Ocean Engineering 165 (2018) 480–487

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Systematic evaluation approach for carbon reduction method assessment – A life cycle assessment case study on carbon solidification method

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ARTICLE INFO

Keywords:
Life cycle assessment
Global warming
Carbon emission reduction
Carbon solidification

ABSTRACT

MEPC 70 foresees a greenhouse gas reduction strategy will be in force in 2018. Researchers are striving to investigate different GHG reduction technologies to determine their feasibility in the aspect of both environment and economy. However, the evaluations are not specific or comprehensive so this paper presents a systematic evaluation approach to guide policy makers to evaluate the performances and to help ship owners to select suitable reduction technologies. One carbon reduction method proposed by authors was proved to be cost effective and this paper applies life cycle analysis focusing on all stages of ship life to investigate, determine and compare the feasibility of this methods in the aspect of environmental and cost impact which are two significant standard for the assessment. The results indicate the application of reduction method leads to a lower global warming potential when the carbon reduction target is increased. Oppositely, the economic benefits increased while complying with strict regulation. This paper also indicates to achieve carbon reduction target set up by regulation, a marginal target will be necessary. Evaluation of carbon reduction method using life cycle assessment is also recommended to policy makers and ship owners to provide them comparable results and reasonable decision makings.

1. Introduction

The global warming has been in focus of researchers from all over the world for decades. It is because the global warming effect is actually influencing human beings' living environment. For instance, sea level arising is one of the most significant impact due to the accumulation of global warming gases (greenhouse gases), especially carbon dioxide which is known to be the largest contributor of global warming. ICCT has been considering the reduction of Greenhouse Gas Emissions from ships since 2011(ICCT, 2011). The consideration is not only focused on the emission abatement but also the costs due to the abasement. Nowadays researchers are striving to develop and investigate novel and efficient carbon reduction methods and techniques in order to mitigate the severe impacts of global warming.

There are large numbers of new developed carbon reduction methods with evaluations:

Perera and Mo have presented their measuring method based on EEDI, EEOI, SEEMP and ECAs to analysis the energy efficiency of a ship. Their results indicate using suitable navigation strategies will help reduce emissions from ships (Perera and Mo, 2016). Wang and Chen also investigate the strategy of refuelling, sailing and containership deployment and how they could affect the emissions, especially carbon emissions, from ship. The research work shows there are many different factors affecting the emissions released and it also considered the cost associated with these factors such as the impacts of fuel price, container transportation quantity, carbon credits, etc (Wang and Chen, 2017). Chen's team evaluate the impact of shipping route on the emissions from ships with data between Asia and Europe. As a fact of emission restriction in ECA area, ships are intended to changing route to go around the area which means the optimal route for fuel saving will not be optimal any more (Chen et al., 2018). Demirel et al. (2014) developed a CFD model to estimate the variation of plate roughness in different coating types in order to reduce the hull roughness and increase the energy efficiency. An experimental study was also carried out by Demirel et al. (2017) to determine the relationship between bio-fouling and ship resistance for an oil tanker and an LNG carrier. Their CFD results were validated with experiments by Owen et al. (2018).

However, these methods are proposed and evaluated by different researchers and the standard or criteria applied are varied based on these researchers' proposal. It is essential to develop and validate a comprehensive approach with standard processes and criteria to help both policy makers and ship owners to evaluate and select the suitable

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https://doi.org/10.1016/j.oceaneng.2018.07.050
Received 21 March 2018; Received in revised form 15 May 2018; Accepted 18 July 2018
Available online 23 July 2018
0029-8018/

carbon reduction methods.

Life cycle assessment is a popular method which has been widely used in many different disciplines. Styles' team used LCA to quantify the growing of willow on river buffer zones and results showed the benefit of willow cultivation on these area (Styles et al., 2016). In fishing industry, Vázquez-Rowe's research group investigated the edible protein energy return on investment (ep-EROI) in Spain and LCA was to assess the energy consumption and environmental impact. These results were expected to provide recommendations for EU's Common Fisheries Policy (Vázquez-Rowe et al., 2014). LCA is also applied to evaluate the power systems, both state-of-art and under developed, by Fredga and Maler, especially on biofuel. A full scope of LCA model considering both emission released and resource required is established in order to provide comprehensive analysis and retrieve precise results (Fredga and Mäler, 2010). There are also many valuable LCA works and researches in the field of shipping industry: Blanco-Davis's works have applied LCA to aid the shipyards to evaluate retrofitting performances of innovative ballast water treatment system and fouling release coating (Blanco-Davis et al., 2014; Blanco-Davis and Zhou, 2014). The performance of fuel cell and diesel engines for marine applications has been investigated and compared by Alkaner and Zhou with the help of LCA (Alkaner and Zhou, 2006). Strazza's research team applied LCA to evaluate the environmental impact of paper stream on a cruise ship with implementation of different green practices (Strazza et al., 2015). In addition, Nicolai's team investigated the environmental impact related to commercial ships by optimization of raw material and energy consumption, and recycle processes using LCA (Nicolae et al., 2014). two case ship studies have been carried out by Ling-Chin and Roskilly to compare the hybrid power system with the conventional marine engine systems in a comprehensive ship life cycle phases - namely, construction, operation, maintenance, and scrapping (Ling-Chin & Roskilly, 2016a, 2016b). With inspiration from these researches, the authors have also carried out two case studies which help shipyards and shipowners to determine the optimal propulsion system for a short-routed hybrid ferry and for an off-shore tug vessel from the perspective of economic and environment (Wang et al., 2018; Oguz et al., 2018).

Since the evaluation processes are different from different research works, the main aim of this paper is to develop a life cycle assessment model which provide a standard and comprehensive evaluation model by considering four stages of ship: construction, operation, maintenance and scrapping and a large scope of activities in these stages.

2. Methodology

2.1. Life cycle assessment

Life cycle assessment is an evaluation approach, considering all the activities from cradle to grave of a system or product (Curran, 2006). The definition of ‘from cradle to grave’ is that starting from the raw material exploiting, all the processes related to the system or product are covered, such as manufacturing, transportation, utilization, maintenance and disposal and recycle at the end of life. Through including and assessing the impact of all these processes and activities in the life cycle of the system or product, LCA provides a comprehensive view of product/system as well as relevant activities from the perspective of environmental impact. With these views and insights, all the participants in the life cycle of the product/system will have a clear and precise understanding about the overall environmental performance which will enable them make reasonable decisions at the design and operation stages.

Basically, to carry out a LCA analysis, there are four main parts interactive with each other (Fig. 1): goal and scope definition, life cycle inventory analysis, life cycle impact analysis and the interpretation of different parts. It is obvious that the first part is to set up goal and define the scope which also means the target and the boundaries. Then the next step is to evaluate the life cycle inventory which are basically considering and identifying the quantities of substances related to environmental potentials (i.e. emission groups) in all the life phases of the system/product, such as energy consumption, material investment, emission released and waste generation. In order to evaluate the environmental impacts, a normalization database will be selected and used such as CML 2001, ReCiPe, ILCD and TRACI (CML, 2016; RIVM, 2011; Wolf et al., 2012; IERE, 2012). Only after the normalization, the environmental potentials due to different energy consumption, raw materials, emissions and wastes could be converted into a same key unit (key function). For global warming potential (GWP), the equivalent carbon dioxide is the key unit but for other potential, the key unit will be different. For example, for acidification potential (AP), the key unit is equivalent sulphur dioxide (CML, 2016).

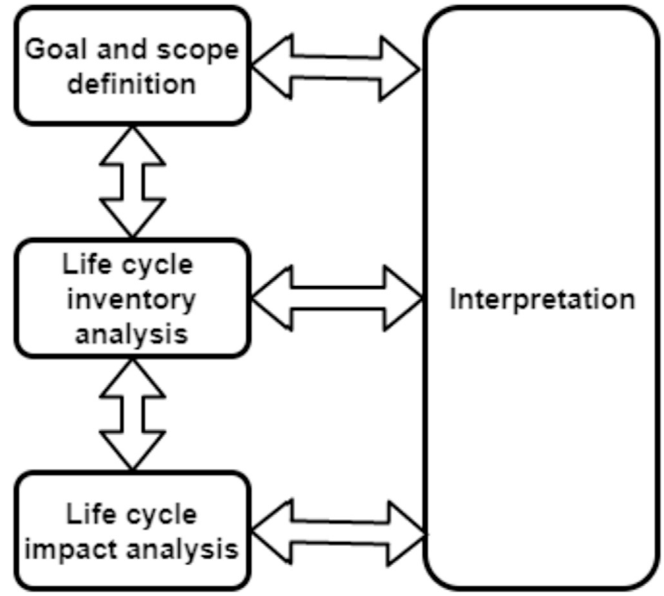

Fig. 1. Life cycle assessment framework.

Sensitivity analysis is also an essential part of LCA which will indicate the consequence of input data changing. As there are many data involved in one LCA analysis, the analysis usually focuses on the most fluctuated data and also the ones clients cared most. After changing the value of one input data, a series of results will be obtained which will illustrate how the life cycle assessment results changing with the varying of data.

Apart from the framework of LCA, the processes consideration in an analysis is also significant. Usually, the life cycle is comprised of four consecutively phases: raw material acquisition, manufacturing, use/reuse/maintenance and recycle. In this paper, the target is about ships in the shipping industry, the phases considered will be constrained and modified into a more relevant life cycle to ships (Fig. 2): construction, operation/maintenance and scrapping.

2.2. Carbon solidification

For carbon reduction method, there are many different technologies as mentioned previously focusing on different parts of ships, for examples, coating applications, route optimizations, speed optimizations and after treatment. This paper tests authors' previous work, carbon solidification on ship, and applies LCA model to evaluate the economic results in order to compare with the results from previous work.

The carbon solidification method applies chemical substances to absorb and solidify carbon content from the exhaust gases. The chemical reactions are listed as following (Zhou and Wang, 2014):

$$CO_2\ (g) + 2NaOH\ (l) = Na_2CO_3\ (l) + H_2O\ (l) - \Delta H_1 \quad (1)$$