A MODELING AND SIMULATION BASED ASSESSMENT OF SWITCHING FUELS FOR A NORWEGIAN FISHING VESSEL

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KEYWORDS

Emissions, fuels, fishing, sustainability, methanol.

ABSTRACT

The Norwegian fishing industry is facing increasing pressure to find more sustainable energy solutions. In response to this, a modeling and simulation based case study of a representative Norwegian pelagic trawler/purse seiner is presented to evaluate the emission reduction potential of transitioning from traditional marine gas oil to alternative fuels. The objective is to begin developing a framework for calculating relevant parameters and key performance indicators, to support more detailed analysis of various fishing activities. A data based simulation model of the fishing vessel is presented, and some potential benefits and drawbacks of switching to some alternative fuels are demonstrated, from an energy perspective. While practical challenges related to this transition were not considered in detail, our results indicate that emission reductions are achievable. We also found that the simulation results aligned closely with real-world measurements, supporting the validity of our models. The study highlights the need for continued research and development of sustainable solutions for the Norwegian fishing industry.

INTRODUCTION

The Norwegian fishing sector is meeting increasing pressure to become more sustainable in the upcoming years (Norwegian Maritime Authority 2020). Some of the pressure is from controllable measures, like the EU taxonomy (SALT 2023) and national regulations. Fisheries is a part of the non-quota sector in Norway, which is required to reduce its climate gas emissions by 50 % by 2030 from 2005 levels. The Norwegian Environment Agency reported in "Klimakur 2030" in 2020 an estimated reduction potential of emissions from Norwegian fisheries of around 0.18 Mt CO_2-equivalents (18 %) (The Norwegian Environment Agency 2020,Kystverket 2023). The current Norwegian fishing fleet is largely fossil fueled (Norges Fiskarlag 2020), which has increasingly being penalized by carbon taxes (Kaushal and Yonezawa 2022). These costs are currently being reimbursed for the fishing industry, but this might not be permanent. Other factors are more volatile, like consumer choices and fuel prices.

Norwegian wild-caught fish is by SINTEF considered among the more carbon-efficient animal protein sources available (Winther et al. n.d.), but there are still major emissions from the sector. Norway exports wild-caught fish for around 35 MNOK annually (Norwegian Directorate of Fisheries 2022), and being able to advertise worldwide with sustainably harvested food could give the sector and nation an even bigger competitive edge moving forward. Consumers comparing different suppliers based on a set of sustainability indexes may arguably become a reality, for example from the carbon footprint of the end-product.

Work is already being done in various fields to make fishing vessels more sustainable. Some areas of focus are emission reductions through energy efficiency measures, as well as introducing alternative fuels with a lower carbon footprint than the current fuels.

There has for example been reported reduction in the water resistance of fishing vessels by optimazing the hull design (Yu et al. 2021,Liu and Zhang 2022), and reduced fuel consumption from reducing the vessel velocity (Chang and Chang 2013). Some other examples are regenerative equipment, wavefoils, shore-power, optimization of the dimensioning and utilization of technical equipment, as well as peak-shaving using batteries (FHF 2021).

There are only a few fuel technologies which are regarded mature enough for large-scale implementation in the maritime sector. Fishing vessels typically have a high energy demand per trip and require volumetrically dense fuels, which can have either fossil or renewable origin (Parikyan 2022). Heavy fuel oil (HFO) is the most used maritime fuel (Oiltanking 2015), but is currently largely fossil Marine Gas Oil (MGO) (Norges Fiskarlag 2020).

The first fully electric fishing vessel was completed in 2015 (Maritimt Magasin 2016), but this solution is limited to coastal fishing vessels which can charge/refuel often. The first fishing vessel fueled by Liquified Natural Gas (LNG) was finished in 2021 (Fiskebåt 2021), but this has not yet become a standard in the fishing industry, although it is a mature technology for other ship segments. Several companies are looking into introducing hydrogen and ammonia to the maritime sector, but there are currently several unsolved challenges.

Another possible alternative is Methanol (MeOH), which by DNV is considered a mature fuel with potential in future ships (DNV 2022), although it's highly corrosive and has ignition problems at low temperatures. Methanol is often mixed with petroleum to get enhanced properties (Salameh 2014), but this reduces its sustainability if the methanol is created from sustainable sources.

Communications of the ECMS, Volume 37, Issue 1,
Proceedings, ©ECMS Enrico Vicario, Romeo Bandinelli,
Virginia Fani, Michele Mastroianni (Editors) 2023
ISBN: 978-3-937436-80-7/978-3-937436-79-1 (CD) ISSN 2522-2414

Some studies have been conducted on the current emissions from fishing vessels, for example a study SINTEF did of the trawler Ramoen (Ramoen 2021). Other companies might have run other thorough analyses of such systems, but there seems to be no comprehensive collections of good models publicly available to quickly evaluate different fuels for different fishing vessels, and their impact on the sustainability of the end-product. More knowledge about the current emissions as well as the future emission reduction potential in the Norwegian fishing fleet is, thus, of growing interest and importance. To better evaluate different fuel alternatives against each other, but also to better convey to the end-users the quality of their products.

Objectives

Emissions from the fuel consumption is a major component to the emissions over the life-time of a fishing vessel, and knowledge about feasible fuel alternatives and their limitations needs to be further explored. The objective of this article is to introduce generic data-based models to evaluate and compare different fuels, which will constitute the basis for further analysis of such systems.

Scope and limitations

The scope of the analysis presented in this article is an existing Norwegian fishing vessel equipped to perform both pelagic trawler and purse seiner operations. It is worth noting that the models are not yet compared to equivalent results from other vessels, and applying these models to analyse other machinery or vessels should be done with caution.

The name and other specific details of the vessel is anonymized for the sake of its owners, and the system description is therefore generalised to avoid revealing the specific vessel. The existing vessel is about 70 m long and 10 years old, and it is representative for a fair share of the Norwegian fishing fleet.

The current vessel is equipped with one main engine (ME) and two auxiliary engines (AE1, AE2), all run on fossil marine gas oil. The power production is covered by a shaft generator (SG) connected to the main engine and two equal generators (DG1, DG2) connected to the auxiliary engines. A separate emergency diesel generator covers emergency power, but this is rarely in use and its details is out of the scope of this analysis. These systems are modeled using historic data from two years, and the models do not take into account details on variations over time, due to for example different fuel composition or maintenance.

The analysis is limited to three currently available fuels, the currently used Maritime Gas Oil (MGO), Heavy Fuel Oil (HFO) and Methanol (MeOH). This is a short-term outlook, and does not take into account all future possible fuels. Details about necessary differences in the machinery to accommodate the different fuels are not included and this is one of the reasons why very different fuels such as methanol and hydrogen is not included.

The emissions calculations only include direct emissions from burning the fuel – not a complete life-cycle analysis.

METHODOLOGY

Measurements from the vessel constitute the basis of the analysis, which was provided by SINTEF Ocean. These are pre-processed before being used to model the system, run simulations, validate the simulation results, and calculate the emissions per weight unit of fish.

A variety of parameters related to the ship operation is available through the onboard logging system. These measurements are related to the navigation, hull motion, machinery and the environment, and the measurements used in this study are

- Vessel velocity
- Engine load and generator powers
- Fuel rate measurements

Automatic Identification System (AIS) data are available through The Norwegian Coastal Administration (Kystverket). This data contains, among other things, values for speed over ground (SOG), longitude and latitude. The AIS data has a time resolution of 20 seconds, and has no values for velocities below 0.3 m/s. Additionally, the Norwegian Directorate of Fisheries stores catch data from each fishing trip. The catch data covers a wide variety of parameters for when the vessel delivers the fish to shore.

The vessel data is pre-processed to exclude outliers, before further analysis. The AIS velocity data is used to check for and remove such outliers in the measurements, where all such points are replaced by linearly interpolating between the existing data points. In particular some AIS data points are physically infeasible, and would not give meaningful results if included.

The vessel measurements are used to model relationships between various parameters of the energy system in terms of its fuel and power efficiencies. This is done for the purpose of obtaining simplified models which can replace the real data in further analysis. The simplified models are of interest in particular in time periods where some parameters are not logged or for calculating fuel consumption at different load conditions.

Some of the models are then validated against real measurements through time-simulation in MATLAB with steplength of 10 s. The input data to both the modeling stage and the simulation stage is 10 s mean values of the measurements. The time resolution of the vessel data is 1 s, but there are not available values for all parameters in every time step of the two years covered. Considering also computational memory challenges, using 10-s mean values is chosen.

The models are further used to evaluate different scenarios, to calculate the difference in the fuel consumption using different fuels. The fuel consumption is further combined with the catch data to find the environmental footprint given as CO_2 emissions per weight unit of caught fish.

Fuel Assumptions

The current vessel is using MGO, and the analysis was run for the three fuels MGO, HFO and MeOH. Volumetric density ρ_{fuel}, gravimetric energy density e_{fuel} and gravimetric CO_2 density $k_{fuel}^{CO_2}$ for the different fuels is found in Tab. 1.

Table 1: *Fuel parameters: gravimetric energy density, volumetric mass density (25 °C, 1 atm) and CO_2 density (Bunker Oil 2023,The Engineering Toolbox 2023,Hydrogen Tools 2023).*

Symbol	Unit	HFO	MGO	MeOH
ρ_{fuel}	kg/l	0.900	0.855	0.786
e_{fuel}	MJ/kg	39.0	42.7	19.9
$k_{fuel}^{CO_2}$	t_{CO_2}/t_{fuel}	3.2	3.17	1.375

It was assumed a constant density, gravimetric energy density and CO_2 factor, regardless of the operating conditions. It is further assumed that the fuels do not have any ignition issues, and that pure methanol can be used.

Data Investigation and Modeling

The engines and generators are first modeled based on each year separate, as well as on the whole data set of two years, in order to look for deviations from one year to the next. The models are generated as piece-wise linear (PWL) functions, where the size of the range depends on the number of data points in the current range, to get reasonable lines compared to the density plots. The final curves are generated from the average of the edges between each sub-function, and compared to the density plots of the data.

The quality of the models are then validated by applying each model on the other half of the data set, to compare the performance against the measured values. Data for the whole two-year period is then used to investigate the properties of the different vessel components related to energy consumption and to further model the system components.

Modeling of the Generators

A model for the mechanical-to-electric power efficiency, $\eta^G(p_m^G)$, is made for DG1 and DG2, as stated by (1). This is generated from calculated efficiencies using the auxiliary engine loads, P_m, and the electric generator outputs, P_e, for the engine/generator pairs. It is assumed that the shaft generator had the same per unit properties as the other generators, i.e. power values given relative to the nominal value. Superscript "G" denotes generator.

$$\eta^G(p_e^G) = \frac{P_e^{DGi}}{P_m^{DGi}} = \frac{P_e^{DGi}}{p_m^{AEi}\, P_N^{AEi}} \tag{1}$$

In (1), p_e^G and η^G are the electrical power output and associated efficiency for a generator, respectively. p_m^{AEi} is the mechanical load acting on diesel generator i by its respective auxiliary engine, and p_e^{DGi} is the electrical output of the same generator. Lowercase p denotes a per-unit power in Wpu and uppercase P_N denotes the nominal power of the equipment.

Modeling of the Engines

The fuel-to-shaft efficiency efficiencies of each engine are modeled directly from the available fuel rate, $\dot{V}$, and load measurements, p_m, using (2). Here, $\dot{V}_{fuel}$, ρ_{fuel}, and e_{fuel} are the combustion rate (l/s), density (kg/l), and energy capacity (J/kg) of the fuel, respectively.

$$\eta^E(p_m^E) = \frac{P_m^E}{P_{fuel}} = \frac{p_m^E\, P_N^E}{\dot{V}_{fuel} \cdot \rho_{fuel} \cdot e_{fuel}} \tag{2}$$

Due to a lack of representative efficiency curves for engines running on different fuels, the same fuel-to-shaft efficiency curve as for the existing engines is assumed representative for all cases.

Calculations and Model Validation

The quality of the models are investigated by calculating the generator input power and engine fuel combustion rates based on the models, and then comparing the results to the real measurements.

Calculation of Combustion Rate of different Fuels

The engine models are used to calculate the consumption of different fuels. Under the assumption of equal efficiency performance of the engine, regardless of fuel type, the combustion rate, $\dot{V}_{fuel}$, is found from rearranging (2) into (3) using different fuel properties. Linear interpolation is used between each point, and it is assumed that the operation of the machinery is unchanged from the original usage.

$$\dot{V}_{fuel} = \frac{p_m^E \cdot P_N^E}{\eta^E(p_m^E) \cdot e_{fuel} \cdot \rho_{fuel}} \tag{3}$$

Calculation of Carbon Emissions

The carbon emissions are assumed to be proportional to the amount of combusted fuel, as stated by (4). Here V_{fuel} and k_{CO_2} are the volume (L) and CO_2 coefficient (t_{CO_2}/t_{fuel}) of each fuel.

$$m_{CO_2} = \rho_{fuel} \cdot V_{fuel} \cdot k_{fuel}^{CO_2} \tag{4}$$

Calculation of Emission Reduction

Calculating the total carbon footprint of the fish products from a thorough LCA was not included in this analysis. Instead, the focus is on the reduction of fossil carbon emissions per weight unit of fish. This was calculated as stated by (5), where m_{fish} is the total weight (kg) of the delivered fish.

$$\Delta\bar{m}_{CO_2} = \frac{\Delta m_{CO_2}}{m_{fish}} \tag{5}$$

RESULTS

The following section presents the results of the analysis. First a presentation of the resulting models and their properties are given, followed by a validation of the quality of the models. Subsequently, the fuel and emission results for the evaluated fuels are presented to give an idea of the impact of switching to different fuels.

Modeling

Fig. 1 shows a density plot of the generator efficiencies, calculated from measured auxiliary engine load and generator power output, together with a PWL model of the generator measurements.

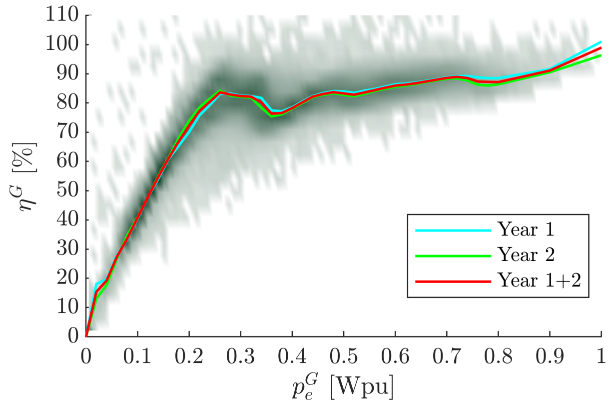

Figure 1: *Density plot and PWL models of generator efficiencies for different per-unit power ouputs. The efficiency axis is cut off for readability.*

Based on the figure, the PWL model seems to follow the trend in the real data. There are, however, many data points both below and above the modeled lines. It could be observed that all three models are fairly similar, but have some deviations both in areas with many data points and in areas with fewer.

An analysis of the two auxiliary engines showed that there is a clear trend in the power-to-fuel-efficiency relationship, as visualised by Fig. 2. Here, p_m^{AE} is the mechanical power output of the auxiliary engine given in pu. Again there are some deviations between the three models, but mainly for engine loads below 23 %.

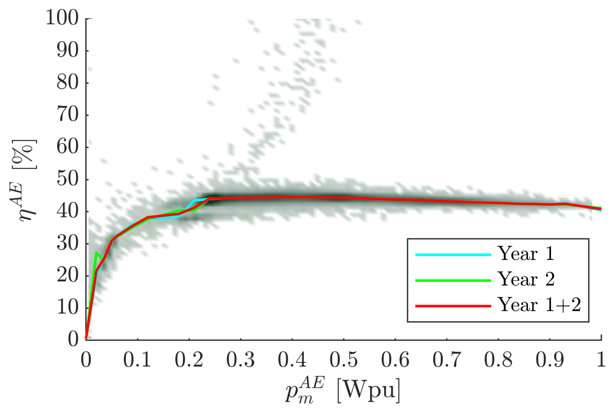

Figure 2: *Density plot for the fuel efficiencies for different auxiliary engine (AE1, AE2) mechanical loads, visualized together with PWL approximations for the first part, second part and full data set. The efficiency axis is cut off for readability.*

The density plot of the same data set is given together with PWL approximations for each engine both separately and for the two engines together in Fig. 2. The trend lines are for the most part overlapping, except for at very high loads, where there is a slight deviation. The density appears as a dark line which follows the trend lines for the most part and has darker areas around 0 %, 20–30 % and 40–55 % power load.

The corresponding models for the main engine is visualized in Fig. 3. As opposed to the auxiliary engines, the PWL approximation for the main engine does not follow the data as well for all loads. There are several darker lines in the data set, instead of only one. Furthermore, the deviations between the three models are larger than for the generator and the other engines.

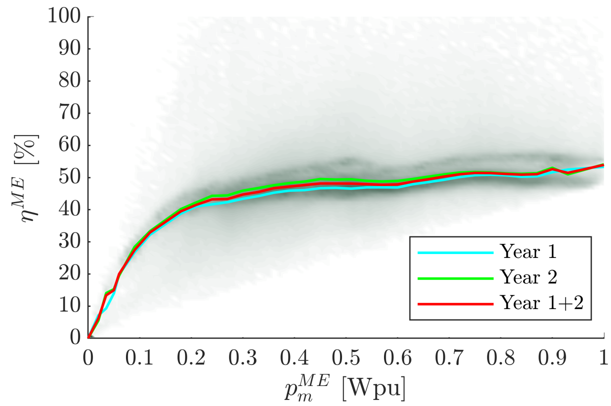

Figure 3: *Density plot for the fuel efficiencies for different mechanical engine loads of ME, visualized together a PWL approximation. The efficiency axis is cut off for readability.*

Model Validation

The total deviation in the generator input power is presented in Tab. 2 for the diesel generators and three engines, for three combinations of data sets (D) and their respective models (M). The numbers refer to the whole data set (0), the first year (1) and the second year (2).

Table 2: *Annual deviation in generator load and engine fuel consumption, resulting from using the models instead of the measured data for the generators and engines.*

Model/Data	Component	Deviation
M0/D0	DG1	−2.51 %
	DG2	+0.79 %
	AE1	−0.05 %
	AE2	0 %
	ME	−1.61 %
M1/D2	DG1	−2.63 %
	DG2	+0.38 %
	AE1	−0.26 %
	AE2	+0.05 %
	ME	+1.89 %
M2/D1	DG1	−2.65 %
	DG2	+1.67 %
	AE1	+0.29 %
	AE2	−0.1 %
	ME	−5.34 %

Tab. 2 shows that there were larger deviations in the generator input power when M2 was used. It should be noted that DG2 was used less in year 2 than in year 1, which gave the model a smaller data basis. The auxiliary engine fuel consumption was not much different between M1 and M2, but the main engine had considerably larger deviations of −5.34 % when M2 was used. Overall model M1 gave the best results of the two.

Tab. 3 shows calculated parameters for the fuel consumption and associated CO_2 emissions, for different fuels compared to the current fuel MGO.

***Table 3:** Output parameters for different fuels: Change of fuel volume (ΔV_{fuel}) and mass (Δm_{fuel}), and change of CO_2 emissions per mass unit of fish ($\Delta \bar{m}_{CO_2}$).*

Fuel	ΔV_{fuel} [m^3_{fuel}]	Δm_{fuel} [t_{fuel}]	$\Delta \bar{m}_{CO_2}$ [t_{CO_2}/t_{fisk}]
MGO	0	0	0
HFO	−80.0	+0.13	+0.017
	(−5.0 %)	(+0.09 %)	(+10.5 %)
MeOH	+2 093.8	+1.55	−0.01
	(+131.7 %)	(+1.15 %)	(−6.6 %)

Tab. 3 shows that the necessary mass of the fuel is not increased more than a maximum of 1.15 %, in the case of MeOH. The volume, however, had an increase of 131.7 % when switching to MeOH. The emissions were simultaneously reduced by 6, 6 %.

The HFO gave a low reduction in the fuel volume of 5 %, a negligible increase in the fuel mass and an increase in the carbon emissions of over 10 %.

DISCUSSION

There were some clear deviations between the calculated and measured values presented above, as well as larger changes in the fuel and emission parameters in the different fuels being applied. The results are further discussed in this section.

The mean deviations between the results using the real values and the models lie in the range from −5.34 % to +1.89 %. The total deviation in the results from year to year could, thus, vary quite a lot. It could be argued that a deviation of 5.34 % is a bit large to be able to use it to conclude on emissions reductions, however, it is only for the ME. The rest of the engines and generators have deviations which are around half of this at the most. These deviations may have been reduced if some of the underlying mechanisms were investigated further to develop the models further. Maybe one single model for each component is not enough for all situations.

There are many outliers in the measurements which are not reflected in the simple models. In particular on the auxiliary engine efficiencies, where there is a cloud of data points with a clear upwards trend in Fig. 2. What causes these were outside of the scope of this study, but could be investigated in further detail.

Some deviations between the models which were made from different parts of the full data set could have been caused by the limited number of available data points, which was few and spread-out for some load ranges, which gives the model low precision in these areas. In this analysis this might not affect the results drastically, since the loads with few data points also make up a smaller part of the time. However, if the model is combined with other data where the machinery is operated a larger share of the time around these loads, this could give even larger deviations in the annual results.

Visibly large deviations were observed in many of the generator efficiencies compared to the values calculated directly from measurements. One likely contributor to this could be dynamics in the machinery delaying the mechanical and electric response and, thus, cause transient deviations from the steady-state output. Additionally, imprecise or lagged measurements of both the mechanical and electric generator power values could cause some deviation, which potentially could skew the data in time and, thus, make the models less precise. It could however be argued that such phenomenon are limited since the 10 s mean data are used which smooths out the fast variations, compared to the 1 s data.

All the data were used to make the models, not only steady-state values. It could have been interesting to see the effects of only using parts of the data set which to some degree does not include transients. However, this would exclude a large amount of data points which in turn would both skew the results away from the total picture, and furthermore result in even less data points in potentially critical areas of the models for which the vessel operates in longer time periods.

Similarly as for the generators, the engine efficiencies deviated some from the models. This was in particular the case for the main engine. A large part of this could maybe be attributed to the fuel measurements which can be quite imprecise, in particular for small volume rates. There were some clear differences between the models of the main engine in the different periods, but some changes in the machinery properties may have occurred over time.

Some of the variations could be due to differences caused by wear and tear over time, reparations or replacements of the equipment or different fuels used. Changes in the composition of the fuel which is being used could explain some of it. Information on such changes over time were not available for this study. It should be mentioned that the presented results are average values per year, and that the period-wise variations from one trip to the next could be larger than assumed here. This analyses was not detailed enough to identify these, but it could be worth analysing further.

Another relevant aspect to look into, is the time resolution of the modeling data and the simulation. The effects of using 10 s mean values instead of the original 1 s data could be investigated further.

There was demonstrated in Tab. 3 an approximate 130 % increase in the necessary fuel volume when switching to MeOH. This could potentially lead to challenges on the longest fishing trips during the year, which lasts for days without refuelling. How large the current fuel tanks are compared to the current fuel consumption is not considered in this study, and should be included in further analysis to be able to conclude which impact this increase has on the feasibility of using MeOH as fuel for such a vessel. It could be conceivable that this would lead to issues for some vessels which do not have the option to refuel often and, instead, will have competing needs for space on the vessel with the caught fish. This would as presented above become better if it had been switched to HFO, but this is a more polluting fuel with higher life-time emissions than methanol. And the long-term goal is to move away from fossil fuels to more sustainable alternatives.

It was further demonstrated that the necessary fuel mass wouldn't change drastically to deliver the same energy over the two years. The draft and time of the vessel should, thus, not be largely affected by the change of mass, unless there needs to be large changes to the engines themselves. However, if the fuel tanks need to have different sizes, a potential relocation of the fuel tanks could change the draft or trim of the vessel.

It was demonstrated that the emissions could be reduced somewhat by switching to methanol. It could be argued, however, that this is a conservative estimate which might be drastically improved if a more comprehensive LCA analysis was included which considered the origin of the fuel. By calculating such detailed emissions per weight unit of fish, this could lead to specific KPIs that the sector could use in marketing. This would be interesting to look further into, in particular when introducing other alternative fuels.

Further Work

The study presented was made to constitute the foundation for further analysis, with higher detail, precision and more alternative fuels. Both in terms of more knowledge on the existing system, as well as more reliable information about the relevant fuel options.

One single model represented whole years of data, which arguably doesn't make it possible to focus on the details of changes over shorter time periods and the impact of other parameters on the machienery efficiencies. One natural next step would be to make models for similar periods, like for all pelagic trawler trips or all purse seiner trips separately. Another approach is to divide the data set by more detailed operations, like different transits, setting the seine, towing the trawl and similar.

No dynamics are included in the model at this point, which is a weakness with the method. The analysis could further be expanded to either focus on stationary periods or by including dynamics in the simulation of the components. Such high-fidelity models would complicate the analysis and it could be of interest to investigate to which degree a high-fidelity model actually contributes largely to increased precision in the results or if the simplified analysis are precise enough.

The engine efficiency was assumed equal regardless of fuel type. A natural next step is to find representative models for each type of fuel and run the analysis again. This would, arguably, be crucial if other power technologies using ammonia engines or fuel cells were to be included in the analysis.

The only key performance index (KPI) included currently is the CO_2 emission reduction per weight unit of fish. It could be of interest to expand with other KPIs in future analysis, like other pollutants (NO_x, SO_x, particular matter) and cost KPIs.

In addition to calculating a larger range of results, it could be interesting to calculate the KPIs for each fish species and quality, specifically, in order to get more detailed information relevant for the fishing industry. This is nothing new, but establishing an open standard of how to calculate this would be interesting. This has been done before but the input data an analysis method is, again, not publicly available.

Another natural next step is to further dig into the practical challenges related to the machinery, namely tank volume, weight and draft issues and similar. One example of this is how the draft and trim of the vessel impacts the energy demand for navigation.

When a more detailed analysis is established, it would be interesting to include data from several vessels and compare the variations in the results. This, to further evaluate which parameters has the biggest impact on the results, and further highlight the possible variation in this sector.

CONCLUSIONS

The analysis demonstrated that the simplified models gave quite similar results as the measured values, but with some deviations. There were some differences is both fuel volume and emissions by switching to the alternative fuels which were investigated. It could also be partly explained by the measurements being imprecise, in particular the fuel measurements. This could potentially get better with more detailed models, or by generating models from a larger set of measurements. However, the average performance over the whole period of two years was quite good compared to the measurements.

Although the method of calculating the fuel and emissions results worked to satisfaction as a first assessment, it is clear that further work is needed. In particular, the models need to be further developed, more fuels need to be investigated, and more information about the realistic efficiencies for different loads needs to be found and applied. It also needs to be investigated how the models would change over time and under different conditions.

List of Symbols

η	[%]	Efficiency
ρ_{fuel}	[kg/l]	Volumetric mass density
e_{fuel}	[MJ/kg]	Gravimetric energy density
$k_{fuel}^{CO_2}$	[$\mathrm{t_{CO_2}/t_{fuel}}$]	Gravimetric CO_2 density
m	[kg]	Mass
P	[W]	Power
p	[−]	Power per unit
V_{fuel}	[$\mathrm{m^3}$]	Fuel volume
$\dot{V}_{fuel}$	[$\mathrm{m^3/s}$]	Volumetric fuel combustion rate

Nomenclature

AE1,AE2	Auxiliary Engines
DG1,DG2	Diesel generators
HFO	Heavy Fuel Oil
MeOH	Methanol
MGO	Marine Gas Oil
PWL	Piece-wise linear
SG	Shaft generator

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