the generic EIO model is judged to be too coarse [16].

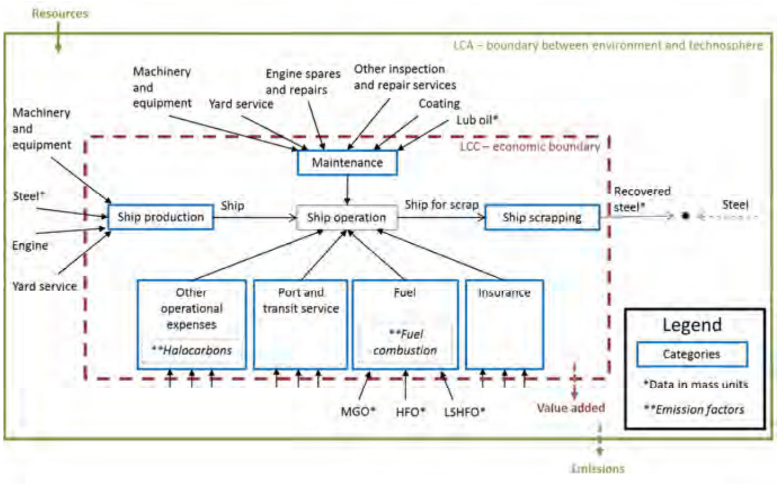

Fig.. 1. Flow chart

The EIO database used in the case study was based on research done in the 6th European Union Framework Program. The research project was called FORWAST and is documented in literature found at the project webpage [17]. The database can be considered a hybrid database, since the Input-output analyses has been fully integrated with mass flow analyses. The transactions in the model are thus in different units: dry matter (kg) for physical products, energy units for electricity/heat/steam, and monetary units for services. The database distinguishes between different waste fractions and various methods of waste treatment: recycling, incineration and landfilling. Waste streams are determined by mass balances for each sector. The reference year of the model is 2003 and it reflects the Danish market with tables for EU and Rest of the World (RoW) for imported flows. A number of the 137 sectors in the original project database have been disaggregated, so that the database used in this study contains data for more than 150 sectors.

3.2. LCC methodology

As mentioned in the introduction, LCC can provide the basis for LCA. But for the economic and environmental analysis to be aligned, the two must have consistent user perspectives. In order to ensure that, we conducted an environmental LCC (eLCC) which is the only type of LCC consistent with ISO 14040 [18]. eLCC assesses all costs associated with the life cycle of a product that are directly covered by 1 or more of the actors in the product life cycle with the inclusion of externalities that are anticipated to be internalized in the decision relevant future [19]. It expands the conventional LCC by requiring inclusion of all life cycle stages and separate non-monetized LCA results, with the perspective of one or more market actors. It should be mentioned, that in this analysis no future externalities are included.

In this paper the product under study is a Medium Range tanker ship and Figure 1 shows how cash flows were allocated to life cycle stages and categories. The figure also shows how the economic boundary for LCC is different from the boundary in LCA. In order to provide data for conducting the LCA, we therefore needed to collect data for the whole life cycle including the background system. Analysis of the cash flows is principally based on primary data, as they were documented in the account structures of the case company while market data relied on various sources of industry statistics. In calculating life cycle costs, eLCC does not simply add all incurred costs, as a cost for one actor is revenue for another and adding all of them would result in double counting. In absolute values, life cycle cost is equal to the total added value by all actors during the life cycle [18].

Added value is defined as the value of output minus the value of all intermediate inputs, representing therefore the contribution of, and payments to, primary factors of production [20]. The price for a given process input (e.g., material, component, and service) can serve as a measure for the aggregated upstream added value [18] while value added downstream can be determined using the IO table. For example, to evaluate the value added from ship breaking that is shown in Figure 2, we calculated the shipowner's revenue from selling the vessel and we used the percentage of the value added in the total cost from the EIO sector "Transport equipment n.e.c." which includes ship breaking.

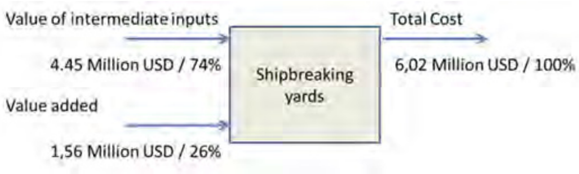

Fig. 2. Calculation of downstream added value for ship breaking

To allow for comparison between costs incurred in different years, all costs were adjusted to 2008 prices based on the new-building rate. The-new-building rate expresses the relative changes of the price of newly delivered ships and is an appropriate measurement for inflation since it determines the replacement cost of the ship [21]. For MR tankers rates were approximately -6.4% in 2009, -22.7% in 2010, +8.8% in 2011, -5.4% in 2012, -8.6% in 2013 [22]. It should also be mentioned that beyond this price adjustment no discounting is applied.

3.3. LCA Method application

We used the cash flows from LCC as starting point for LCA. In total, we allocated more than 300 cash flows to the most representative sector in the EIO model. Since the American Dollar (USD) is the principal currency in shipping and the EIO model requires input in the currency EURO2003, all cash flows were turned into 2003 prices using inflation indexes and changed into EUROs based on the average exchange rate in 2003. Then purchase price was converted to basic price and for materials, dry weight commodity prices for the specific sector as provided by FORWAST were applied. For example, for the vessels' engine stores, which mostly covered hand tools, we used the average price that the sector "Transport by Ship" paid for "Fabricated metal products".

For inputs where data was accessible and price uncertainty high, we used physical units directly. These were: fuel, lub oil and steel in the ship production. For emissions from fuel combustion, we used specific emission factors for the different type of bunker fuels as provided by the environmental reports of the case company. Direct emissions reported by the case company include CO_2, NO_x, SO_2, CO, particles and halocarbons from refrigerants. In addition, emissions of CH_4, N_2O and NMVOC from incomplete combustion were estimated [12].

For ship production, we obtained an estimated production price for the specific type of ship produced in China in 2008, including estimations on the division between the costs for steel, engine, equipment and yard service. So, instead of using the EIO sector "Transport equipment n.e.c.", which covers manufacturing of different transport equipment including ships, we used a hybrid approach, modelling the yard service based on the service-categories in that specific sector, but replacing the material inputs with the more accurate sectors for steel, engine and equipment.

Costs during operation include Maintenance, Port and transit service, Insurance, Other operational expenses and Fuel. Since vessels operate worldwide, these categories are also regarded as a worldwide mix. For dry dock service, supplier invoices were used to divide the overall cost into subcategories in order to identify how much came from yard service, engine repair, new machinery, coating and other repair services. Some of the same subcategories are also part of regular maintenance. Therefore, Maintenance consists of both the regular five year dry dock service and other more continuous maintenance costs.

Port and transit service includes harbor fees, cargo handling, sludge disposal, inspections, canal dues etc. Other operational expenses include all crew costs such as wages, travel, training, food, uniforms and IT equipment. This category also includes consumables and deck, engine and cabin stores. Insurance costs cover deductibles and premiums paid for hull and machinery on board, loss of freight, war risks and accidents.

Vessels consume three types of fuel: Marine Gas Oil (MGO), Heavy Fuel Oil (HFO) and Low Sulphur Heavy Fuel Oil (LSHFO). HFO is the main fuel used for propulsion and electricity generation. MGO is a lighter distillate compared to the HFO and mainly consumed when the ship is in port. Finally, when sailing in Emission Control Areas (ECAs) in Europe and North America, ships are obliged to consume LSHFO [11]. From 2015, the requirement for low sulphur content in ECAs will be further tightened (sulphur content<1%), forcing the ships to use MGO in ECAs.

As mentioned, waste flows were modelled according to the FORWAST model. However, the recovery of the steel from the ship during scrapping was modelled separately with the assumption that 95 % of the steel is recovered, substituting virgin iron in the EIO model,

All calculations were performed in SimaPro [23], an LCA software capable of handling EIO databases.

4. Results

In this section we present the results for one ship from the sister vessels. We have chosen to present results for the ship which is most representative of the average vessel in terms of maintenance costs, tkm and fuel consumption. The analyzed ship produces 2.87 billion tkm per average year. The total GHG emission pr. year is 32 million ton of CO_2 equivalents (CO_2e), corresponding to 11.1 g CO2e/tkm. In Figure 3 the distribution between the categories from Figure 1 are shown for both CO_2e and cost. Fuel is the dominating contributor in both cost and GHG emissions. Ship production, Port and transit services and Other operational expenses are also considerable costs, but are not big contributors to the overall climate change impact.

The biggest contributor to GHG emission is CO_2 from fuel combustion. This accounts for 8.8 g CO_2/tkm, corresponding to 79.1 % of all GHG emissions. In total, fuel accounts for 88.9 % of the climate change impact, including combustion related emissions of CH_4 and N_2O (1.1%) and upstream emissions from fuel production (8.7%).

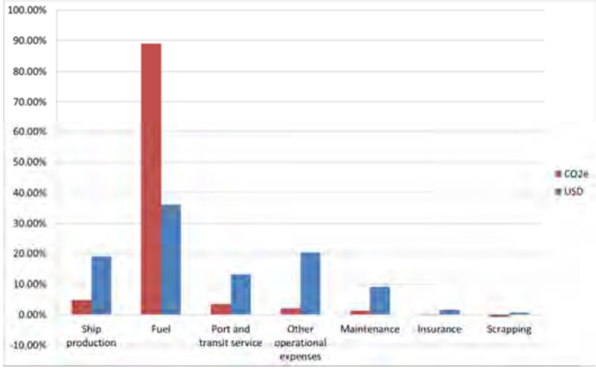

Fig. 3. Categories' relative share of CO_2e emissions and costs

In Figure 4, the relation between CO_2e and cost is shown, indicating which categories have the highest impact per spent USD.

We can see that cost categories with high service content such as insurance have low CO_2e per USD. Port and transit services are somewhat higher due to high costs for towage when in port. Scrapping is shown to have a negative CO_2e per USD because, as mentioned before, the scrap substitutes virgin ore in the iron production and therefore results in net avoided or ‘negative emissions’ to the environment.

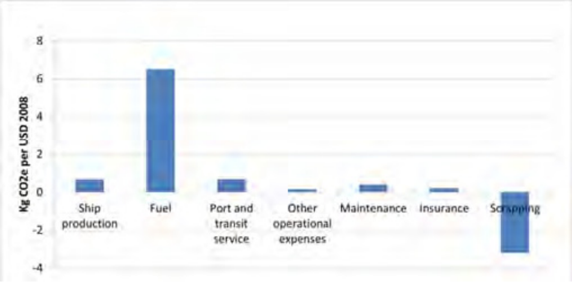

Fig. 4. Kg CO_2e per USD for each category

In Table 2, the EIO sectors with highest climate change impact are listed. The sectors contribute across categories, e.g. the sector “Machinery Disaggr: Mfr. of marine engines, compressors etc.” is used in both ship production and maintenance.

Sectors with less than 0.3% of the total impact are not shown in the table, but summed up in *remaining processes*.

Table 2. EIO sector contribution, cut off 0.3%

EIO sector	g CO_2/tkm	%
Refined petroleum products and fuels	0.965	8.66%
Transport by ship	0.308	2.76%
Machinery Disaggr: Mfr. of other general purpose machinery	0.190	1.70%
Iron basic, virgin	0.098	0.88%
Machinery Disaggr: Mfr. of marine engines, compressors etc.	0.080	0.72%
Cargo handling, harbours and travel agencies	0.089	0.80%
Air transport	0.055	0.50%
Recycling of iron basic	-0.094	-0.85%
Remaining processes	*0.41*	*3.66%*
Total	**2.10**	**18.83%**

The biggest contribution to upstream emissions is the production of the fuel (represented by the sector “Refined petroleum products and fuels”) followed by “Transport by ship” (mainly from tug boats and assisting vessels) and production and maintenance of machinery and equipment. Steel, used mainly for producing the ship, is contributing with 0.88 %; most of this is however recovered during recycling. Altogether, the results shows that about 19 % of the climate change impacts occur as upstream emissions in the value chain.

The analysis was built on data for the first five years of operation which were assumed representative of the whole life cycle. That is not the case however for maintenance costs, which are expected to increase as the vessel gets older [21]. To assess the effects of increasing maintenance, a sensitivity scenario was performed under which all maintenance costs were increased by 33% across the whole life cycle. As a result the USD/tkm increases by 2.9% and the CO_2e/tkm by 0.72%, indicating that the assumption is of minimal influence for the overall picture.

5. Discussion and conclusion

This paper has investigated the joint use of LCC and environmental input-output LCA for economic and environmental life cycle assessment of a Medium Range tanker ship. The analysis helped identify “win-win situations” which can contribute to the goals of sustainable development. Both LCA and the LCC show that fuel is the biggest impact.

The LCA showed that the indirect emissions are minor compared to the direct emission from burning the fuel. We have shown that focus on fuel savings in the shipping industry will have a greater environmental reduction potential than other cost-savings, e.g. on maintenance. It might not come as a surprise that fuel is the most important source of greenhouse gas emissions, and the results confirm what has been shown in previous LCA studies on ships [4][6]. However, the fact that even when including all indirect emissions, fuel related emissions are still dominating by several orders of magnitude can be used to justify that a shipping company’s main focus with regard to GHG emission should be on optimizing their own operation by saving fuel.

The life cycle model of the ship presented in this article might be further developed with a forecast concerning the next 15 years of operation. In the result section we took the first step by adding more maintenance costs based on how these typically develop over time. Other influencing factors to consider include fuel prices and fuel mix in the future. Use of MGO is likely to increase in the future, due to stricter regulations of SO_2 emissions from ships. MGO is more expensive and has slightly higher carbon content; however, the calorific value is also higher, resulting in a small decrease in fuel consumption. This entails similar GHG emissions from using the two types of fuel, however with use of MGO resulting in slightly less emissions [8]. The effect of these changes could be investigated further.

In this paper, we provided a preliminary demonstration of how an LCC can be used as a basis for an LCA and how the results can be presented together to support sustainable decision-making. The approach provides an understanding of which cash flows result in the largest environmental impacts. We see that in general, more service dominated costs have less environmental impact pr. USD. This way, the approach entails an understanding of the Return on Investment from an environmental perspective. Presenting the costs and environmental burden together shows where there are potential misalignments between the two and where there is a risk of external costs (e.g. pollution from fuel combustion) being internalized in the future (e.g. through taxes). For example, in the case study, Fuel accounts for 89 % of the CO_2e but only 36 % of the cost. With the likelihood of climate change continuing to be an increased societal issue in the future, there is a risk that fuel prices will rise – if not from a resource availability point of view then via the introduction of carbon taxes or other market-based measures. Thus, the LCA supports the LCC in decision-making by highlighting which initiatives (in this case fuel efficiency initiatives) are most sustainable on both short and long-term.

Using the LCC as starting point for the LCA ensures full completeness in terms of which processes to include in the study. The EIO methodology is a relatively fast way of screening which processes to consider as important from an environmental perspective, irrespective of where in the supply chain the impact may occur. Moreover, EIO assists the cost analysis since it can provide an estimate of the value added in processes for which data gathering is difficult or impossible. As an example, during the analysis we used the shipowner's revenue from selling the vessel to evaluate the value added from ship breaking. However, since the EIO category used here is much aggregated, containing many other industries than ship breaking, future work should include a better assessment of the value added during ship scrapping.

The method has the advantage that financial data is usually well documented and readily available within an organization. This makes the method suited for internal purposes, e.g. where the LCA is undertaken by or on behalf of an organization as part of a hot spot analysis. However, relying on internal and often confidential financial data limits the method to be used for comparison against competitors or other industries.

In the case study presented, all upstream emissions were based on the average data in the EIO model, meaning no supplier-specific data was used. The facts that (i) the model is based on the Danish market, (ii) sectors are aggregated, and (iii) the model is based on relatively old data (2003) result in higher uncertainty for the calculated upstream emissions. In this specific case study, this increase in uncertainty can be tolerated, since the upstream emissions are relatively small (18.8 %). Therefore, from the perspective of a shipowner, indirect emissions are of relatively low importance compared to the direct emissions. This might, however, be very different for other less energy-intensive systems. For other industries, where a larger part of the environmental burden occurs upstream in the supply chain, an environmental strategy might include initiatives aimed at reducing the suppliers' emissions. In these cases, the EIO approach must be supplemented with more precise data for the specific suppliers in order to reduce the uncertainty and enable decision-making support. This asks for further hybridization, where process-based LCA data are integrated with the EIO database processes. Future work could help explore this potential.

In regards to the shipping industry, future work could analyze the economic and environmental impact of services with fuel saving potential such as weather routing, route planning and hull & performance monitoring. Also the analysis could include other environmental impacts such as the impact of ballast water treatment and antifouling paint on ecosystems.

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