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Fuzzy multi-criteria decision-making method for technology selection for emissions reduction from shipping under uncertainties

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ABSTRACT

This paper describes a methodology for the application of Multi-Criteria Decision-Making (MCDM) on the technology selection for emissions reduction from shipping under uncertainties and incomplete information. Nine criteria in four aspects, including technological (maturity), economic (capital cost and operation cost), environmental (effects of SO_x, NO_x, GHG, and PM reduction), and social–political aspects (government support and social acceptability), were used for the sustainability assessment. The study aims at developing the methodology for technology selection for emissions reduction from shipping by combining Fuzzy Analytic Hierarchy Process (AHP) and VIKOR. Fuzzy AHP was used to determine the weights of the evaluation criteria and the relative performance of the alternatives with respect to each evaluation criterion, and VIKOR was used to prioritize the alternative technologies. The two methods of VIKOR and the traditional AHP were combined to validate the proposed methodology. Three alternative technologies of low sulphur fuel, scrubber and LNG were studied using the proposed model, and the results indicate that the proposed methodology is capable of assisting the decision-makers to select the most sustainable technology for emissions reduction from shipping under uncertainties and incomplete information.

Introduction

The shipping industry, which undertakes more than 80% of international trade by volume, is one of the world's largest and most important industries (The Chamber of Shipping, 2009). In addition to making a significant contribution to the world's economy, shipping also causes various environmental problems. Shipping is estimated to contribute approximately 3% of the global CO_2 emissions (Eide et al., 2011; Eide and Endresen, 2010; Dalsøren et al., 2009); shipping also accounts for global emissions of NO_x and SO_x at the levels of 15–30% and 5–7%, respectively (Corbett and Koehler, 2003; H. Wang et al., 2009; J.J. Wang et al., 2009). Thus, the emissions from ships have recently attracted increasing attention due to the severe negative impacts of such emissions on air quality.

The International Maritime Organization (IMO) has taken various actions to regulate air pollution from ships. One of the most important regulations is MARPOL Annex VI, which was first adopted in 1997 to prevent air pollution from shipping (IMO, 1997). To satisfy these regulations, various technological and operational measures have been studied, i.e., speed

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reduction (Eide et al., 2011), the use of scrubbers (Aronietis et al., 2014), and LNG (Helfre and Boot, 2013). However, different measures provide different responses in economic, environmental and social aspects, and it is usually difficult for decision-makers to make correct decisions among multiple alternative technologies because it is a multi-criteria decision-making (MCDM) problem, which refers to scoring or ranking a finite number of alternatives with the consideration of multiple evaluation criteria. Accordingly, methodologies for assisting decision-makers to select the best scenario for the emissions reduction of ships are of vital importance, and many studies have focused on this issue. Schinas and Stefanakos (2014) developed a multi-criteria decision-making tool based on the analytic network process to assist the operators in selecting the necessary technological alternatives to achieve compliance with MARPOL Annex VI. Yang et al. (2012) proposed a subjective generic methodology for assisting ship owners to select their preferred NO_x and SO_x reduction technologies based on an analytic hierarchy process and the TOPSIS method. All of these studies are significantly helpful for the relevant officials to make correct decisions among multiple alternatives. However, there are also reasons for improving on the previous studies on selecting the best measure among multiple alternatives for emissions reductions from shipping, for two reasons: One reason is the uncertainty problems that exist in the evaluations of the measures for emissions reduction from shipping, and another is the inaccurate incorporations of the preferences of the decision-makers.

Uncertainties mainly refer to the variations that are associated with physical systems or the environment, and the lack of data due to the lack of knowledge and information (Liu and Huang, 2012). In the evaluation of emissions reduction measures, various criteria are usually used, including both hard criteria and soft criteria. Hard criteria refers to the criteria that can be depicted quantitatively (i.e., the capital cost, operation cost, and effect on NOx emission), while soft criteria refer to the criteria that are difficult or impossible to quantify (maturity, government support, and social acceptability). Although the hard criteria are allowed to be described quantitatively, some of them are also difficult for the decision-makers to depict by crisp numbers. For example, the capital cost and operation cost are not fixed values due to the variations in the prices of goods in a changeable market. At the same time, the value of each of the hard criteria with respect to the same alternative provided by different researchers could also be different due to the spatial differences and the temporal inconsistencies. For example, the effects on the PM reduction of scrubber reported by different researchers are different (CNSS, 2014; Helfre and Boot, 2013). Moreover, the data of the emissions reduction measures with respect to each of the evaluation criteria are reported in the format of intervals rather than crisp numbers. In addition to the difficulties in determining the data of the emissions reduction measures with respect to the hard criteria, the incorporation of soft criteria in decision-making makes the problem even more complicated, and thus, the previous MCDM methods do not perform well for the decision-makers to select the best measure for emissions reduction from shipping. Accordingly, handling the uncertainties and soft criteria for determining the relative performances of the emissions reduction measures with respect to the evaluation criteria is a prerequisite. Some methods cannot determine the weights of the criteria accurately due to the vagueness, ambiguity, and subjectivity that exists in human judgments. For example, the Analytic Hierarchy Process (AHP) developed by Saaty (1980), which has the ability to decompose a complex problem into several sub-problems in different hierarchies, in which each element is compared to other elements in the same hierarchy through pair-wise comparisons, has been widely used in the evaluation of emissions control measures. This method has been widely used in other multi-criteria decision-making problems, also, i.e., the assessment of noise pollution in urban areas (Abbaspour et al., 2015), evaluation of transport strategies (Shiau, 2012), evaluation of competitiveness of air cargo express services (Park et al., 2009), and prioritization of low-carbon energy sources (Ren and Sovacool, 2015). Unfortunately, the traditional AHP method, which uses the scale of 1–9 to measure the relative preferences/importances, does not perform very well due to the vagueness, ambiguity and subjectivity of human judgments (Afgan et al., 2008). However, fuzzy theory enables the users to use fuzzy numbers, which are more suitable for depicting human preferences compared with crisp numbers, in decision-making. Thus, the extension of AHP by combining it with fuzzy theory, the so-called "Fuzzy Analytic Hierarchy Process (FAHP)", has recently been widely used. More details regarding fuzzy theory can be found in the literature. (Manekar et al., 2011; Ren and Sovacool, 2014).

The objective of the present study is to solve the following two problems: (i) the uncertainties and incompletion that exists in the decision-making; and (ii) the difficulty in determining the performances of each alternative with respect to the evaluation criteria. A multi-criteria decision-making method was developed by combining the fuzzy analytic hierarchy process (AHP) and VIKOR, for the decision-makers to select the most sustainable scenario for emissions reduction from ships.

This paper is organized as follows: Section 'Methodology' presents the methodology that is involved in the criteria for the sustainability assessment of technologies and the MCDM method; an illustrative case is studied and discussed in Section 'Case study'; and finally, conclusions are offered in Section 'Conclusion'.

Methodology

The objective of this study is to help decision-makers to prioritize the technology alternatives for emissions reduction due to shipping according to their sustainability performances. Economic issues, environmental performances, and social concerns are the three pillars of sustainability. However, technological and political aspects are also incorporated because these two aspects influence the three pillars of sustainability. A Multi-Criteria Decision-Making (MCDM) method is formed by combining the Fuzzy Analytic Hierarchy Process and the VIKOR method for determining the prior sequence of the alternative technologies for emissions reductions from ships.