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Life Cycle Assessment as a complementary utility to regulatory measures of shipping energy efficiency

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ABSTRACT

The purpose of this paper is to document that LCA, aside from showing indication of compliance to both current IMO regulatory metrics (i.e. EEDI and EEOI) –not only as a practical environmental indicator, but also as a tool able to highlight energy efficiency–, can also be used in parallel to these, serving as a complementary utility able to assist with their practical implementation.

An LCA model formulation is summarised and also applied on a case study vessel, utilising it for validation, and additionally for comparing the LCA approach to the IMO regulatory metrics.

Results show that aside from the environmental score of CO2 emissions per unit of work –recognised by the current regulatory metrics–, LCA can also offer NOx and SOx scores, along with other hazardous releases. Moreover, LCA –aside from showing compliance to the formulation of both IMO regulatory metrics– is able to present material and energy utilisation throughout different stages within the vessel's lifetime.

Lastly, it is documented that LCA can be used in parallel to the regulatory metrics, in order to efficiently emphasise detailed environmental information. Furthermore, the implementation of LCA could be considered as a potential aid for the European Commission's recent MRV legislation.

1. Introduction

LCA is a methodology which has been constantly evolving for the past three decades (Guinée et al., 2011). What started out as a theoretical approach into the assessment of the potential environmental impacts of a chosen and predefined system, has developed into a highly pragmatic application, which could, additionally from the environmental standpoint, produce relevant impacts encompassing economic and social angles (Guinée et al., 2011; Weidema, 2006).

The methodology can also serve to identify environmental improvement opportunities within the different phases of the life cycle of a product or system, in turn providing prospects for product and process design or re-design. Most importantly, however, is the recognised potential of the tool to allow for the proper selection of a relevant indicator of environmental performance, including measurement techniques and indicator appraisal (ISO, 2006a, 2006b; PE-International, 2011).

As far as the shipping and shipbuilding and repair industry goes, LCA application extends from process or product design (Ellingsen et al., 2002; Koch et al., 2013), construction and repair or retrofitting (Blanco-Davis, 2013b; Fet, 1998), transportation and fishing (Fet and Michelsen, 2000; Utne, 2009), alternative power sources and fuels (Alkaner and Zhou, 2006; Bengtsson et al., 2012), onboard system assessment (Blanco-Davis and Zhou, 2014; Cabezas-Basurko and Mesbahi, 2012), and systems engineering and management (Fet et al., 2013).

The application of the methodology within this paper, however, is focused specifically at underlining LCA as an environmental perfor-

Abbreviations: A/F, antifouling paint; AIS, automatic identification system; Cd, cadmium; CFC, chlorofluorocarbon; CH_4, methane; CO, carbon monoxide; CO_2, carbon dioxide; CO_2eq, CO2 equivalent; EC, European Commission; EEDI, Energy Efficiency Design Index; EEOI, Energy Efficiency Operational Indicator; EPI, Environmental Performance Indicator; EVDI, Existing Vessel Design Index; FRC, Fouling Release Coating; GHG, Greenhouse gas; GT, Gross tonnes; GWP, Global Warming Potential; ISO, International Organization for Standardization; LCA, Life Cycle Assessment; MRV, EU system for monitoring, reporting and verification of carbon dioxide emissions from maritime transport; NO_x, nitrogen oxides; PM, Particulate Matter; Ro-Ro, Roll-on/Roll-off vessel; SFC, specific fuel consumption; SO_x, sulphur oxides

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mance indicator (EPI) for ships, which could additionally highlight and report energy efficiency. This has been briefly mentioned by Blanco-Davis (2014), and while in a different context than presented herein, also endorsed by Fet et al. (2013), relative to implementing EPIs on ships' life cycle designs.

2. Current energy efficiency metrics

2.1. Introduction

The aim to measure and improve energy efficiency within a ship, relative to an environmental context, is not novel. The discussion, however, has been intensified during the past decade; probably due to the harmonised advertisement from intergovernmental and global environmental organisations, with regards to the potentially irreversible downsides brought about by climate change. In 2013, for example, the Intergovernmental Panel on Climate Change remarkably underlined, in their IPCC's Fifth Assessment Report, that the current climate warming trends are highly likely to be induced by human activities (BBC, 2014; IPCC, 2013).

Following this trend, the shipping industry has reacted accordingly in order to strive to regulate shipping energy efficiency, and consequently reduce greenhouse gas (GHG) emissions. The International Maritime Organization (IMO), shipping's main regulatory body, has dedicated relevant efforts to develop technical and operational measures aimed at enhancing onboard environmental efficiency. These measures include the following:

- The Energy Efficiency Design Index (EEDI),
- The Energy Efficiency Operational Indicator (EEOI), and
- The Ship Energy Efficiency Management Plan (SEEMP).

Aside from these regulatory measures, other metrics have also been developed, voluntary in nature, and allegedly offering to cover the gaps of the previous. Examples of such metrics are the Existing Vessel Design Index (EVDI), developed by Rightship (2014), and the AIS-based performance metric proposed by Smith et al. (2013); the former offers an attempt to develop a single efficiency metric capable of being applied to new ship designs as well as to existing vessels, while the latter proposes separate formulations, not specifically in favour of a single or simplified energy efficiency indicator.

To add to the above mix of energy efficiency metrics, the European Commission has also decided to contribute with a regulation applicable to regulate CO_2 emissions within Europe –aimed at being applicable globally, however, if ultimately acknowledged–, establishing a regulation "on the monitoring, reporting and verification [MRV] of carbon dioxide emissions from maritime transport" (EC, 2013).

In its current form, the MRV regulation is applicable to all ships above 5000 GT calling into, out of, and in between EU ports, with an underlined entering-into-force date of July 1st, 2015, and with a reporting period starting on January 1st, 2018 (EC, 2013, 2015). The regulatory requirements highlight the monitoring of CO_2 emissions per voyage and on a yearly basis. It is relevant to point out as well that in the long term the MRV is aimed at addressing all emissions, including SO_x, NO_x and PM. The above can be similarly related to LCA, as a consolidated methodology that can offer a consistent account of GHG, SO_x, NO_x, and PM, among other emissions.

The problematic carried forward by the available performance measures underlines the issues of applicability within the different metrics (e.g. newbuilds and existing vessels), the incomparability or non-equivalency of the scores between them, the on-going discussion of a single metric approach, and their partial coverage and application, among other concerns. The last emphasises an evident prospect for a standardised alternative performance method –utilised as supplementary to the current regulatory measures–, and capable of not only highlighting energy efficiency but also serving as a widespread accepted environmental performance indicator, in order to strive to cover the inherited gaps of the regulatory metrics.

2.2. IMO energy efficiency regulatory measures

The following section includes a brief discussion into the actual regulatory metrics in place by IMO, i.e. the EEDI, the SEEMP and EEOI –and their implementation methodology–.

2.2.1. EEDI

The EEDI is based in the fundamental characteristic that fuel consumption is the most direct measure of energy use onboard. Similarly, CO_2 emissions are directly proportional to fuel consumption; therefore, as explained by Kedzierski and O'Leary (2012), the amount of CO_2 emitted by a ship can be calculated using the fuel consumption relative to that ship, and an emission factor relative to that fuel. Fuel mass to CO_2 conversion factors, additionally, have been established by the IMO for marine diesel, light and heavy fuel oils, liquefied petroleum and natural gas (IMO, 2014); thus, the CO_2 calculation is as simple as multiplying the fuel consumption by the carbon conversion factor (Kedzierski and O'Leary, 2012).

The full EEDI formula is specified by IMO (2014), and it includes various adjustment factors, applicable to specific types of ships and alternative configurations. The equation calculates the CO_2 produced as a function of the ship's transport-work performed (Lloyd's-Register, 2012), which is considered as the *attained* EEDI, and equates to a figure of grams of CO_2 over tonnes per nautical mile (gCO_2/tonne-nm).

By regulation, the attained EEDI shall be calculated for all ships of 400 gross tonnes (GT) and above (GL, 2013), defined by the types found in Table 1. A ship's attained EEDI must be equal to or less than the required EEDI for that ship type and size (Lloyd's-Register, 2012). The required EEDI –which is calculated for all ships using 100% of the deadweight (DWT) at summer load draft, except for passenger ships where GT is used (GL, 2013)–, is a function of the reference line value (see Table 1), defined by the following formula (see Eq. (3)): Required EEDI = a *(b)^(-c).

2.2.2. SEEMP and EEOI

The Ship Energy Efficiency Management Plan, in short SEEMP, is aimed at providing a potential approach for monitoring and optimising the ship and fleet –operational– efficiency performance over time (IMO, 2012). Although currently in voluntary form, IMO (2012) additionally promotes the use of the EEOI as a valid ship and/or fleet energy efficiency indicator, but also recognises other resources could be appropriate as supplementary. The last is of relevance, when consider-

Table 1
Reference values for calculating the required EEDI (GL, 2013), as adapted from (IMO, 2013a, 2013b).

Ship type	a	b	c
Bulk carriers	961.79	DWT	0.477
Gas carriers	1120.20	DWT	0.456
Tankers	1218.80	DWT	0.488
Container ships	174.22	DWT	0.201
General cargo ships	107.48	DWT	0.216
Refrigerated cargo ships	227.01	DWT	0.244
Combination carriers	1219.00	DWT	0.488
Vehicle/car carriers	(DWT/GT)−0.7 × 780.36 where DWT/GT < 0.3; (DWT/GT)−0.7 × 1812.63 where DWT/GT ≥ 0.3	DWT	0.471
Ro-Ro cargo ships	1405.15	DWT	0.498
Ro-Ro passenger ships	752.16	DWT	0.381
LNG carriers	2253.7	DWT	0.474
Cruise passenger ships having non-conventional propulsion	170.84	GT	0.214