EXTENDED EMISSION INDEX FOR FISHING VESSELS: ASSESSMENT OF THE ENVIRONMENTAL FRIENDLINESS OF A PURSE SEINER WITH AN ALTERNATIVE POWER SYSTEM

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ABSTRACT

Current regulations in the marine sector require an assessment of a ship's effect on the environment and its reduction. Depending on the ship type and navigation areas, these regulations become ever stricter and different technical and operational measures are being investigated to increase ship energy efficiency. For merchant ships energy efficiency is regularly expressed as a ratio of CO_2 emission and transport work (denoted as a benefit for society (BS)), while some fleets, for instance the fishing one, remain under investigation. There are some studies considering the fuel use intensity index as a relevant quantity of fishing effort which can be further used to express the environmental friendliness of fishing vessels, but there is no unified solution. Environmental problems in marine fishery development are very important nowadays and in order to adopt the low-carbon and green development concept, it is necessary to evaluate the current status of the fishing fleet. This work deals with the formulation of the extended emission index (EEI) for fishing vessels which is formulated as a ratio of emissions generated by the ship's power system and amount of catch which is considered as BS. Adding SO_x and NO_x emissions to usually calculated amounts of CO_2 emissions represents an extension of existing approaches in the formulation of energy efficiency indices for ships, while expression of the benefit for society is adapted to the fisheries sector. An illustration of the newly introduced index is done by taking into account a purse seiner operating in the Adriatic Sea. The work also discusses the applicability of EEI for fishing vessels powered by alternative fuels as well as relevant sensitivity studies.

Keywords: extended emission index, EEI, environmental friendliness, fishing vessels, purse seiners, alternative fuels.

1 INTRODUCTION

The carbon footprint of shipping, including fishing vessels, is a significant concern due to its impact on climate change. Fishing vessels contribute to greenhouse gas (GHG) emissions, although specific data on their carbon footprint can be limited. Several factors contribute to the carbon footprint of fishing vessels. Most fishing vessels are powered by diesel fuel, which results in GHG emissions. According to Alma Maris [1], in 2018 world fisheries consumed 12.86 million tonnes of fuel, which resulted in 40.7 million tonnes of GHG emissions.

Without taking into account the energy used to construct the vessel, the energy needs in fisheries are mostly related to fuel consumption during fishing operations for moving the vessel on the water, hauling the gear, and making ice to preserve the catch, while the energy needed for updating fishing gear, applying antifouling paint, and scrapping the vessel at the end of its operational life is less significant [1]. The size and efficiency of the vessel's engine and its operational practices influence fuel consumption and emissions [2]–[4]. Researchers showed that fuel consumption rates vary widely among different fleets, vessel types, fishing gears, and fishing practices, and mention fuel efficiency measures (technological improvements, e.g., more efficient engines, hull design, alternative fuels) as a method to lower GHG emissions [5], [6].

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Reducing the carbon footprint of fishing vessels requires a multi-faceted approach. Strategies include energy-efficient vessel design, integrating renewable energy sources, improving engine efficiency, exploring fuel alternatives, optimizing operations, promoting sustainable fishing practices, and investing in carbon offset projects. Regulations and policies, such as those established by the International Maritime Organization (IMO), also play a crucial role in driving emissions reductions in the shipping industry. The energy efficiency design index (EEDI) is an international regulation established to promote energy efficiency of new ships. Its purpose is to reduce GHG emissions and improve the overall environmental performance of the shipping industry. The EEDI sets specific energy efficiency targets for different types of vessels based on their size and ship type [7], [8]. In January 2023 a new regulation entered the shipping industry; the energy efficiency existing ship index (EEXI) is a regulation that complements the EEDI. While the EEDI focuses on new ships, the EEXI aims to improve the energy efficiency of existing ships. The EEXI requires ships to meet specific energy efficiency targets based on their ship type, size, and age. Ships that do not meet the required energy efficiency levels will be required to implement technical and operational measures to improve their efficiency [9].

When analysing fisheries specifically, the European Union (EU) has implemented several environmental regulations and measures in fisheries to ensure sustainable fishing practices and protect marine ecosystems. These regulations set standards and promote sustainable practices within the fishing vessel sector. The primary regulatory framework is given by the Common Fisheries Policy (CFP), which promotes sustainable fishing practices, prevents overfishing, and protects marine resources while ensuring the long-term viability of the fishing industry [10].

This paper deals with the assessment of the energy efficiency of fishing vessels and introduces the extended emission index (EEI). The index gives an insight into the environmental impact in accordance with the benefit for society. It takes into account the global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP). As a benefit for society, the estimated value on catch is applied. The calculation was performed for one purse seiner operating in the Adriatic Sea. Data on operational characteristics were obtained by direct monitoring of the selected purse seiner.

2 MATHEMATICAL MODEL

EEI is formulated by extending the basic index in Koričan et al. [11], and it includes different emission contributions compared to the benefit for the society (BS). Emissions include the GWP, AP and EP [12], and are calculated as follows using eqn (1):

$$EEI = \frac{\alpha \cdot GWP + \beta \cdot AP + \gamma \cdot EP}{BS}. \tag{1}$$

The weighting factors *α, β* and *γ* are determined based on the area of application – in this case the values are obtained from the study by Perčić et al. [12]. The GWP, AP and EP are calculated by multiplying the emissions with specific factors:

$$GWP = 1 \cdot E_{CO2} + 36 \cdot E_{CH4} + 298 \cdot E_{N2O}, \tag{2}$$

$$AP = 1 \cdot E_{SOx} + 0.7 \cdot E_{NOx}, \tag{3}$$

$$EP = 0.13 \cdot E_{NOx}. \tag{4}$$

The GWP is considered the most significant GHG and it represents how much energy the emission of one ton of a gas will absorb over a given period relative to the emission of 1 ton of CO_2. The AP calculates the energy of the acidifying gas by the $SO_{2\text{-eq}}$ factors, while EP calculates the nitrogen oxide emission with $PO_{4\text{-eq}}$ factor [12].

The tailpipe emissions E_i considered in eqns (2), (3) and (4) are calculated depending on the type of the power system. In this paper, three different power systems are considered – diesel, liquified natural gas (LNG) and methanol, presented in Fig. 1. First step is calculating the fuel consumption (FC) by multiplying the specific fuel consumption of the considered power system (SFC) with the engine power and operating time. For the diesel engine-powered system, the equation takes into account both the main (P_{ME}, SFC_{ME}, T_{ME}) and auxiliary engines (P_{AE}, SFC_{AE}, T_{AE}):

$$FC_D = P_{ME} \cdot SFC_{ME} \cdot t_{ME} + P_{AE} \cdot SFC_{AE} \cdot t_{AE}. \tag{5}$$

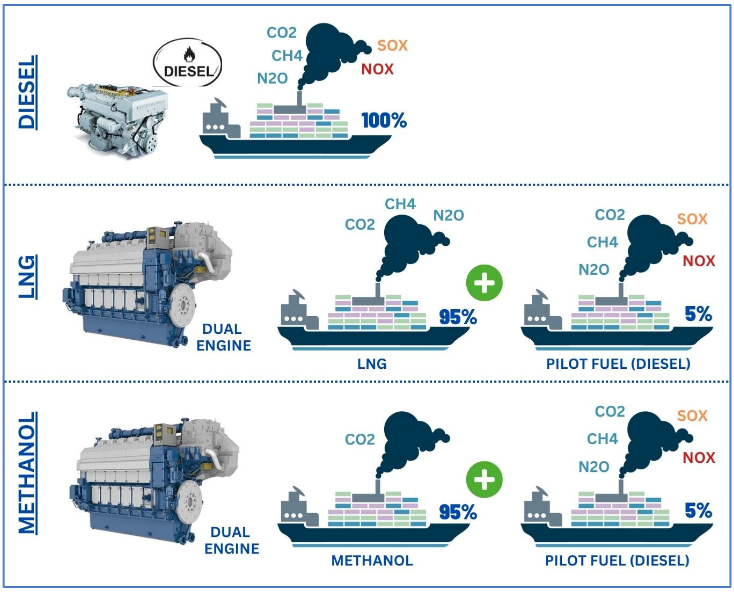

Figure 1: Different power systems and their emissions.

By using the calculated FC_D, the emissions released during fuel combustion can be calculated [4]:

$$E_i = FC_D \cdot EF_i, \tag{6}$$

where EF_i stands for emission factor for different emissions. The values are obtained from Istrate et al. [13].

In the case of using LNG or methanol, the calculation is slightly different. Namely, both energy systems consist of a dual engine that includes pilot fuel, most often diesel [4]. For this reason, when calculating fuel consumption, it is taken into account that 95% of consumption is LNG/methanol (x_{LNG}, x_M), while 5% is pilot fuel ($x_{P\text{-}LNG}$, $x_{P\text{-}M}$):

$$FC_{LNG} = x_{LNG} \cdot SFC_{LNG} \cdot EC, \tag{7}$$

$$FC_{P-LNG} = x_{P-LNG} \cdot SFC_{P-LNG} \cdot EC, \tag{8}$$

$$FC_M = x_M \cdot SFC_M \cdot EC, \tag{9}$$

$$FC_{P-M} = x_{P-M} \cdot SFC_{P-M} \cdot EC. \tag{10}$$

For the same reason, when calculating emissions released during fuel combustion, both LNG/methanol and pilot fuel (diesel) were included:

$$E_i = EF_{LNG,i} \cdot FC_{LNG} + EF_{P-LNG,i} \cdot FC_{P-LNG}, \tag{11}$$

$$E_i = EF_{M,i} \cdot FC_M + EF_{P-M,i} \cdot FC_{P-M}. \tag{12}$$

The values of the emissions factors, weighting factors and specific fuel consumption are presented in Table 1. The values for the specific fuel consumptions are obtained from IMO [9] and Perčić et al. [12].

Table 1: Specific fuel consumption, emissions factors and weighting factors for different fuels.

Specific fuel consumption, g/kWh		**Emissions factor, g emissions per kg fuel**				**Weighting factors**	
		Emission	**D**	**LNG**	**M**		
SFC_D	215	CO_2	3206	2750	1375	α	0.095
SFC_{LNG}	154.4	CH_4	0.06	51.2	0	β	18.3
SFC_{P-LNG}	1.8	N_20	0.15	0.11	0	γ	21.1
SFC_M	327.2	SO_X	61.21	~ 0	~ 0		
SFC_{P-M}	10.1	NO_X	2.64	~ 0	~ 0		

3 RESULTS AND DISCUSSION

The Croatian fishing fleet consists of 7,808 vessels and is responsible for 5.74% of total catch in the Mediterranean area [14]. Purse seiners have the most significant contribution to total landings (around 50% in 2020), which is why they are observed in this paper. The paper observers a specific purse seiner ‘Briljant’, whose technical and operational characteristics are presented in Table 2. The operational characteristics such as operating times of main and auxiliary engines are obtained via monitoring system MAPON. The monitoring system, with fuel consumption monitoring, provides GPS tracking, route mapping and time records. One example is presented in Fig. 2.

Table 2: Main particulars of the observed purse seiner [14], [15].

Purse seiner	
Length overall, m	32.28
Breadth, m	7.40
Draught, m	2.88
Main engine power, kW	480
Auxiliary engine(s) power, kW	370
Gross tonnage	182
Average catch – annual, t	568.1
Daily operating time – main engine, h	4
Daily operating time – auxiliary engine(s), h	10

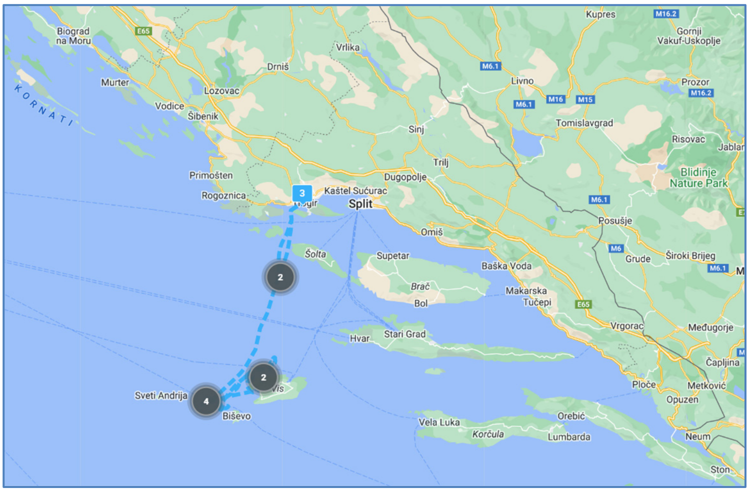

Figure 2: Snapshot from the monitoring system.

The calculations of EEI are made for several scenarios – diesel, 70% diesel, 50% diesel, methanol and LNG. Given that certain regulations for fishing include a reduction of diesel consumption to 70% (most often through limiting engine power [10], [14]), the EEI was calculated for a different proportion of diesel. It is assumed that the rest of the energy is supplied from batteries, which have no tailpipe emissions. The EEI results for different shares of diesel are shown in the Fig. 3. The propulsion system, which uses 100% diesel, achieved an EEI of 1.95 kg emission-eq per kg catch. The reduced diesel systems of 70% and 50% resulted in EEI of 1.36 and 0.97 kg emission-eq per kg catch, respectively.

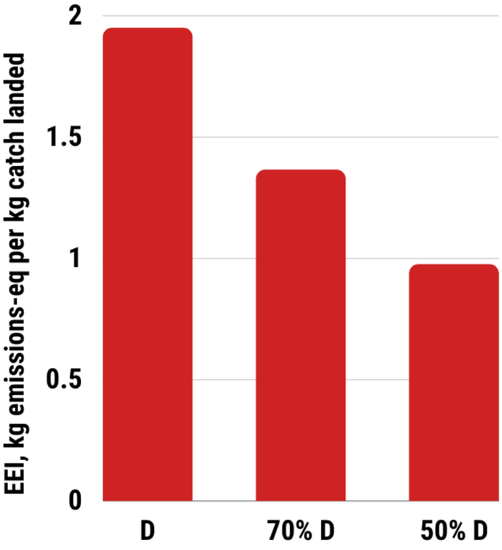

Figure 3: Comparison of EEI for different diesel systems.

If the traditional diesel system was replaced with LNG or methanol, significantly lower EEI values are obtained. Given that using LNG or methanol, SO_x and NO_x emissions can be significantly or completely reduced, the EEI values resulted in 0.17 for methanol and 0.39 for LNG $CO_{2\text{-eq}}$ per kg catch.

Similar calculations were made by Perčić et al. for the Croatian ro-ro passenger fleet. The results showed a range from 0.25 to 2.5 kg emissions-eq per €, which was expected since the observed passenger fleet differed by the size of ships and ferry routes [12]. Given that there is a significant difference in the operational profile of passenger and fishing fleets, it is more accurate to observe calculations made specifically for fishing vessels. Sala et al. [3] performed an environmental assessment of trawl fisheries and showed a range of 7.64 to 922 kg CO_2 per t fish, depending on the type of trawl. Purse seiner were observed by Parker and Tyedmers [5], who obtained a result of 2.2 kg $CO_{2\text{-eq}}$ per kg of landed fish and invertebrates, much lower than trawls.

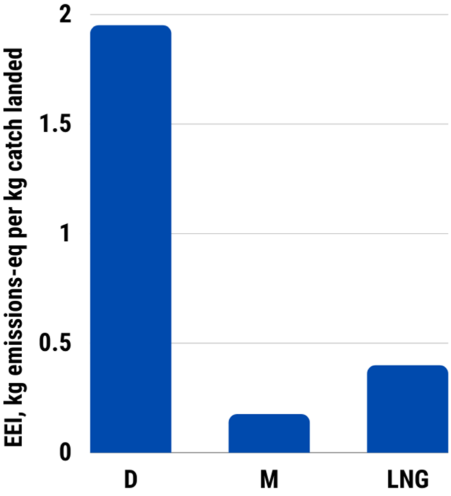

Figure 4: Comparison of EEI for different power systems.

4 CONCLUSION

The paper highlights the significance of addressing the carbon footprint and emissions of fishing vessels, considering their contribution to GHG emissions within the maritime sector. The authors propose the EEI as an evaluation tool for the environmental impact of fishing vessels, taking into account GWP, AP and EP. The EEI is calculated as a ratio of emissions generated by the ship's power system to the benefit for society, which is represented by the amount of catch. The paper evaluates the EEI for a purse seiner powered by various fuels, including diesel, LNG, and methanol, and discusses how the different power systems influence emissions and energy efficiency. The propulsion system using 100% diesel resulted in an EEI of 1.95 kg emission-eq per kg catch. When diesel consumption was reduced to 70% or 50% with the rest supplied by batteries, the EEI values decreased to 1.36 and 0.97 $CO_{2\text{-eq}}$ per kg catch, respectively. Replacing traditional diesel with LNG or methanol significantly reduced the EEI values due to lower SO_x and NO_x emissions. The EEI for methanol was 0.17 kg emission-eq per kg catch, while the EEI for LNG was 0.39 kg emission-eq per kg catch. In conclusion, the paper highlights the significance of assessing the energy efficiency and environmental impact of fishing vessels, particularly purse seiners. The EEI provides valuable insights into the emissions associated with different propulsion systems and fuel choices, with the potential to guide future decisions for achieving more sustainable and environmentally friendly fishing practices.

It should be noted that the presented research has some limitations, whereas the analysis boundaries are set to the ship power system, and therefore electricity obtained from batteries is considered as emission-free. However, there are emissions associated with electricity generation, but here they are related to energy but not to fishing sector. Also, further investigations should consider costs of different low-emission solutions as well as wider range of alternative power options.

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