The CO2 and fuel efficiency of the Sea Ranger Service sailing work vessels explained

By Dr. Teale Phelps Bondaroff, Wietse van der Werf, August 2019

The Sea Ranger Service uses sailing work vessels for its offshore work. These vessels, which are primarily powered by the wind, will produce between 80.4% and 94.6% less CO2 than motorised work vessels of similar size engaged in similar activities, and the fuel costs may be 82.1% and 94.3% lower.

This paper details our calculations pertaining to the fuel cost savings and CO2 emissions reductions resulting from operating a sailing work vessel as opposed to a motorised one. Throughout 2020, the Sea Rangers will carry out measurements to validate the exact CO2 output and fuel use onboard its operational vessel, these calculations serve as a preliminary validation of the model.

A. Cost-effectiveness

Fuel costs typically represent one of the largest costs associated with operating a vessel providing offshore services. Researchers generally estimate that fuel costs account for as much as 50-60% of a total ship's operating costs, depending on the type of ship and operations in which it is engaged.[1] Given that global marine fuel prices are predicted to rise significantly in the upcoming years,[2] operating a sail-powered work vessel is a highly efficient solution.

When comparing the savings from operating a sailing work vessel with that of operating a fossil fuel-powered work vessel, we can hold all other

The vessel *Fantastiko* which the Sea Ranger Service will deploy from October 2019 and is of similar size to *Sea Ranger I*, which is still under construction.

factors equal and focus on fuel consumption. Fuel cost does not represent the only cost difference between these two types of vessels, but other variations cannot be accurately calculated without operational data.

Estimating the exact fuel consumption of a vessel varies depending on a variety of factors and conditions, for example vessel size, age, and condition, engine power, vessel speed and gear configuration, sea state and weather conditions.[3]

Operation costs of the Sea Ranger vessel

For purposes of calculations, we are using the operational capabilities of the *Sea Ranger I*, a 22 meter sailing yacht, displacing 31 tonnes. While primary propulsion for this vessel will be canvass, sailing vessels of this type are equipped with an engine for purposes of navigating in and around ports, as well as effective navigation in adverse wind conditions, and where required to accomplish its objectives. Electricity on board the vessel comes from batteries charged by turbines which generate power whenever the propeller turns (such as when sailing).

The *Sea Ranger I* will be equipped with a John Deere 4045TFM50 marine diesel engine. The engine has an M3 rating, which makes it ideally suited for use in “offshore crew boats, research boats, short-range ferryboats, and dinner cruise boats,” and is compliant with all relevant international emissions regulations.[4] We are fortunate that the primary theatre of operation, the North Sea North Sea is an ideal location to operate a sail powered work boat, as this body of water has the second highest average annual wind speed in the world, second only to the Southern Ocean.[5]

The engine has an hourly fuel consumption of 26.3 L/hour.[6] Rotterdam fuel prices for low sulfur marine gas oil (LSMGO),[7] averaged between 1 February 2019 and 31 July 2019 is €481.50/mt (or €0.43 per litre).[8]

The daily average number of hours of engine use is difficult to calculate as engines will typically be used for entering and exiting port, in adverse conditions, and where necessary to accomplish tasks. The *Sea Ranger I* will operate on a 2 week rotation, which means it will need to enter and exit port every 2 weeks. Each rotation will require one entry and one exist to port, which we estimate will require 1 hour of engine use each. The vessel will be in operation for 301 days per year (43 weeks), which is roughly 22 rotations.

In addition to engine use in and around port, adverse weather and accomplishing tasks may required engine use. The typical full power operation of an M3 engine of this sort, as noted by the manufacturer, is no more than 4 hours out of every 12 hours. While there is potential for considerable variation in engine use, we can estimate an additional 24 hours of engine use per 2 week rotation. This works out to 26 hours of engine use per 2 week rotation, or 1.86 hours of engine use per day.

Calculation

We calculate the daily fuel costs as:

26.3 L/hour x 1.86 hours = 48.92 L/day x €0.43/L = €21.03/day

Thus, the daily fuel costs of the *Sea Ranger I* can be estimated at €21.03. Given 301 days of operation per year, this would give the *Sea Ranger I* an annual fuel cost of €6,330.03. Please note that this cost does not include lubricants and other engine necessities.

Operation Costs of Equivalent Powered Vessel

We can compare this amount to the fuel costs of an equivalent vessel powered exclusively by fossil-fuel engine. Given that the Sea Ranger Service model entails delivering a number of different maritime environmental services, in varying proportions throughout a year of operation, identifying analogous examples is difficult. As a result, we selected roughly analogous maritime activities conducted by vessels of a similar size to the proposed Sea Ranger Service test vessel, for which fuel consumption rates and costs are available, we then averaged all these numbers to generate a daily fuel cost of fulfilling the maritime services of the Sea Ranger Service with a fossil-fuel powered vessel.

Please note that for the purposes of the calculations powered vessel propulsion costs are fuel costs, and do not include other costs associated with maintaining the engine, such as maintenance, parts, and lubricants. For these calculations, we have used UK fisheries numbers (days operational and costs) averaged between 2011 and 2012.[9] For the purposes of cost calculation, we are holding all other costs as equal, Sea Ranger Service operations may be cheaper in other areas as well, further increasing the savings to clients.

Please also note that for purposes of averaging, we are considering these three scenarios to represent equal parts of the general operation of the Sea Ranger vessel, whereas actual operations may vary.

Scenario 1: A pot and trap fishing vessel over 12m

We saw the action of circulating between a series of pots or traps, with periods of sailing interspersed with periods of hauling (requiring the use of specialize equipment), as being roughly comparably to inspecting wind or seaweed farm installations, and to marine research including such activities as visiting sites to replace underwater acoustic equipment. The annual fuel costs of this type of vessel are €52,479, and vessels are typically operational for 171.5 days per year. This averages out to a daily fuel cost of €306, or 619 litres.

Scenario 2: Offshore trawler between 10 and 24m

We saw the action of a typical medium trawler operating not too far from shore as roughly comparable to patrolling an area as part of a monitoring operation, the types of activities involved in sample collection or wildlife observation as part of a scientific voyage, or visits to remote installations for inspection. The annual fuel costs of this type of vessel are €35,444, and vessels are operational for 162 days per year. This averages out to a daily fuel cost of €219, or 442 litres.

Scenario 3: Demersal trawler over 24m

Demersal trawling entails hauling a large funnel-shaped net along the bottom of the sea bed, given added drag. This is one of the most fuel intensive forms of fishing practiced in the UK, second only to pelagic trawling. This represents the most intensive level of activity, and could be seen as roughly comparable to very intensive habitat restoration efforts. It has been selected to serve as a rough maximal rate, given the size of the vessels and levels of energy involved. The annual fuel costs of this type of vessel are €429,733, and vessels are operation for 207.5 days per year. This averages out to a daily fuel cost of €2,071, or 4184 litres.

While there is considerable disparity between the fuel and cost amounts between the three scenarios, this reflects the considerable diversity in fuel costs in various fisheries.[10] The third scenario represents a maximal fuel expenditure scenario and this type of activated would only constitute a small percentage of the services provided by the Sea Rangers. A such, rather than simply averaging these fuel usage and expenditures, we instead calculated the comparative fossil fuel powered vessel using a ratio of 5:5:1 between these three different scenarios.

Likewise, we calculated the annual fuel cost of an equivalent fossil fuel powered vessel using 301 days of operation, rather than the shorter fishing seasons used in the three scenarios. In the table, the annual fuel costs of the three scenarios reflect the number of days of operation typical to those fishing seasons, 171.5, 162, and 207.5 respectively.

Under all scenarios, the fuel costs of the *Sea Ranger I* are considerably lower.

Table 1: Fuel Consumption, Costs, and Savings

Vessel Type	Daily Fuel Consumption (litres)	Daily Fuel Cost (€)	Annual Fuel Cost (€)	*Sea Ranger I* Fuel Cost Savings (%)
Sea Ranger I	48.9L	€21.03	€6,330	-
Powered Vessel Scenario 1	619L	€306.00	€52,479	87.9%
Powered Vessel Scenario 2	442L	€219.00	€35,444	82.1%
Powered Vessel Scenario 3	4184L	€2,071.00	€429,733	98.5%
Powered Vessel 5:5:1 Ratio	862.6L	€370.93	€111,651	94.3%

As a result, we have calculated that the daily fuel cost of operating the *Sea Ranger I* will likely be €21.03, resulting in annual fuel costs of €6,330.00. This would make the fuel costs of the *Sea Ranger I* between 82.1 and 94.3% lower than the fuel costs of a similar fossil fuel powered vessel providing similar maritime services.

Increased Engine Use Scenario

Given variable engine use, we calculated the same numbers using double the engine use by the *Sea Ranger I*. This, rather than 26 hours per 2 week rotation, we will use 52 hours per 2 week rotation. This averages to 3.71 hours of engine use per day, which is consistent with manufacturer guidelines for an M3 rated engine.

Thus, we calculate the daily fuel costs as:

26.3 L/hour x 3.71 hours = 97.57 L/day x €0.43/L = €41.96/day.

Thus, the daily fuel costs of the *Sea Ranger I* can be estimated at €41.96. Given 301 days of operation per year, this would give the *Sea Ranger I* an annual fuel cost of €12,628.87.

Table 2: Fuel Consumption, Costs, and Savings with Increased Use

Vessel Type	Daily Fuel Consumption (litres)	Daily Fuel Cost (€)	Annual Fuel Cost (€)	*Sea Ranger I* Cost Savings (%)
Sea Ranger I	97.6L	€41.96	€12,628	-
Powered Vessel Scenario 1	619L	€306.00	€52,479	75.9%
Powered Vessel Scenario 2	442L	€219.00	€35,444	64.4%
Powered Vessel Scenario 3	4184L	€2,071.00	€429,733	97.1%
Powered Vessel 5:5:1 Ratio	862.6L	€370.93	€111,651	88.7%

As a result, we have calculated that the daily fuel cost of operating the *Sea Ranger I* with increased engine use will likely be €41.96, resulting in annual fuel costs of €12,628. This would make the fuel costs of the *Sea Ranger I* between 64.4% and 88.7% lower than the fuel costs of a similar fossil fuel powered vessel providing similar maritime services.

B. CO2 saving

The need for reducing the shipping industries dependence on fossil fuels is pressing. The global shipping industry is responsible for emitting 938 million tonnes of CO2, approximately 2.8% of annual global greenhouse gas (GHG) emissions.[11]

Emissions from fossil fuel powered vessels include carbon dioxide (CO2), sulfur oxides (SOx), oxides of nitrogen (NOx), which are GHS, and particulate matter, which includes black carbon.[12]

In April of 2018, the International Maritime Organization (IMO) established the goal of reducing GHG emissions by at least 50% by 2050 compared with 2008 levels, with the aim to phase out emissions entirely.[13]

Ship emissions are responsible for approximately 2.8% of annual global greenhouse gas emissions.

The amount of pollutants emitted by a ship is proportional to the fuel consumed by that vessel, and as a result, the need for reducing the shipping industry's dependence on fossil fuels is urgent.[14] As a result, "eco-friendly vessels are recognized as a new competitive advantage because of environmental regulations, fines, and incentives."[15]

Calculations

We will use the same fuel consumption rates used in the fuel cost savings calculations in order to calculate the CO2 emissions of the *Sea Ranger I* and compare these emissions to those of powered vessels conducting similar operations. While there is considerably diversity in precise numbers, we selected a median emissions number with which to calculate the following numbers, and used the value of 3.082 kg CO2/L.[16] Regardless of the level of accuracy of this value, the relative CO2 emissions for the operation of the *Sea Ranger I* will remain constant.

Please note that emissions are only being calculated as direct emissions resulting from burning of fuel for propulsion. These values do not include embodied carbon of equipment and other materials used, or carbon emissions associated with land-based operations supporting the vessel (for example, transporting Sea Rangers to the vessel for their rotations).

Table 3: Comparative CO2 Emissions[17]

Vessel Type	Daily Fuel Consumption (litres)	Daily Emissions (kg CO2/Day)	Annual Days of Operation	Annual Emissions (metric tonne CO2/year)	*Sea Ranger I* Emissions Saved (%)
Sea Ranger I	48.9L	150.71	301	43.36	-
Powered Vessel Scenario 1	619L	1,907.76	171.5	327.18	86.7%
Powered Vessel Scenario 2	442L	1,362.24	162	220.68	80.4%
Powered Vessel Scenario 3	4,184L	12,895.09	207.5	2,669.28	98.4%
Powered Vessel Average	862.6L	2,658.53	301	800.22	94.6%

The following table compares the emissions resulting from 52 hours of engine use per 2 week rotation.

Table 4: Comparative CO_2 Emissions with Increased Engine Use[18]

Vessel Type	Daily Fuel Consumption (litres)	Daily Emissions (kg CO2/Day)	Annual Days of Operation	Annual Emissions (metric tonne CO2/year)	*Sea Ranger I* Emissions Saved (%)
Sea Ranger I	97.6L	300.80	301	90.54	-
Powered Vessel Scenario 1	619L	1,907.76	171.5	327.18	72.3%
Powered Vessel Scenario 2	442L	1,362.24	162	220.68	59.0%
Powered Vessel Scenario 3	4,184L	12,895.09	207.5	2,669.28	96.6%
Powered Vessel Average	862.6L	2,658.53	301	800.22	88.7%

We estimate that the operation of the *Sea Ranger I* with increased engine use, will produce between 59.0% and 88.7% less carbon than a powered vessel engaged in delivering similar maritime services.

C. Validation

From October 2019 the Sea Ranger Service will start operating the 22.8 meter sailing vessel *Fantastiko* which is of similar size to *Sea Ranger I* (still under construction). Over a period of 6 months we will record engine use and fuel consumption, from which we can calculate emission output from this vessel. Results will be published in a validation study in March 2020, followed by a second publication in September 2020. This will enable the Sea Ranger Service to validate and compare the actual outputs and usage against the calculated numbers in this paper. For more information, please contact wietse@searangers.org

D. Endnotes

[1] Thomson Reuters Research cited by George, Libby, and Ghaddar, Ahmad. (2018). “New Rules on Ship Emissions Herald Sea Change for Oil Market.” *Reuters*, May 17; Stratiotis, Elizabeth. (2018). “Fuel Costs in Ocean Shipping.” More Than Shipping.com, January 22. Available at: https://www.morethanshipping.com/fuel-costs-ocean-shipping/; and see Davie, Sarah, Ninto, Cóilín, Officer, Rick, Lordan, Colm, and Jackson, Emmet. (2015). “Modelling Fuel Consumption of fishing vessels for predictive use.” *ICES Journal of Marine Science*, 72:2, 708-719, 708.

[2] Bonduelle, Antoine, Métivier, Simon, and Rynikiewicz, Christophe. (2015, October). “Roadmap for Sail Transport.” *Interreg IVB SAIL*. Available at http://www.nsrsail.eu/wp-content/uploads/2015/12/Roadmap-SAIL-Transport-WEB-Bonduelle-WP4.pdf (accessed January 26, 2019), p.27; and see World Maritime News. (2018, October 26). “Ship Operating Costs Set to Rise in 2018 and 2019.” Available at https://worldmaritimenews.com/archives/263339/ship-operating-costs-set-to-rise-in-2018-and-2019/ (accessed January 25, 2019).

[3] Tyedmers, 2001; Schau et al., 2009; Driscoll and Tyedmers, 2010 cited by Davie, Sarah, Ninto, Cóilín, Officer, Rick, Lordan, Colm, and Jackson, Emmet. (2015). “Modelling Fuel Consumption of fishing vessels for predictive use.” *ICES Journal of Marine Science*, 72:2, 708-719, 709.

[4] John Deere (n.d.). “Marine Applications – Diesel Engine Ratings.” Available at https://www.deere.com/en_CAF/docs/product/equipment/marine_engines/marine_engine_pocket_guide.pdf (accessed July 20, 2019), p. 8-11.

[5] Of 12 major bodies of water surveyed by Rehmatulla, Nishatabbas, Parker, Sophia, Smith, Tristan, and Stulgis, Victoria. (2017). “Wind Technologies: Opportunities and Barriers to a Low Carbon Shipping Industry.” *Marine Policy*, 75, 217-226, 218.

[6] John Deere (n.d.). “Marine Applications – Diesel Engine Ratings.” Available at https://www.deere.com/en_CAF/docs/product/equipment/marine_engines/marine_engine_pocket_guide.pdf (accessed July 20, 2019), p. 8-11.

[7] This fuel type as a maximum of 0.1% sulfur distillate making it compliant with 2015 ECA Regulations.

[8] See Ship and Bunker (2019, July 31). “Rotterdam Bunker Prices.” Available at https://shipandbunker.com/prices/emea/nwe/nl-rtmrotterdam#LSMGO.

[9] Anderson, John, Stewart, Anne-Margaret, Curtis, Hazel, and Dawe, Robert. (2013). “2011 Economic survey of the UK Fishing Fleet – Key Features.” *Seafish Economics*, May. All numbers used are averages between 2011 and 2012 and are corrected for inflation.

[10] Anderson, John, Stewart, Anne-Margaret, Curtis, Hazel, and Dawe, Robert. (2013). “2011 Economic survey of the UK Fishing Fleet– Key Features.” *Seafish Economics*, May, p.13.

[11] Mofor, Linus, Nuttall, Peter, and Newell, Alison. (2015, January). “Renewable Energy Options for Shipping: Technology Brief.” *International Renewable Energy Agency (IRENA)*. Available at http://www.nsrsail.eu/wp-content/uploads/2015/12/IRENA_Tech_Brief_RE_for-Shipping_2015.pdf (accessed 25January 2019), p.3; and see IMO. (2015). “Third IMO Greenhouse Gas Study 2014.” *IMO*, London, UK.

[12] World Shipping Council. (2018). "Air Emissions." Available at http://www.worldshipping.org/industry-issues/environment/air-emissions (accessed 26 January 2019).

[13] IMO. (2018, April 13). "UN Body Adopts Climate Change Strategy for Shipping." Available at http://www.imo.org/en/mediacentre/pressbriefings/pages/06ghginitialstrategy.aspx; and see DeBeukelaer, Christiaan. (2018, May 27). "Plain Sailing: How Traditional Methods Could Deliver Zero-Emission Shipping." *The Conversation*. Available at https://theconversation.com/plain-sailing-how-traditional-methods-could-deliver-zero-emission-shipping-97180 (accessed January 26, 2019).

[14] Harrould-Kolieb, Ellycia, and Savitz, Jacqueline. (2010, October). "Shipping Solutions: technological and Operational Methods Available to Reduce CO2." *Oceana*. Available at https://oceana.org/reports/shipping-solutions-technological-and-operational-methods-available-reduce-co2 (accessed January 26, 2019), 12.

[15] Nam, Hyunjeong, and Lee, Taehee. (2017). "A Study on Green Shipping in Major Countries: In the View of Shipyards, Shipping Companies, Ports, and Policies." *The Asian Journal of Shipping and Logistics*, 33:4, 253-262, 254.

[16] Kontovas, C.A., and Psaraftis, H.N. (2009). "An online ship emissions calculator as a decision-making aid and policy evaluation tool." Paper presented at 13th Congress of International Maritime Association of Mediterranean (IMAM), Istanbul, Turkey, 12-15 October. Available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.494.2054&rep=rep1&type=pdf. Other sources offered variation around this number: 3.530 kg CO2/L suggested Lean & Green Europe (2016). "Introduction to the calculation of CO2 emissions for participation in Lean & Green." Available at http://lean-green.eu/wp-content/uploads/2017/08/4-Introduction.pdf (accessed July 20, 2019); while Sailors for the Sea. (n.d.). "Carbon footprint." Available at https://www.sailorsforthesea.org/programs/green-boating-guide/carbon-footprint (accessed July 20, 2019), suggested and 2.545 kg CO2/L.

[17] Calculated using emissions value of 3.082 kg CO2/L.

[18] Calculated using emissions value of 3.082 kg CO2/L.