International Conference on Applied Energy 2021
Nov. 29 - Dec. 2, 2021, in Bangkok, Thailand
Paper ID: 0387

Analysis of environmental footprint of a fishing trawler with overview of emission reduction technologies

Nikola Vladimir[1*], Marija Koričan[1], Maja Perčić[1], Neven Alujević[1], Neven Hadžić[1]

1 Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Ivana Lučića 5, 10002 Zagreb, Croatia
* Corresponding author; nikola.vladimir@fsb.hr

ABSTRACT

Energy efficiency and environmental performance become important aspects of all transportation branches involving diesel engines as prime movers. The same is for the fishing sector, where besides ensuring sustainability, one seeks for minimizing operative costs through the reduction of fuel consumption. Ship emissions can be determined at different levels of complexity and accuracy, i.e. by analysing ship technical data and assuming its operative profile, or by direct measurements of key parameters and their postprocessing to obtain exact amounts of exhaust gases. This paper deals with the analysis of the environmental footprint of a fishing trawler operating in the Adriatic Sea, including both Well-to-Pump (WTP) and Pump-to-Wake (PTW) phases of the fuel. Based on the data on fuel consumption and exploitation scenarios of the considered ship, provided by the ship-owner, the ship emissions have been determined. Also, a review of different emission reduction technologies has been provided Among various alternatives to diesel engine-powered fishing vessels a hydrogen-powered option is considered, where the obtained results show that hydrogen is rather far from application in the Croatian fishing sector.

Keywords: fishing trawler; ship power system; exhaust gas; decarbonization; alternative fuels

NOMENCLATURE

Abbreviations	
CF	Carbon Footprint
FPI	Fisheries Performance Indicator
GT	Gross Tonnage
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
FPI	Fisheries Performance Indicators
LCA	Life-Cycle Assessment
PTW	Pump-to-Wake
WTP	Well-to-Pump
Symbols	
EC	Energy consumption (kWh)
EF	Emission factor (kg emission/kg fuel)
FC	Fuel consumption per year (kg/year)
LOA	Length overall (m)
P	Power (kW)
SFC	Specific fuel consumption (kg/kWh)

1. INTRODUCTION

Global emissions of NOx produced by marine vehicles are in range 14 – 31%, while SOx emissions are in range from 4% to 9%, [1]. Marine industry consumes 330 Mt of marine fuel per year and 77% of it is heavy fuel oil (HFO). The stated energy demand produces 2-6% of global CO_2 and these emissions are projected to rise with a 270% increase by 2050, compared to 2007 [1].

The Paris Agreement, signed in 2016, aims to limit the increase in the global average temperature to well below 2°C, above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C. The implementation entails economic, social and technical transformations in every sector, including the maritime [2].

International Maritime Organization (IMO) recommends a range of measures for preventing and controlling pollution from ships [3]. However, the research is mainly focused on larger ships such as tankers, bulk carriers, passenger or container vessels, while fishing vessels and other coastal vessels are slightly out of focus. However, these ships operate near the coastline (within inhabited areas) and therefore their

Selection and peer-review under responsibility of the scientific committee of the 13_{th} Int. Conf. on Applied Energy (ICAE2021).

effect on both population and environment should not be neglected.

2. FISHING TRAWLERS

The fishing sector accounts for 134 million tonnes of CO_2 emissions in the atmosphere. These emissions are directly related to the energy consumption, which depends on the type of fishing vessel, type of fishing activity and fishing route [4]. Significant factor in fuel consumption is also the type of caught fish. For example, purse seining tuna consumes 15 times more fuel per tonne of land fish than purse seining herring, almost 1,500 l per tonne [5]. Trawlers consume more fuel than purse seiners, e.g. trawling shrimp consumes 3,000 l per tonne of land fish, but trawling cod consumes just about 530 l per tonne of land fish [5]. An interesting analysis is given in [4], where the relation between operating mode and fuel consumption is presented. The paper states that purse seiner dedicates 56% of total fuel consumption to cruising while trawlers 68% of fuel dedicate to catching fish, i.e. trawling. Previous research stated that trawlers are the most fuel-demanding fishing vessels [6]. Typical fishing actions inherent to trawlers are sailing to the required location and fishing, i.e. net dragging, Figure 1. The principles of purse seining and trawling are illustrated in Figure 2.

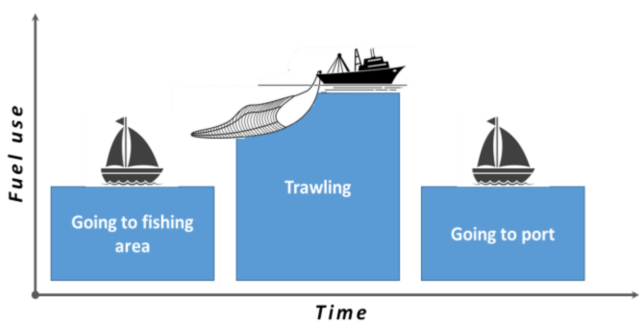

Figure 1. Fishing actions of trawlers

The net dragging accounts for almost 60% of total resistance, which is why the majority of fuel is dedicated to catching [6]. Fuel-saving can be obtained in different ways, from reducing the navigation speed to choosing a different fishing gear. One example is using pelagic or semi-pelagic trawl doors, which reduces the drag and forward resistance and therefore causes fuel savings [4]. Another example is given in [7], where two semi-pelagic trawlers, with an engine power of 900 kW, in the Adriatic Sea were tested. The results showed that reduction of speed in steaming conditions by half a knot leads to a reduction in fuel to 18%.

Overcapacity in the fishing sector, obsolescence of the fleet and large presence of fossil fuels cause less profitability and a number of environmental problems. This paper deals with the analysis of the life-cycle environmental footprint of fishing operations and possibilities for its reduction, where a fishing trawler operating in the Adriatic Sea is taken as a test case.

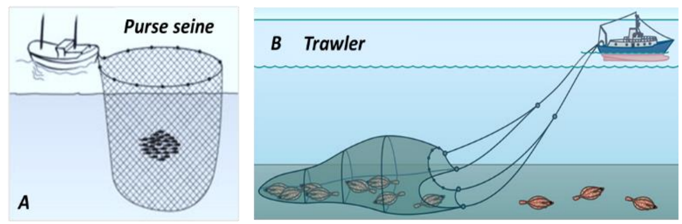

Figure 2. Types of fishing vessels: a) purse seine; b) trawler

3. METHODOLOGY

3.1 Life- Cycle Assessment (LCA) of a diesel-powered trawler

As presented in the introduction, the shipping sector is being pushed to reduce and control the emissions produced during its lifetime. To estimate the amount of harmful gases being produced and the effect that different fishing techniques have on it, a Life-Cycle Assessment (LCA) of a diesel-powered trawler was performed.

The LCA is performed by means of GREET 2021 software [8][6]. As presented in [9], the emissions can be analysed in three phases:

1. WTP (Well-to-Pump) phase analyses the fuel cycle (from the extraction of raw material, production of fuel and transport to the refuelling station).
2. PTW (Pump-to-Wake) phase analyses the fuel usage in a power system that causes tailpipe emissions (TE).
3. Manufacturing phase analyses the manufacturing process of the main elements in a power system.

These emissions contribute to the Carbon Footprint (CF) of a diesel-powered system. The CF represents a relative measure of the total amount of CO_2 or $CO_{2\text{-eq}}$ emissions caused by indirect or direct activity or is accumulated over the life cycle of a product [9]. The phases are presented in Fig. 3.

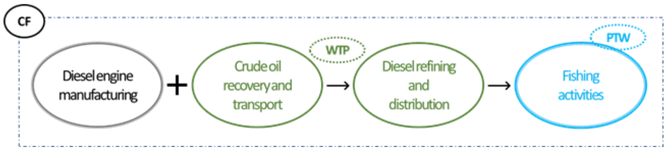

Figure 3. The LCA of a diesel-powered trawler

The first step of the analysis is calculating the annual energy consumption by dividing the annual fuel consumption (*FC*) by the specific fuel consumption (*SFC*). The *SFC* is considered to be 0.215 kg/kWh [9]. The tailpipe emissions (*TE*) are calculated by multiplying the annual fuel consumption (*FC*) with the emissions factors (*EF*). The LCA analysis considers emissions released from the processes of the WTP phase and the PWT phase. In this paper, the manufacturing phase is neglected since the engine power is low and, therefore, the emissions would be rather small.

3.2 Fisheries Performance Indicators (FPI)

Chu et al. [10] emphasized importance of fisheries on the coastal community and their need for improvement. According to [10], improvement actions in fisheries are mainly focused on one task, either environmental progress or greater profit. Since fishing is a complex system, the social, economic and environmental aspects should be intertwined and complementary. Fisheries Performance Indicators (FPI) are an evaluation tool for analysing the performance of fisheries, with the goal to accomplish environmental, economic and social aims [10].

Profit is the main focus of any production sector, including fishing. It is difficult to show a unified price of catch per kg of fish, because each catch differs depending on the quality of the fish, i.e. the species. For example, the catch may consist of shrimps, squids, sharks, etc. The price of shrimp varies from 30 €/kg to 65 €/kg, the price of squid 5-12 €/kg, sharks around 5 €/kg, flathead mullet 2.50 €/kg etc. [11]. The price of diesel is assumed to be 0.78 €/kg [12]. The price of alternative fuels depends on the mixture and in this paper, an example of a hydrogen mixture is given. According to [12], the price of hydrogen varies from 5.35 €/kg to 9.5 €/kg, but a price drop to 3 €/kg is possible in the near future. By reducing the use of fossil fuels a reduction in harmful emissions is expected, but a detailed research of different power configurations will give an insight into the profitability. With the gathered information, a suitable configuration that ensures profitability and has a positive impact on the environment can be chosen.

4. CASE STUDY

The Croatian fisheries sector has a long tradition and it is widespread through the entire coastline. Purse seiners make about 5% of the entire fishing fleet and land the majority of catches, while trawlers make about 14% of the fishing fleet. However, because of different types of fish being caught, the profit is similar for the purse seiners and trawlers [11]. In this paper, a trawler with an engine power of 223 kW is analysed, Figure 4. The trawler mainly operates around Primošten, central Adriatic in Croatia, Figure 5.

Figure 4. Analysed fishing trawler

Figure 5. Location of Primošten, Croatia

The main engine is powered on "Eurodiesel Blue", a fuel which consists of diesel with up to 0.5% sulphur [9]. This type of fishing vessel regularly catch different types of white fish (cod, haddock, pollock etc.), molluscs (squid) and crustaceans (shrimp). The main particulars of the trawler are presented in Table 1, [14]. The speed was obtained from AIS (Automatic Identification System) [15].

Table 1. Main particulars of the trawler [14]

TRAWLER				
Annual average energy consumption, kWh		297,650.0		
Length overall (LOA), m		22.1		
Gross Tonnage (GT)		65		
Engine power, kW		223		
Speed – average, kn		3.6		
Speed – maximum, kn		6.3		
Fuel consumption *FC*, kg per year				
2015	**2016**	**2017**	**2018**	**2019**
61,830.8	65,753.3	60,691.4	62,654.8	69,042.7
Landed fish, kg per year				
2015	**2016**	**2017**	**2018**	**2019**
32,554.4	45,685.4	42,621.1	41,464.8	45,490.1

5. EMISSION MITIGATION TECHNOLOGIES

The IMO prescribes number of technical and operative measures to reduce environmental effect of shipping. In general, technical measures are: measures related to the propulsion system, vessel design and vessel equipment, exhaust after treatment, engine internal measures, use of alternative fuels, while the set of operational measures is comprised of: measures related to speed reduction, smart steaming, journey planning, on board information systems, optimal maintenance, etc. Replacing conventional, fossil fuels with a cleaner ones is a research subject in many transport sectors. A good overview regarding the application of alternative fuels in marine transportation is given by Perčić et al. [12]. The paper presented a comparison of a diesel-powered vessel with a fully electrified vessel and the effect of different types of alternative fuels on the reduction of harmful emissions. An LCA comparison showed that total electrification, by replacing the diesel engine with a battery, reduces the CF by 36% for the cargo ship, 51% in the passenger ship and 40% for the dredger. The cost analysis showed that electrification of cargo ships and dredgers is a quite expensive solution, while for passenger ships is the most economical [12]. Since fishing vessels carry a lot of equipment, electrification may not be the always an optimal solution and it is necessary to calculate which energy system is the most cost-effective. Alternative fuels have many advantages in terms of environmental acceptability, but also various negative properties per se. Great diversity of alternative fuels provides a greater chance of finding an economically viable option. One option presented in [12] is methanol, a sulphur-free, biodegradable fuel but with a high level of toxicity. On other hand, hydrogen is a non-toxic fuel, usually used in a fuel cell. Since it is rarely found in pure form, its production includes additional expenses such as manufacturing of fuel cells, natural gas recovery, hydrogen production, liquefaction and other expenses. When mentioning hydrogen, ammonia as a hydrogen-rich fuel is also investigated. Because of the lack of carbon content, ammonia presents a promising option for the marine energy sector. A very affordable option, in relation to the method of production, is biodiesel. Biodiesel is a fuel derived from biological sources, such as animal fat and vegetable oil, and is usually used as a blend with fossil fuels [12]. The LCA analysis of ammonia-powered vessels showed the highest CF compared to other power systems. Other solutions showed a reduction in CF but the results of the cost analysis are depended on the type of ship being investigated [12].

Based on the presented results, it is logical to assume that the use of alternative fuels will contribute to the reduction of CF in fishing vessels as well. Thus, wider research should be done to determine the optimal share of alternative fuels in fishing vessels that will assure the same or greater profit and better environmental friendliness.

6. RESULTS & DISCUSSION

The LCA is performed for a diesel-powered trawler. The results are separated into phases, the WTP and PTW phases. As mentioned previously, the manufacturing phase is neglected due to its low values. Figures 6 and 7 show released annual emissions of the considered vessel. Almost 99% of emissions in the WTP phase are made of $CO_{2\text{-eq}}$ and the rest is NO_X, SO_X and PM. Emissions in the WTP phase are approximately 10 times lower than the emissions in the PTW phase. These emissions depend on the production process of diesel and the only way to reduce them is to replace diesel fuel with a more environmentally friendly option. The emissions in the PTW phase also show a large share of $CO_{2\text{-eq}}$. A larger share of NO_X is visible, about 1.8%. The PTW emissions depend on the emissions factors and fuel usage. As seen in Figure 8, in 2017 the fuel consumption was approx. 12% lower than in 2019, due to which the PTW also show lower values in 2017. Therefore, the emission in the PTW phase could be easily reduced if fossil fuel usage is reduced. However, trawlers for their work require a certain amount of fuel that cannot be easily reduced and at the same time to ensure successful performance.

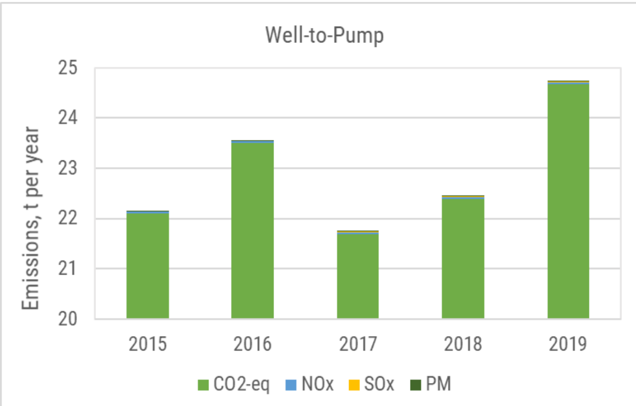

Figure 6. The results of WTP phase

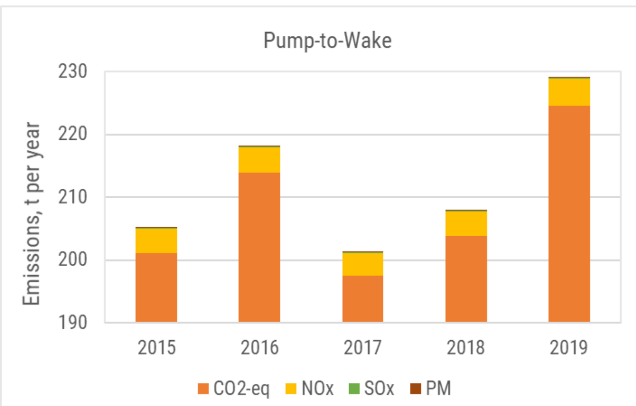

Figure 7. The results of PTW phase

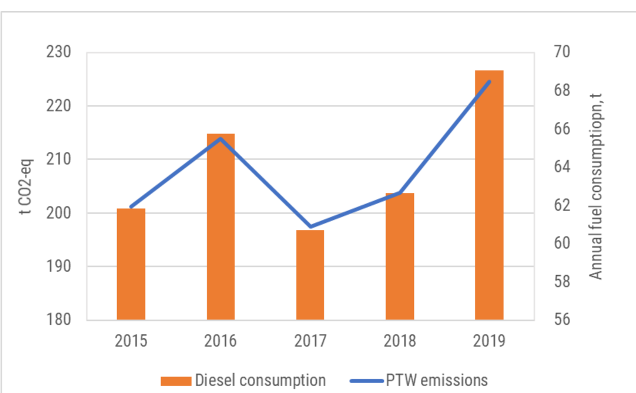

Figure 8. Relation between fuel consumption and PTW emissions for diesel engine powered ship

Various configurations could effectively replace the diesel engine and a cost analysis is inevitable during its selection. Important parameters for the calculations are shown in Table 1. Total costs include investment costs, maintenance costs and operative costs. The cost of a diesel-powered vessel includes the cost of a diesel engine (250 €/kW) and the maintenance cost is calculated using the conversion factor of 0,014 €/kWh [12]. Operative costs are calculated by multiplying the fuel consumption with the price of diesel fuel [12]. Hydrogen was taken as an example of alternative fuel. According to [12], the investment cost of a hydrogen-powered vessel includes the price of a PEM fuel cell of 368 €/kW and hydrogen storage cost of 5€/kWh. Maintenance costs are equal to the cost of a fuel cell. The costs of different power configurations are compared to the income from the sale of fish, Figure 9. A hydrogen-powered vessel requires much higher investment, unjustified in relation to profit, and isn't practical for implementation. So, this alternative is quite far from implementation in the Croatian fishing sector. Other options need to be analysed to show their contribution in environmental and economic aspects. Also, some countries encourage the reduction of CF and provide incentives for this type of investment that should be also be calculated in the life cycle costs.

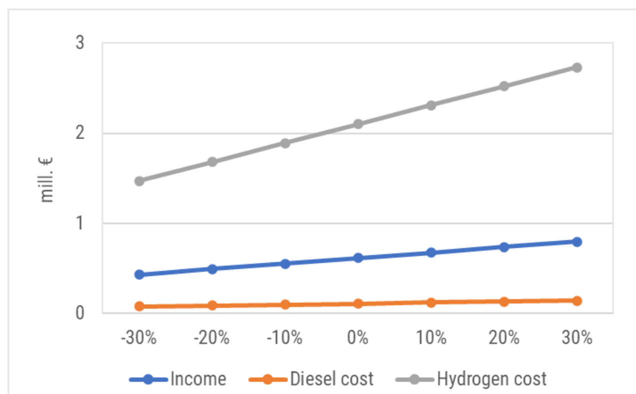

Figure 9. Comparison of costs for diesel engine- and hydrogen-powered fishing trawler

7. CONCLUSION

This paper deals with the environmental analysis of a fishing trawler operating in the Adriatic Sea. The LCA shows that a great amount of CO_2 emission is released during fishing activities (PTW phase). Based on a five-year set of data, it is visible that a reduction in fuel consumption leads to a reduction in harmful gases. Higher investment costs in green technologies could significantly reduce harmful emissions and establish a better environment for the marine area and coastal communities. Among different alternative fuels to be implemented in the Croatian fishing sector, a brief analysis of hydrogen potential has been performed. The results indicate that it is rather expensive option with a number associated issues to be resolved prior its wider application. Therefore, future analyses should consider other technical and operative measures to reduce environmental footprint of fishing operations.

ACKNOWLEDGEMENTS

This investigation has been funded by the European Maritime and Fisheries Fund of the European Union within the project “Autonomous Auxiliary Fishing Vessel (APROPO)”, granted by the of the Ministry of Agriculture, Directorate of Fisheries, Republic of Croatia (Award No. 324-01/19-01/968).

REFERENCES

[1] Prussi M., Scarlat N., Acciaro M., Kosmas V., 2021, Potential and limiting factors in the use of alternative fuels in the European maritime sector, Journal of Cleaner Production 291, 125849.

[2] UNFCCC, 2021, Paris Agreement, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (accessed 24 September 2021).

[3] IMO, 2021, Marine Environment, https://www.imo.org/en/OurWork/Environment/Pages/Default.aspx (accessed 24 September 2021).

[4] Basurko C.O., Gabina G., Quincoces I., 2016, Fuel consumption monitoring in fishing vessels and its potential for different stakeholders.

[5] Food and Agriculture, 2012, Fuel savings for small fishing vessels: A manual, http://www.fao.org/publications/card/en/c/98995c6b-bd40-56c7-bcf5-768c1d8eccc1/ (accessed 25 September 2021).

[6] Parente J., Fonseca P., Henriques V., Campos A., 2008, Strategies for improving fuel efficinecy in the Portuguese trawl fishery, Fisheries Research 93, pp. 117-124.

[7] Sala A., De Carlo F., Buglioni G., Lucchetti A., 2011, Energy performance evaluation of fishing vessels by fuel mass flow measuring system, Ocean Engineering 38, pp. 804-809.

[8] GREET, https://greet.es.anl.gov/ (accessed 25 September 2021)

[9] Perčić M., Vladimir N., Fan A., 2020, Life-cycle cost assessment of alternative marine fuels to reduce the carbon footprint in short-sea shipping: A case study of Croatia, Applied Energy 279, 115848.

[10] Chu J., Garlock T.M., Sayon P., Asche F., Anderson J.L., 2017, Impact evaluation of a fisheries development project, Marine Policy 85, pp. 141-149.

[11] Food and Agriculture, GLOBEFISH - Information and Analysis on World Fish Trade, https://www.fao.org/in-action/globefish/prices/ (accessed 21 October 2021).

[12] Perčić M., Vladimir N., Fan A., 2021, Techno-economic assessment of alternative marine fuels for inland shipping in Croatia, Renewable and Sustainable Energy Reviews 148, 111363.

[13] Ministry of Agriculture Croatia, https://ribarstvo.mps.hr/default.aspx?id=13 (accessed 25 September 2021).

[14] IHS, World Register of Ships – WROS manual, 2015.

[15] FleetMon, Jadran 3, https://www.fleetmon.com/vessels/jadran-3_0_10651264/ (accessed 25 September 2021).