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The evolution of the fishing fleet and its energy demand

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Abstract

Maritime and coastal areas are the lifeblood of many countries, being essential to their well-being. They provide trade routes, regulate the climate, and supply both organic and inorganic resources, along with energy, a crucial requirement for living and recreation. However, there are emerging disparities and barriers in terms of marine exploitation. On the one hand, existing and evolving technologies and knowledge allow better utilization of the sea, while on the other hand, the cumulative effect of human activity leads to conflicts of interest and to a deterioration of the marine environment. This article aims to consider the impact of changes in the world economy on the evolution of the fishing fleet, including the characteristics of vessels produced in consecutive years. We also attempt to determine the most common type of vessel presently operating in the world fleet. A number of external factors impact the organization and operation of the world's fishing fleet, including economic, geographical, and political factors. The strength of each factor varies depending on the conditions in which the fleet operates. Also, we would also like to establish to what extent efforts aimed at energy demand reduction have affected the characteristics of the current fleet, determining the scale and direction of change, while also identifying any relevant constraints and limitations. The intention behind this paper is to discover the size and structure of the fishing fleet and whether it is changing as a result of environmental transformation. With this objective in mind, we have outlined a review of the literature and used statistical methods in order to carry out a comparative analysis of the size and structure of the world's fishing fleet.

Introduction

The EU's Integrated Maritime Policy (IMP) sets out a coherent strategy for the sustainable development of the maritime sectors. As stated in the European Commission's 2007 Blue Paper, the main objectives of the IMP are to develop and implement integrated, coordinated, coherent, transparent, and sustainable decision-making in relation to the oceans, seas, coastal and insular regions, and maritime sectors (Commission of the European Communities, 2007). These objectives are based on the premises that all matters relating to the oceans and seas are interlinked and that maritime economic and political activities should be conducted in a harmonized and well-planned manner in order to achieve the desired results. Contemporary challenges for the IMP include the creation of sustainable fishing principles, ensuring the supply of quality food products, the development of coastal communities, and ensuring profitable production activities as well as attractive and safer jobs (Czermański, Oniszczuk-Jastrząbek & Pawłowska, 2021, p. 48).

In harmony with the general trend, fishing – much like other industries – is focusing on energy demand reduction, the use of alternative energy sources, and a more efficient utilization of energy sources. The resulting changes in the structure of the fleet have set a new direction for the industry.

It is necessary to look for new, innovative energy sources that are both clean and secure. Marine energy is one such source, being widespread, geographically diverse, and renewable. The seas and oceans have the potential to become an important source of clean energy, and the energy resources available globally exceed both current demand and projected energy needs. The Carbon Trust has estimated that the global market for wave and tidal energy could be worth up to €535 billion between 2010 and 2050 (Carbon Trust, 2006). The development of marine and ocean energy can strongly support the achievement of strategic goals in several ways, by increasing renewable energy generation capacity, providing clean and renewable energy and therefore contributing to climate change and energy sustainability goals, while also creating new, high-quality jobs (European Commission, 2014b). This development includes *blue growth*, a long-term strategy to support sustainable development in the fisheries and marine sector, which is defined as '(...) *economic growth and social development based on the use of the living resources of the oceans and inland waters, while minimizing environmental degradation, biodiversity loss and unsustainable use of aquatic resources*' (Ababouch, 2015). At the same time, the EU strategy, which has adopted the same approach, highlights the importance of marine areas for innovation and growth in five sectors: ocean energy, aquaculture, biotechnology, tourism, and mineral extraction. Consequently, the EU's overall strategy does not focus exclusively on fisheries, even though the fishery sector is traditionally a cornerstone of the *blue economy*. This lack of focus is due to the expected, relatively low growth potential in the fishery sector, as compared to other *blue economy* sectors (European Commission, 2014a).

Impact on capacity management in fishing fleets

The vessels that make up the fishing fleet comprise all those used to catch, dredge, search for, transport, off-load, preserve and/or process fish, shellfish, other aquatic organisms, residues, and plants (FAO, 2021a). This article looks at *fishing vessels* used only or primarily for catching fish. Depending on the scale of operation, area, and fishing region, these vessels differ with respect to parameters such as payload measured as gross tonnage (GT), boat length, deadweight (DWT), and total engine power. It was estimated that in 2018, the global yield from the fishing industry reached about 179 million metric tons, with the total value of first-sold goods being estimated at $401 billion. Of that total, 156 million metric tons were used for human consumption, corresponding to an estimated annual supply of 20.5 kg per capita. The remaining 22 million metric tons were for non-food uses, mainly for fishmeal and fish oil (FAO, 2020). Between 2021 and 2030, the projected year-on-year increase in production is 1.2% and is expected to translate into 201 million metric tons at the end of this period, representing an increase in annual production of 23 million metric tons (+12.8%) over the 2018–2020 average (OECD-FAO, 2021).

The excess capacity of fishing fleets is mainly due to the rapid development of technology and the intensity of efficient fishing. The development of technology, and therefore improvement in engine design, has had a great impact on the motorization of the global fleet (Rousseau et. al., 2019, p. 12242). This relationship has had a strong impact on fish stocks and fish product supply globally in recent decades (Villasante & Sumaila, 2010, p. 720). Therefore, capacity management is an important tool designed to ensure the sustainable exploitation of fishery resources, which is among the principal objectives of the Common Fisheries Policy. The excess capacity of fishing fleets, and hence the overexploitation of fish, is often cited as a primary contributing factor in the decline of commercial resources. Spatial management policies, including the setting up of marine protected areas (MPAs), are increasingly proposed as a way to manage the distribution of fishing vessels. However, it is largely up to human behavior, including compliance and willingness to protect all or some high seas areas, whether the expected socio-ecological benefits envisioned by these policies can be accomplished (Collins et al., 2021, p. 743). Key determining factors for the coverage of fish stocks by MPAs include (European Commission, 2018, p. 11):

- the locations outlined in fisheries partnership agreements (FPAs) determine what they protect, and the location of FPAs relative to each other (their interconnectivity) contributes to network benefits;
- the impact of MPAs is decided by their number and size within the network and the total size of

the network. The larger the total area covered, the greater the conservation benefits (all else being equal). However, it remains unclear how a single MPA's relative impact compares to a network covering the same total area;
- the nature of conservation measures covered by MPAs – no-take zones provide greater conservation benefits than multi-purpose areas, but from a fisheries perspective, the role of no-take zones depends, for example, on the extent to which fishermen can take advantage of externalities (e.g., air pollution, water pollution, noise and vibration);
- the movement of organisms in and out of the area; less outbound movement of a species or population, such as low-mobility invertebrates or other sedentary species, leads to greater conservation benefits;
- activity outside the MPA – if surrounding habitats and water quality are degraded, MPA effectiveness may be undermined. Similarly, the greater the fishing pressure on stocks outside the MPA, the greater the proportion of the stock covered by MPAs must be in order to maintain the harvested stock.

Over the past three decades, rights-based fisheries management systems in which fishermen are given individual fishing quotas have been introduced in many fisheries worldwide in order to address problems of excessive fishing and stock depletion. These systems changed the incentives of fishermen from maximizing their share to minimizing the harvesting cost for a given amount of fish (Asche, Bjørndal & Gordon, 2009). Asche's research showed that the number of vessels was reduced by at least 30% within a few years of the introduction of individual fishing quotas. Consequently, it can be seen that traditional management regimes that were designed to govern the fishing effort, such as limited access, have allowed for significant overcapacity (Asche, Tranberg Bjørndal & Bjørndal, 2014, p. 170). Over the past few decades, total fish production has grown significantly on the seas adjacent to all continents, with the exception of Europe (which has seen a gradual decline since the late 1980s, although it has increased slightly in recent years) and the Americas (which has seen fluctuations since the peak period in the mid-1990s) (FAO, 2020).

In 2018, the total global number of fishing vessels was estimated at 4.56 million, down 2.8 percent from 2016, with the EU fleet accounting for just over 2 percent of the global total (FAO, 2020). According to the study of Sumaila and Pauly, the size of the fishing fleet is higher than that needed to ensure conservation (Sumaila & Pauly, 2007).

In 2018, the EU fishing fleet comprised approximately 81,199 vessels (of which 22% were out of service) with a total GT of 1.56 million metric tons and engine power of 6.2 million kilowatts. The EU's fleet capacity continues to decline steadily: by 2.1% in terms of numbers, 2% in terms of engine power, and 0.4% in terms of GT, as compared to 2017 (European Commission, 2020).

Size and structure analysis of the fleet – original research

Objective of this study

The aim of this study was to assess the potential of the world fishing fleet expressed primarily in terms of the weight, GT, and engine power of fishing vessels. This study was based on 29,186 records, giving consideration to variables such as vessel type, overall length, draft, side height, total main engine power, generator power, and cargo capacity. The research used full data valid as of 25 May 2021.

Research methodology and data sources

This research used statistical methods and measurements, along with elements of decision theory. When describing the distributions of selected variables, the following measures of key regularities were used: the arithmetic mean of the central tendency, the standard deviation of the dispersion, and the skewness coefficient of the asymmetry distribution. The universality of the statistical measures applied here means the research methodology needs no in-depth discussion. This part covers the results of pure statistical analysis carried out on the world fishing fleet in order to determine the technical parameters (length, capacity, and weight) adopted in further studies.

Vessel data were extracted from the IHS Markit commercial database (Maritime Portal, 2021), reflecting the situation as on 27 May 2021. A total of 31,514 records were obtained pertaining to fishing vessels categorized into two groups: "fish-catching vessels" and "other fishing vessels." Unfortunately, some of the records did not have complete technical information on the vessels, and so we ended up with 29,186 vessels fully covered by the technical parameters required in this research, which represented 92.6% of the entire fishing fleet population.

Free open-source computer software was used for the study: for supporting statistical analysis – JASP version 0.14.1 and for data visualization – RStudio (v. 4.1.0) with ggplot2 library (v. 3.3.3).

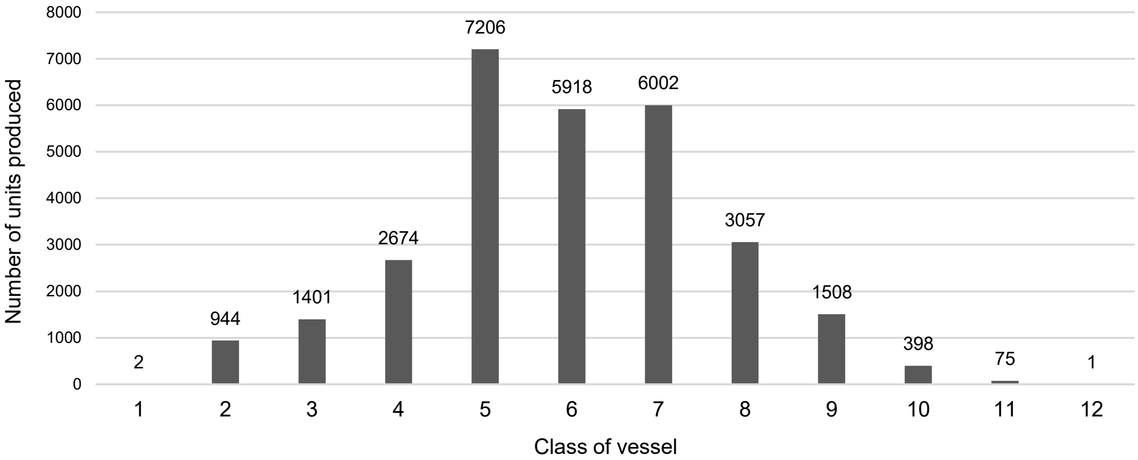

Figure 1. The world fishing fleet classified by size class. Data from May 27th 2021

In order to organize the data and assign individual vessels to larger sets, it was decided to classify them according to the FAO-approved division into 12 classes depending on GT size (Figure 1). This assignment resulted in sets of different sizes, where three of them (classes 5, 6, and 7) represented more than 65.5% of the total fleet.

Test results

The capacity of the world fishing fleet, as classified by categories of vessel length, is shown in Table 1. It showed that statistically the newest vessels belonged to groups covering smaller vessels, i.e., up to 10 meters (LLT10) and between 12 and 18 meters (L12T18). On the other hand, the oldest were those between 30 and 36 meters in length (L30T33, L33T36). The largest GT and the greatest total engine power were found in the largest vessels over 42 meters long. These also constituted the largest cluster in the base.

Table 1. Basic characteristics of the world fishing fleet by vessel length (based on IHS Markit database (Maritime Portal, 2021))

Length of vessel	Number of vessels	GT	Motor power in kW	Average age in years
LLT10	308	68,381	54,691	28
L10T12	8	342	1675	30
L12T18	2011	109,470	358,814	27
L18T24	6433	824,570	1,732,525	32
L24T30	6388	1,200,538	2,247,398	32
L30T33	2001	548,391	928,706	34
L33T36	2028	547,086	1,088,891	35
L36T42	3170	1,124,511	2,302,980	31
LGET42	9166	8,909,356	13,661,386	29
Total	**31,513**	**13,332,645**	**22,377,066**	**31**

In the data for 31,510 vessels that had a stated tonnage, we observed a high variability for the following basic measures: registered GT, total engine power, boat length, and year of production. Half of the analyzed vessels were manufactured after 1989, with a high standard deviation of 16 years. This was due to the fact that the durability of particular hull structures was extremely varied, and it was difficult to define the average service life of a given vessel due to many factors, such as operating conditions, care and maintenance, and the materials used for production.

The related index of GT and total engine power were similarly statistically scattered; depending on the increase in payload, the average power of a given vessel increased. In the whole of the analyzed set, the average GT was 423.1, but for as many as half of the vessels the GT value did not exceed 184 (Table 2). The average was increased by extremely high GT values for vessels of the highest classes (Table 3, 4), reaching as much as 49,367 (the maximum value in the set) (Table 5).

Table 2. Descriptive statistics of the analyzed population of the world fishing fleet

	GT	Total power (kW)	Length	Year of production
Correct data	31,510	25,270	31,207	31,208
Missing data		6244	307	306
Average	423.124	885.519	36.095	1990
Median	184	597	31	1989
Standard deviation	869.310	958.972	17.321	16.320
Minimum value	3	40	2.9	1882
Maximum value	49,367	14,400	228.610	2021

Table 3. Correlation between total engine power and GT

Variable		Total power (kW)	GT
1. Total power (kW)	Pearson's *r*	–	
	p-value	–	
2. GT	Pearson's *r*	0.535	–
	p-value	< 0.001	–

Table 4. Classification of the fishing fleet by GT (FAO, 2021b)

Minimum GT value	Maximum GT value	Ship class
0	0.9	01
1	24.9	02
25	49.9	03
50	99.9	04
100	149.9	05
150	249.9	06
250	499.9	07
500	999.9	08
1000	1999.9	09
2000	3999.9	10
4000	9999.9	11
10 000	–	12

Table 5. Sum of total boat engine power in a given class and average for the class

Fleet GT class No.	Total fleet engine power (kW)	Average engine power (kW)
1	1,883	470.75
2	279,445	536.36
3	260,081	384.17
4	742,193	507.66
5	2,572,892	428.74
6	3,173,066	600.39
7	5,332,882	908.96
8	3,616,333	1,215.17
9	3,277,349	2,136.47
10	1,987,085	3,149.10
11	1,092,223	3,677.52
12	41,634	2,775.60
Total	22,377,066	885.52

In the analyzed collection, there were a handful of boats manufactured before 1950, but most of the current fleet were produced from the years 1950–1960 onwards. The production peak was in the period 1980–1990, when the production of Class 8 and 9 boats (500–2000 GT) tended to increase. A similar increase in the production of large boats also appeared around 2010 (Figure 2).

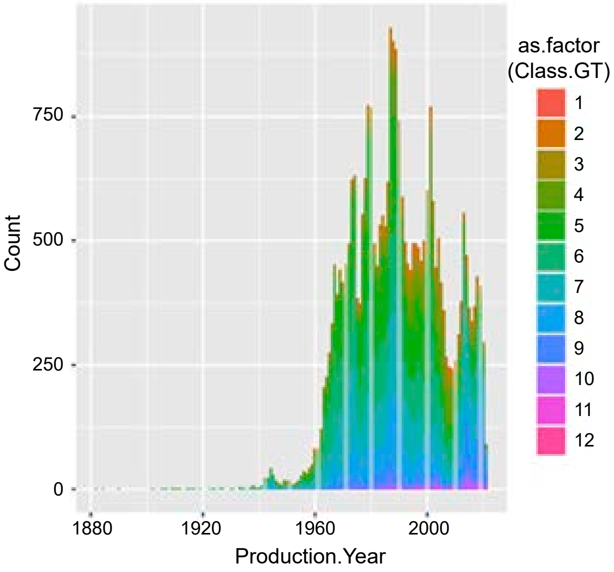

Figure 2. Number of vessels produced in a given year, classified by vessel class

An analysis of the total engine power for each of the defined classes showed how dispersed this measure was, not only within the whole set, but also in the assumed subsets. The average values in classes 2–4 (1–100 GT) were close to each other, from classes 5 to 8 (100–1000 GT) the increase was linear, and above class 8 the increase had exponential characteristics. It is noteworthy that there was a large dispersion in each class, as illustrated by the standard deviation and single vessels exceeding the average power of vessels categorized up to four classes higher (Figure 3).

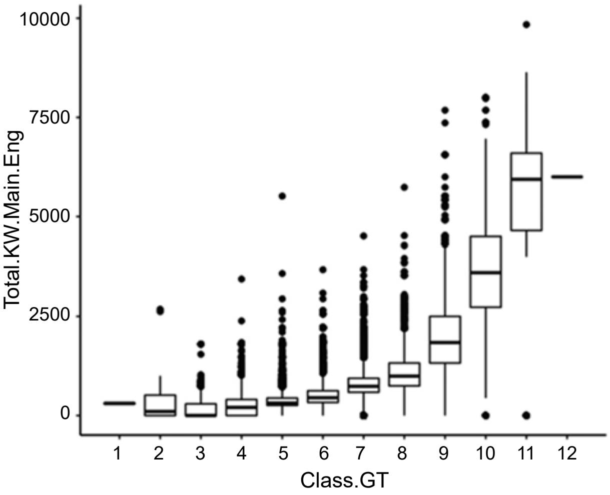

Figure 3. Overall engine power of a boat in relation to its class

In individual years, the demand for boats of particular classes did not change, or changed only slightly and for a short period of time. An analysis of the data showed a lower density of small boat production (classes 1–4) until 1980, but this was possible because such boats tend to have a shorter service life. Their number increased dramatically until 2010, where a tendency emerged for production to slow down. At the same time (2010), a gap appeared in classes 8–9, but this went back to normal in the subsequent years. Other classes did not show great variability; a clear predominance of classes 5–7 could be seen in fixed proportions and at a stabilized level (Figure 4).

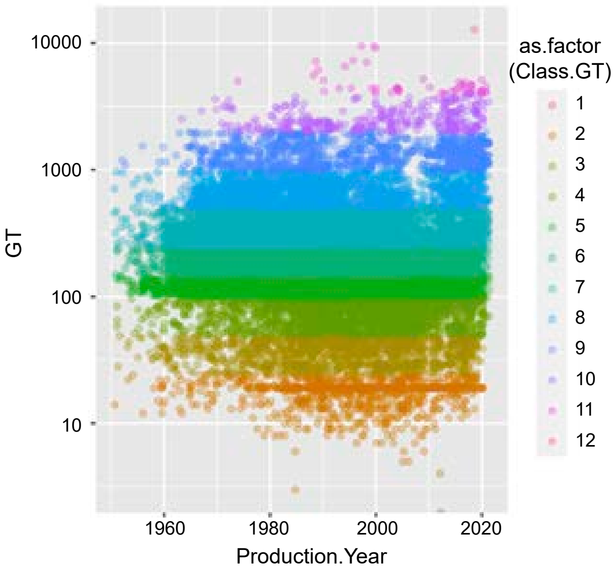

Figure 4. GT of boats according to their class based on the year of production

An analysis of changes in production trends (e.g., downsizing) was carried out on the basis of an analysis of the vessels (and the power of their engines) that were manufactured in successive years starting in 1950. These were then considered in terms of the GT class to which they belonged. The results turned out to be again very dispersed, without providing a basis on which to confirm that the average engine power increased (or decreased) in a given class. An interesting case was a series of large vessels (class 11) with an extremely low power of about 1000 kW, a value typical of much smaller boats (class 7). However, their production only took place in the early 1980s (Figure 5).

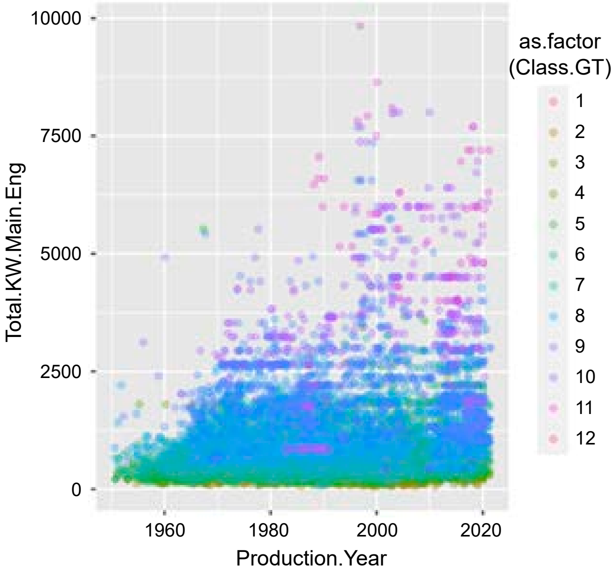

Figure 5. Total engine power of vessels produced after 1950 by GT class

Also, an examination was carried out to establish a correlation between the year of production and total engine power. However, no strong correlation was found. Therefore, it can be assumed that the characteristics of boats produced during the last 70 years have not changed (Table 6).

Table 6. Correlation between the year of production of a boat and its total engine power

Variable		Year of production	Total engine power
1. Year of production	Pearson's *r*	–	
	p-value	–	
2 Total engine power	Pearson's *r*	0.195	–
	p-value	< 0.001	–

Energy requirements of the world's fishing fleet

Bearing in mind the sustainable development goals of the United Nations, it should be emphasized that while fishing is a strategic and supported component of the blue economy, it contributes quite significantly to man-made GHG emissions through fuel consumption by vessel traffic and processing.

These emissions can be estimated by two methods. We can estimate fuel demand or measure actual fuel use. The second model has limited feasibility, as there is as yet no requirement for fishing vessels to report fuel consumption. Therefore, we are left with the first model, which has its limitations as it is based on historical averages.

To determine the potential GHG emissions, it is necessary to calculate the total engine power of ships comprising the world fishing fleet, assume the average time of use of that power in a year, and correlate that with the emission factor of marine fuels used in the sector under analysis. Since fishing vessels are usually smaller vessels, they are under pressure to reduce the space available for the engine. Therefore, medium-speed diesel engines based on Marine Gas Oil (MGO) are most often found on this type of vessel. In total, there were only 66 fishing vessels powered by residual fuel (HFO), with only nine powered by LNG. Therefore, nearly the entire world fishing fleet is distillate-based.

In order to calculate the annual CO_2 emissions of the fishing fleet, some initial assumptions were made. Knowing the total power of the main engine room, the time of its operation needed to be determined. For simplicity, the average time at sea of fishing vessels was assumed, following Kirkley and Squires (Kirkley & Squires, 1999), to be 285 days per year, without distinction between berthing, maneuvering, and at-sea stages. Thus, the total annual time at sea for one vessel was estimated as 6840 hours. An assumption of power use for MCR = 0.8 was also made, while fuel consumption was set at 180.0 g MGO per 1 kWh of power (Kuiken, 2012). The above assumptions were only the authors' suggestions. However, we are aware that these values vary with time and location, changes and restrictions in fishing being a product of decision-making at EU or national level aimed at curbing fish capture. Variability occurs in terms of fuel consumption per 1 kWh of engine power depending on atmospheric or technical conditions (Czermański, 2019, p. 77). Consequently, it was possible to determine the annual fuel demand (FD) of the world fishing fleet by the following formula:

$$\mathrm{FD} = \mathrm{TEP}\cdot T_{AS}\cdot \mathrm{MCR}\cdot 180.0 \qquad (1)$$

where:

TEP – total engine power of the fishing fleet (18,560,828 kW),

T_{AS} – total time at sea (6840 h),

MCR – maximum continuous rating of the engine (0.8),

and assumed MGO supply per 1 kWh (180.0 g/kWh).

The calculation results indicated that, under the assumed operating conditions, the annual fuel demand of the fishing fleet could amount to 18,281,673 metric tons of MGO fuel. Considering the fact that slow steaming is rare in the segment it may be assumed that the result depends primarily on the time spent at sea by individual vessels during the year, which is a consequence of the seasons and – perhaps more importantly – closed seasons or even fishing bans, especially within the EU's Atlantic seas and oceans. Therefore, fishing restrictions or limits may turn out to be the basic tool for regulating emissions in this segment. However, considering that as many as 12% of all employees in the EU blue economy sectors are employed in the fisheries sector (more than 540,000 people relying on this sector for their livelihoods), and fisheries account for 11% of the gross value (GVA) of the blue economy, i.e., EUR 19.36 billion (Comer et al., 2017, p. 18; European Commission, 2021), such a tool must be used with utmost caution.

With the abovementioned annual marine fuel demand of the world fishing, it is possible to estimate potential yearly emissions of major pollutants and GHG from the fisheries sector. Using the emission intensity standards for different types of marine fuels (Czermański, 2019), we can estimate that the consumption of over 18.28 million metric tons of MGO per year generates:

- 58.6 million metric tons of CO_2,
- 1.21 million metric tons of NOx,
- 50.8 thousand metric tons of SOx,
- 25.4 thousand metric tons of PM.

Conclusions

Research concerning the world's fishing fleet is scarce in the literature. Also, it does not seem to be of much interest to the International Maritime Organization (IMO) in connection with the reduction of pollution and GHG emissions to air. This sector is undergoing decarbonization, but no distinctions are currently made as to the types of vessels, but this

Table 7. Average values of basic technical parameters of the world fishing fleet from 2000 to 2019

Year of production	Av. GT	Av. main engine power (kW)	Av. DWT	Av. length (m)
2000	363.35	769.87	142.72	31.25
2001	289.82	620.86	74.76	30.93
2002	267.31	657.70	55.37	30.17
2003	360.97	815.92	129.50	31.57
2004	330.43	670.83	112.92	31.35
2005	232.75	539.32	60.32	28.72
2006	260.47	579.92	95.29	29.72
2007	239.55	545.08	71.08	28.27
2008	248.45	612.05	99.06	29.57
2009	302.21	638.13	125.21	30.39
2010	372.73	719.55	128.48	35.64
2011	384.69	583.91	63.93	37.98
2012	439.89	765.92	93.01	37.63
2013	550.74	893.75	113.73	41.58
2014	701.15	1169.86	217.02	45.18
2015	622.52	1044.36	224.48	43.33
2016	524.07	772.19	150.02	39.56
2017	526.12	874.97	157.53	38.12
2018	635.77	921.96	202.41	41.85
2019	880.94	1110.33	317.55	47.48
Mean value	**428.45**	**777.31**	**130.42**	**35.48**

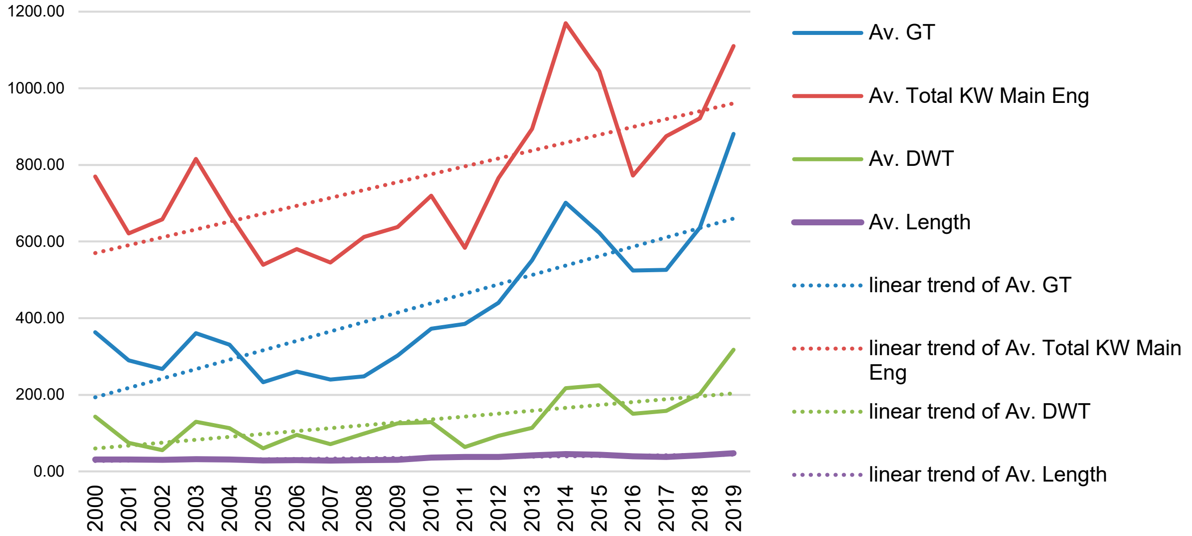

Figure 6. Basic technical parameters of the vessels of the world fishing fleet from 2000 to 2019 (based on Table 7)

is not the case for the EEDI and EEXI indexes, which are implemented for particular types of cargo and passenger ships. The regulations introducing these two indexes do not envisage a fishing vessel category. The average values of the basic technical parameters and the development of the basic technical parameters of the world fishing fleet between 2000 and 2019 should be presented here (Table 7, Figure 6).

As shown in Table 7 and confirmed by the trend lines in Figure 6, the average registered GT of these vessels has been increasing in recent years and has exceeded the 400 GT limit since 2012. This is the limit above which all newly-built ships falling under MNARPOL Annex VI must comply with the EEDI index (IMO MEPC 62), while existing ships must comply with the EEXI index (IMO MEPC 76) (IMO, 2011; 2021). It is therefore reasonable to expect that fishing vessels could also be included in the IMO decarbonization of the maritime fleet. By 2030, the EEXI reductions of CO_2 will be different than in 2019, as new ships will be introduced either as direct replacements for existing ships that are being decommissioned or as ships introduced to meet increased commercial demand. New ships built in 2022 and beyond will already meet the EEXI requirements through their compliance with the equivalent EEDI requirements.

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