Analysis of Shipping Emissions Based on the Sustainability Index

Taru Tanhuanpää (taru.tanhuanpaa@xamk.fi)

Elias Altarriba, Sirpa Rahiala

South-Eastern Finland University of Applied Sciences, Kotka, Finland

Introduction

Air emissions from shipping contribute to global warming and deteriorate local air quality. Emissions include carbon dioxide, nitrogen and sulfur dioxide, carbon monoxide, black carbon, and particulate matter. Sulfur and nitrogen dioxide emissions from bunkers are internationally regulated, and the Baltic Sea belongs to an area with stricter emissions limits (NECA and SECA).

The European Commission's legislative proposal "Fit for 55" will enact regulations to reduce the greenhouse gas intensity of the energy used by ships by 80% by 2050. Furthermore, the proposal will extend the EU Emissions Trading System to maritime transport (EU, 2021). Further, the IMO has an even more ambitious target of full carbon neutrality of the sector by 2050 (IMO, 2023). Remarkable investments are needed in maritime transport to achieve these greenhouse gas reduction targets. Investments are usually economically significant and long-term decisions since a ship's service life is usually 30–40 years. Therefore, shipowners need information to compare different emission abatement methods' cost-effectiveness and environmental impact. Thus, we compared different emission abatement alternatives by applying a sustainability index.

Materials and methods

In this study, we created an Excel-based tool with which the end-users can analyze the overall sustainability effects of different shipping fuels and emission abatement techniques. The fuels included in this study were heavy fuel oil (HFO), marine gas oil (MGO), and liquefied natural gas (LNG). The studied emission abatement techniques were selective catalytic reduction (SCR) and exhaust gas recirculation (EGR) for reducing NOx emissions from diesel fuels, and open- and closed-loop scrubbers for reducing SOx emissions from HFO. These abatement technologies are assumed to fulfil NECA and SECA areas' stricter nitrogen and sulfur oxide limits. LNG fulfils the limits without additional abatement technology.

The tool calculates an overall sustainability index (SI) comprised of an economic index and environmental index. The environmental index consists of four impact categories: eutrophication potential (EP), acidification potential (AP), global warming potential (GWP), and human health particulate air (HHPA). The environmental index includes emissions from fuel production and the use of fuel. We used the characterization factors from the FuelEU Maritime initiative (FuelEU Maritime, 2021) for the greenhouse gas emissions of the fuels during their lifecycle. Our previous article (Altarriba et al., 2022) utilized emission factors from the Fourth IMO GHG Study (2020).

The economic index is calculated via the Net Present Value method, and the expected project lifetime is 25 years. The index includes the investment costs of the different emission abatement techniques, operation and maintenance costs for different alternatives, fuel costs, and CO_2 tax. For fuel costs, we created three different price scenarios (low, mid, and high) based on future estimates from the literature (Åström et al., 2018). We created two additional fuel price scenarios based on recent fuel price history to reflect the record high and fluctuating fuel prices in recent years. The first scenario (hereafter called Current Price Scenario 1) is based on the prices between December 2021 and June 2022, and the second (hereafter Current Price Scenario 2) on the prices between September 2022 and August 2023 (www.shipandbunker.com). The prices in Current

Price Scenario 2 are somewhat lower than in the Current Price Scenario 1. The methods, including the underlying assumptions for the calculations, are presented in more detail in Altarriba et al. (2022).

Results

The overall sustainability index shows clear differences in the economic and environmental performance of different fuels and emission-reduction methods in this study. The results show the importance of considering various impact categories in the environmental index. For instance, LNG is superior to conventional diesel fuels in the eutrophication and acidification potential categories**.** In the global warming potential category, the difference between these fuels is smaller when black carbon emissions are included. Despite this, LNG performs best among all the options in the environmental index. MGO is the second-best option after LNG. Additionally, the environmental performance of HFO is impacted by the assumed particle reduction capacity of sulfur scrubbers.

In the overall sustainability index, LNG also performs the best among the options in the fuel price scenarios, based on Åström et al. (2018). In Current Price Scenario 1, our previous study showed that the SI for LNG weakened compared to MGO and HFO. This is because LNG is remarkably more expensive in our current price scenarios. However, in this paper, LNG remained the best option in the overall SI in both current price scenarios. This demonstrates that the emission factors in the FuelEU Maritime initiative are somewhat more favorable towards LNG than the emission factors from IMO. Overall, our results highlight that the assumptions in fuel prices and emission factors may play a key role in determining the overall sustainability index of different fuels.

Since the overall sustainability index combines environmental and economic indexes, their weighting factors in the index impact the results. Here, we used equal weights for both, but the users of our tool can choose the weighting factors according to their preferences. Generally, it is important to consider the influence of the assumptions while interpreting the results of our study.

Implications on sustainable maritime operation

The maritime industry is facing tighter environmental regulations globally and regionally. A challenge in the sector is finding economically viable options with a low overall environmental impact. Shipowners and authorities need research-based data on the effects of different fuels and emission reduction techniques. Thus, we developed a tool for analyzing the overall sustainability impacts of the alternatives in maritime transport. Our results highlight the importance of considering multiple impact categories when comparing sustainable options. It is important to include different emission types comprehensively when estimating the environmental impact. For example, we have shown that black carbon emissions impact the sustainability index of LNG. In the future, black carbon emissions might gain increased attention in environmental regulation.

In our previous paper (Altarriba et al., 2022), we analyzed the impacts of fossil fuels with the sustainability tool. With alternative fuels, the share of production in the environmental impact increases compared to the traditional fuels. Including a social aspect in the sustainability index for biofuels would be beneficial. The social aspect could include, for instance, the possible losses of food crops. Further, the competitiveness of prices compared to conventional fuels will significantly affect the economic index of alternative fuels. Including maritime transport in the EU Emissions Trading System will increase the competitiveness of low-carbon fuels. However, in the future, fuel prices will remain difficult to forecast.

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