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THE ECO-EFFICIENCY OF FISHERIES IN EU COUNTRIES

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ABSTRACT: The main goal of this article was to (1) assess the dynamics of eco-efficiency of fisheries in EU countries and its components and (2) identify potential sources of inefficiencies and efficiency surpluses through slack analysis. The hybrid data envelopment analysis (DEA) model was used for the 2008-2019 period. Progress in eco-efficiency was found among 11 countries (out of 23), but the average eco-efficiency index for the sample was 0.988. Differences in the levels and dynamics of eco-efficiency between the studied countries were mainly driven by the efficiency change component, i.e. internal factors. The largest input-saving potential was found in relation to number of employees and gross tonnage of the vessel, suggesting that sample countries deal with the problem of overinvestment and overstaffing. We also found that greenhouse gas emissions could be reduced by approximately a third.

KEYWORDS: sustainable development, fisheries, marine resources, data envelopment analysis

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Introduction

Faced with declining levels of maritime biodiversity, humanity has become forced to simultaneously maintain a socioecological balance and sustain satisfactory levels of fish catches. The idea of sustainable fisheries stems from the idea of sustainable development, which is the simultaneous possibility of meeting present needs and not limiting the possibility of meeting these needs in the future. This idea is based on simultaneous work on three levels – social, economic, and ecological – making it possible to achieve the well-being of individuals and entire societies (Unic Warsaw, 2015). One of many methods for quantitatively measuring the implementation of sustainable development is to examine eco-efficiency levels (Caiado et al., 2017). In the face of environmental catastrophes and societies' continued dependence on fisheries, it is important to know effective institutional solutions that can reconcile the needs of current and future generations.

The fishing industry is not a green industry, but some efforts are being made to change this. For example, the European Union (EU) is trying to introduce sustainability principles, including multiannual management plans, Total Acceptable Catches (TACs), closed seasons for fishing, and other environmental restrictions. But is the implementation of sustainable fishing principles producing satisfactory results in light of current social, economic, and environmental challenges? Research in this area would provide answers on how to achieve high levels of fishing while caring for the health of the environment and society.

The purpose of this research was to assess the level of eco-efficiency of fisheries in EU countries

This research aims to broaden the knowledge of sustainable fisheries by using secondary data, administrative data, and other statistical data sources. It is based on a review of the agricultural (as a broad field) and marine (as a specific field of science) literature. The next stage is to construct and calculate eco-efficiency indices. The eco-efficiency index is a relationship between effects – O1 (i.e., good output presented as a capture production quantity) and O2 (i.e., bad output presented as greenhouse gas emissions in the fishing sector) – and inputs: I1, average gross tonnage (GT); I2, labour input; I3, costs of consummated energy; and I4, consumed fuel.

Data envelopment analysis (DEA) was used to construct these indices. In contrast to existing studies in the literature (Avadí et al., 2014; Avadí & Acosta-Alba, 2021), this study was conducted at the international level rather than at the national level. In other words, in this study, the decision-making units (DMUs) were entire countries rather than individual vessels, which added certain political and managerial dimensions. Also, this study covered a longer period than is usually done in the literature (Vázquez-Rowe et al., 2010; González-García et al., 2015). The shift of this study to the sectoral level can attract the other groups of stakeholders. These can be officials and politicians related to national and international maritime economies, especially those connected with the process of maritime legislation regarding fish catches and other qualitative regulations.

An overview of the literature

Sustainable Fisheries

Overfishing is a serious problem for the global marine economy. Today, nearly 90% of the world's wild fish stocks are overfished or threatened with extinction. Nearly 60% of these stocks are completely fished out, indicating the total extinction of these species (FAO, 2020). Sustainable fishing minimises its impact on the marine ecosystem. Fishing in such a system aims to leave more fish in the seas and oceans and does not affect other marine animals, thus not disturbing the marine ecosystem's natural balance.

Nowadays, fisheries are assessed using a more holistic approach that understands the connections between economic, environmental, and social aspects. In terms of social considerations, like in branches of agriculture, the main problems in fisheries are economic deprivation and low mobility in relation to the factor of production—in this case, the sea. A further widening of the wage gap may

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make work in fisheries unattractive and consequently reduce employment and production levels. Globally, when fish provide more than 3.3 billion people with 20% of their average daily intake of animal protein, and in countries such as Bangladesh, this figure reaches 50%, an absence of fishermen would result in famine. Another common phenomenon in fishing is the failure to pay for completed work, such as the labour of tool owners (preparation of tools for work) or the missing value of the labour of the crew performing the necessary activities on land and the family labour contribution, which may not be paid. The value of unpaid work in the EU in 2020 was estimated at over 269 mln €, and it varied depending on the country. On average, the highest value of unpaid labour expressed in € per ton of live organisms caught was recorded in 2020 in Greece – it is more than €1,290 per ton of catch. This is followed by Malta, with almost €787 per ton, and Cyprus, with almost €565 per ton of catch. The lowest values were recorded in Ireland – €1.83 of unpaid labour value per ton, Latvia €0.74 per ton and Lithuania €0.14 per ton of organisms caught (European Commission, 2023).

Fishing is a highly masculinised sector (apart from processing), as being a fisherman is still a risky and physical occupation. Back at the local EU level, experts have confirmed the ineffectiveness of the Common Fisheries Policy in reducing overcapacity and have illustrated the continuing threat of overcapacity to the long-term sustainability of fishery resources (Villasante, 2010). A higher level of overcapacity, especially at the level of small–medium marine enterprises, may indicate an increase in the number of underpaid fishermen and an increase in both energy consumption and costs. The results of the work of Avadí et al. (2014) revealed that the small fleet/medium fleet enterprises sector showed slightly lower levels of eco-efficiency than vessels designated for industrial fleets or coastal fleets; this is due to differences in the way fuel consumption is managed.

The Concept of Eco-Efficiency

The concept of eco-efficiency emerged in public debate as an idea for operationalising the United Nations Sustainable Development Goals (Sulewski et al., 2020). The concept of eco-efficiency was cast as the term “environmental efficiency” (Freeman, 1973). Thereafter, Schaltegger and Sturm (1990) introduced the phrase “eco-efficiency” as the link between business and sustainable development. Caiado et al. (2017) described it as a quantifiable assessment of attaining economic goals while maintaining environmental responsibility. The UN’s Food and Agriculture Organization (FAO) defines sustainable development as the way of the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations (FAO, 2014).

The World Business Council For Sustainable Development (WBCSD) defines eco-efficiency quantitatively as the quotient of the value of a product or service divided by the environmental impact. Eco-efficiency entails reaching commendable environmental standards, signifying a minimal environmental footprint resulting from a company’s or sector’s operations (Repar et al., 2017). Measuring the level of eco-efficiency is a prevalent practice within agricultural industries, such as the dairy industry (Basset-Mens et al., 2009) and wineries (Vázquez-Rowe et al., 2012). Exploring eco-efficiency analyses can offer fresh perspectives on the wealth generation process (Hoffren, 2006), and even provide answers to the question of how the impact of long-term policy preferences affects environmental outcomes (Matuszczak et al., 2020).

The concept of eco-efficiency can be treated as a proposal for a practical approach to implementing the idea of sustainability at the organisational level, although further work on this concept undertaken by the Organisation for Economic Co-operation and Development (OECD) and the European Environmental Agency has extended the application of this approach to entire sectors, regions, and countries (Rybaczewska-Błażejowska & Gierulski, 2018; Caiado et al., 2017; Schaltegger & Burritt, 2000).

This concept is seen as a quantitative tool for the simultaneous assessment of the economic and environmental aspects of economic systems and is thus one of the most important instruments analysing their sustainability levels (Rybaczewska-Błażejowska & Gierulski, 2018; Huppes & Ishikawa, 2005; Caiado et al., 2017). Examining the connections between the economic and environmental facets of sustainable development (Huppes & Ishikawa, 2005) can be a valuable tool for supporting the dissemination of the concept of sustainability (Caiado et al., 2017). The eco-efficiency approach is an effective way of evaluating the parameters of sustainable development aimed at reducing resource

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consumption and reducing the harmful environmental impacts of production processes. Presently, one of the most prevalent techniques for measuring eco-efficiency in agriculture is DEA (Matuszczak et al., 2020).

Eco-efficiency in Fisheries

As our literature review showed (Piwońska, 2021), the concept of eco-efficiency in fisheries has not been widely developed. The primary definition of eco-efficiency cited by the authors of the surveyed literature is the one put forth by the WBCSD in 1992. There exist notable parallels in the methods used to gauge eco-efficiency levels within the agricultural sector. The most frequently used method is DEA, while in its subsector, fisheries, the DEA+lifecycle assessment (LCA) method predominates. LCA frequently complements DEA and serves as a methodology for pinpointing environmental impacts across all stages of commodity production (the so-called cradle-to-grave environmental damage identification of a product) (Stępień et al., 2020).

In agriculture, the recognised unit of analysis is a single farm, while in fisheries, the equivalent unit is represented by one vessel. Nonetheless, a notable distinction lies in the ease and reliability of measuring detrimental inputs, which tends to be more straightforward in the agricultural sector overall compared to fisheries alone, especially those involving the high seas. Until the issue of by catch practices is addressed, research in this domain will remain inadequate. Most studies underline the uncertainty of surveyed data, the need to reproduce surveys in a broader timeframe or with more information related to biodiversity factors (in relation to the by catch phenomenon) or social aspects of the sector, especially when the skills and experience of a captain (the “skipper effect”) is highlighted as a key factor influencing the eco-efficiency level of a specific fishing unit.

Based on Avadí and Acosta-Alba’s (2021) conclusions, it was decided in this current paper to conduct our own study of the level of eco-efficiency in fisheries over a wider time range and on a greater number of countries and provide a basis for future studies to consider more social factors.

Research methods

Measuring countries’ respective indices levels over the study period was done using methods based on data envelopment analysis (DEA)– **a super-efficiency hybrid DEA.** This method has two major advantages over basic DEA. First, in the standard DEA model, it is quite often the case that a high proportion of decision-making units (DMUs) are found to be efficient (efficiency score equal to 1). However, the relative position of these DMUs on the frontier is not the same. In the super-efficiency model, it is possible to compare and rank objects identified as fully efficient in standard DEA. In practice, efficiency scores can be greater than 1, and for all DMUs, an artificial frontier is constructed that excludes a given DMU. Then, a given DMU is compared to this artificial frontier, and it may happen that it lies above this, meaning that its efficiency is calculated as more than 1.

The second, advantage of the adopted hybrid model is that it enables distinguishing between variables that should be treated as radial (i.e. their values need to change proportionally), as in standard DEA, and variables that can behave independently (as in nonradial slack-based models). Using a hybrid approach is more flexible; it does not impose that all variables should be treated in the same way. In the present case, the inputs I3 and I4 were assumed to be correlated (and therefore treated as radial). The inputs I1 and I2, as well as outputs, were retained as nonradial (see Table 1).

Using DEA methods, it is possible to calculate a total productivity index – TFP – using the Malmquist index (MI), which in this case would measure eco-efficiency progress. The advantage of using the MI is that it can be decomposed into the rate of change in technical efficiency (EC) and the rate of technical progress (technological change – TC). In this work, a modified sequential version of the MI was used (Alene, 2010). This approach assumes that past production technologies are always available; therefore, no technological regress is possible. For European fisheries, which is still a developing industry, such an assumption seems more realistic. Therefore, in practice, the TC component may take values equal to or greater than 1. Any deterioration in total productivity (an MI value below 1) is, in this approach, due to negative changes in technical efficiency.

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Table 1. Variable list with its justification in the literature and data origin

Variable code	Variable	Data source	Previous studies in which a given variable was used
O1	catch in tonnes (good output)	FIGIS FAO	González-García et al. (2015), Avadí et al. (2014), Laso et al. (2018a), Laso et al. (2018b)
O2	greenhouse gas emissions in tonnes of CO_2 equivalent (bad output) in the sector	Eurostat	Bravo-Olivas and Chávez-Dagost-ino (2020)
I1	the amount of GT (gross tonnage of the vessel) in the country	Eurostat	Avadí et al. (2014), Laso et al. (2018a), Laso et al. (2018b)
I2	the number of employees (fishermen) in the sector in units	OECD Database	Sulewski et al. (2020)
I3	the amount of energy costs in thousands of €	STECF	Avadí and Acosta-Alba (2021)
I4	the amount of energy consumption in litres of fuel	STECF	Vázquez-Rowe et al. (2010), González-García et al. (2015), Avadí et al. (2014), Laso et al. (2018a), Avadí and Acosta-Alba (2021)

Source: authors' work based on Piwońska (2021).

In DEA-based methods, the term "slack" can occur. The slack basically means that there is space to reduce a particular input and/or undesirable output and/or expansion potential of desirable output without introducing changes in a given technology or other inputs/outputs. It is important to highlight that desirable outputs may be increased, and bad outputs and inputs may be reduced simultaneously. In the nonradial part of the hybrid model, it is assumed that individual inputs and outputs do not have to be expanded or reduced proportionally (as in the standard radial DEA model), which seems to be more realistic for the agricultural sectors (Czyżewski & Kryszak, 2022). The method used is nonparametric and neither output-oriented nor input-oriented since increasing production as well as decreasing inputs and bad outputs is equally important.

The current study covered 23 countries (treated as DMUs) over 10 periods (years 2009-2018). Two outputs and four inputs were considered, which are presented below in Table 1.

Table 1 also presents the primary data origins for this current study: the FAO, Eurostat, OECD, and the European Commission; it also provides examples of literature in which given variables were used. In this study, the variables were selected via a double-selection process. First, the vast majority had been identified as important factors in previous studies. Second, the variables reflect and relate to the classical factors of production—land, labour, and capital. Therefore, the variable I2, the number of fishermen not previously found in the literature, was added to the model as a surrogate for labour, as well as the less frequently mentioned I1 – tonnage and I3 – fuel costs as factors of capital (fixed and current, respectively). Also, variable I2 provides a foundation for further work on the social aspect of sustainable development, and it is widely used in DEA models in agricultural research (Sulewski et al., 2020). Austria, Slovakia, the Czech Republic, Luxembourg, and Hungary were excluded from this study of EU28 countries, as they are land-locked countries that do not have marine fish catch volumes.

This research focused mainly on commercial marine fisheries. Catch volumes are given in tons of live weight and include demersal fish species, pelagic species, and other saltwater species (the catches of commercial marine fisheries and marine aquaculture catches combined). Mollusks, crustaceans, and other by catch organisms were excluded. Annual emissions of carbon dioxide (CO2), nitrogen dioxide (N2O), methane (CH4), hydrofluorocarbon (HFC), perfluorocarbon (PFC), sulfurhexafluoride (SF6), and nitrogen trifluoride (NF3) in CO2 equivalents from a country's fisheries were included in the greenhouse gas (GHG) emissions.

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Results of the research

Descriptive statistics on the variables under study are shown in Table 2. The EU is the fifth largest fish-product producer worldwide, accounting for about 3.3% of global fisheries and aquaculture production (European Commission, 2022). On average, during the period under review, Spain, Denmark, and the United Kingdom had the largest number of catches, and Romania, Malta, and Slovenia had the smallest. Spain, France, and the UK were the largest emitters of greenhouse gases, and Cyprus, Slovenia, and Bulgaria were the smallest. On average, Spain, the UK, and France had the highest tonnage, and Cyprus, Romania, and Slovenia had the lowest. Portugal, Italy, and Spain had the highest number of fishermen, and Malta, Cyprus, and Slovenia had the least. France, Italy, and Spain have the highest fuel consumption and fuel costs, while Estonia, Cyprus, Romania, and Slovenia have the lowest.

It is worth noting that the share of fisheries in national economies varied considerably: for example, accounting for 0.06% of the volume of total GDP in France, 0.1% of GDP in the United Kingdom (countries with strong economies and high fish catches), and 0.014% of GDP in the much smaller economy of Slovenia (World Bank Database, 2022).

Table 2. Average values of inputs and outputs among EU countries under study in 2009-2018

no	Country	I1	I2	I3	I4	O1	O2
		Gross tonnage of the vessel	Number of fishermen	Energy costs	Energy consumption	Catch	Greenhouse gas emissions
		GT	Full-Time Equivalent	€ in thousands	Litres in thousands	Tonnes	Tonnes
1	Belgium	14 592.40	543.10	20 601.01	41 206.69	23 978.70	184 834.16
2	Bulgaria	6 796.40	1 538.80	1 420.46	2 300.99	8 581.00	3 271.19
3	Croatia	65 154.20	7 429.10	36 181.78	23 684.76	68 373.80	30 787.60
4	Cyprus	8 754.40	423.20	2 146.43	2 944.15	1 379.40	8 688.13
5	Denmark	67 562.30	1 952.30	48 439.1	92 459.44	747 062.80	404 950.79
6	Estonia	14 296.00	2 865.40	2 178.16	3 509.18	76 591.30	102 695.10
7	Finland	16 277.30	3 010.60	8 817.82	15 167.87	144 591.44	134 163.31
8	France	173063.70	14453.40	181246.50	326890.79	477000.24	1431555.60
9	Germany	63833.20	2554.10	21684.20	42104.87	230095.60	70607.72
10	Greece	77610.00	14204.90	103601.14	104919.17	68996.20	128151.16
11	Ireland	64922.80	3483.40	43206.87	81695.47	253417.40	128274.95
12	Italy	147615.60	27731.90	205458.94	368810.90	202080.70	624347.22
13	Latvia	30313.50	707.20	3410.49	5643.30	125866.34	39124.96
14	Lithuania	41359.00	973.00	15222.74	35425.44	111219.40	71157.26
15	Malta	8042.10	564.90	2913.15	4500.06	2338.00	13389.85
16	Netherlands	140357.60	2038.50	80912.82	178670.49	388575.20	574093.33
17	Poland	33916.50	4378.00	9640.90	17346.31	190327.70	524855.07
18	Portugal	95745.50	17113.30	61246.94	94494.56	194300.80	361550.25
19	Romania	1083.20	2255.30	406.00	463.91	3470.70	79431.78
20	Slovenia	726.40	113.00	303.38	348.09	381.70	4449.08

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no	Country	I1	I2	I3	I4	O1	O2
		Gross tonnage of the vessel	Number of fishermen	Energy costs	Energy consumption	Catch	Greenhouse gas emissions
		GT	Full-Time Equivalent	€ in thousands	Litres in thousands	Tonnes	Tonnes
21	Spain	371459.10	29588.70	334902.02	659931.31	960641.87	2069233.24
22	Sweden	30105.20	1791.60	26282.89	48928.48	192888.50	122229.90
23	United Kingdom	195879.30	12084.20	152823.52	285340.44	664393.98	800624.15
-	**European Union**	**72585.47**	**6599.91**	**59262.93**	**105947.25**	**223328.38**	**344020.25**

Source: authors' work based on data provided by FIGIS FAO, Eurostat and STECF databases.

Table 3 contains information on the progress of eco-efficiency in the studied countries (geometric means of the MI), with its decomposition into efficiency change (EC) and technological change (TC).

Table 3. Averages of Malmquist index, rates of efficiency changes and rates of technological changes

DMU	MI	EC	TC
Cyprus	1.181	1.132	1.043
Finland	1.119	1.068	1.047
Croatia	1.117	1.083	1.032
Malta	1.064	1.025	1.038
France	1.048	1.028	1.019
Sweden	1.046	1.012	1.033
United Kingdom	1.027	1.005	1.022
Netherlands	1.026	1.003	1.023
Belgium	1.023	0.996	1.026
Portugal	1.008	0.980	1.028
Estonia	1.007	0.926	1.087
Ireland	1.000	0.956	1.046
Slovenia	0.998	0.808	1.235
Latvia	0.985	0.966	1.020
Greece	0.981	0.952	1.031
Denmark	0.964	0.929	1.037
Poland	0.931	0.912	1.021
Germany	0.926	0.887	1.044
Spain	0.918	0.827	1.110
Lithuania	0.895	0.882	1.015
Bulgaria	0.894	0.839	1.065

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DMU	MI	EC	TC
Romania	0.882	0.744	1.186
Italy	0.676	0.666	1.017
UE	**0.988**	**0.940**	**1.053**

Source: authors' calculations in the software Max Dea.

The largest increases in MI over the study period were in Cyprus (on average, 18% per year), Finland and Croatia (almost 12%), Malta (6%), and France (almost 5%). This means that, for example, the level of eco-efficiency in Finland had improved by 12% per year, on average. In contrast, the largest decreases were recorded in Lithuania and Bulgaria (10%), Romania (11%) and Italy, with a fall in MI of almost one-third per year during the period under review (see Table 3). As shown in Table 3, during the surveyed period, the average value of MI for the surveyed countries was 0.988, which means a slight general regress in terms of the eco-efficiency of the sector.

TC resulting from general exogenous progress had the highest impact in Slovenia, Romania, and Spain, and the smallest impact was recorded in France, Lithuania, and Italy. This study assumed that overall exogenous technical development does not take a value below 1. This means that the general deterioration of eco-efficiency resulted from a decrease in EC, which implies that resources were not managed optimally. The highest deterioration in EC was recorded in Bulgaria, Romania, and Italy. In turn, countries such as Cyprus (13%), Finland (12%), and Croatia (11%) experienced significant annual growth in efficiency.

Overall, differences in the levels of efficiency between the studied countries were mainly due to internal factors in the fisheries sectors of these countries (Table 4). The MI averages of countries in which MI progress was recorded equalled 1.060 for MI, and for countries in which deterioration in eco-efficiency was recorded, the average MI equalled 0.9208. The most important is the fact that the difference between ECs was greater (0.159) than TCs (0.032) and that the positive impact of technological progress was even higher in countries where MI had been decreasing. This further shows that internal (endogenous) factors play a major role in the improvement of the eco-efficiency of the countries studied.

Table 4. Comparison of averages of MI components for countries of different levels of MI

DMU	MI	EC	TC
mean	0.988	0.940	1.053
MI>1	1.060	1.023	1.036
MI<1	0.921	0.864	1.0688

Source: authors' calculations in the software Max Dea.

Table 5 presents the average slack values (expressed in percentages) for the variables for each country over the study period. Slack values show the potential for reducing given inputs (or undesirable output) and the potential for increasing outputs. In the case of good output, when the average slack is positive, this indicate show much the decision-making unit should increase this output to be effective. On the other hand, when the slack for good output is negative, it means that the unit would be able to reduce the effect by that much while still remaining efficient. There are several countries with a negative average value of slack on good output (catches), but this may be due to negative values only in very specific periods, as most of the countries with average negative slack have an average efficiency score below 1. Cases worth noting are Bulgaria and Latvia, which have negative slack on output (so they could even lower their catches) and had average efficiency scores above 1.

Table 5. The average value of efficiency score and the average size of slack of outputs and inputs (in %)

DMU	Efficiency score	Gross tonnage of the vessel	Number of employees	Energy costs	Energy consumption	Catch	Greenhouse gas emissions
Belgium	0.110	-82.36	-69.61	-6.99	-7.50	0.00	-90.72
Bulgaria	1.048	-10.74	-22.35	-13.85	-12.16	**-0.12**	14.05
Croatia	0.162	-73.96	-91.90	-28.95	-5.52	0.00	-31.35
Cyprus	0.087	-27.01	-50.99	-8.96	-3.54	1026.18	0.00
Denmark	0.964	-11.52	-8.52	-16.43	-5.21	-11.26	-5.99
Estonia	0.849	1.08	-33.20	-10.26	0.00	-4.06	-26.98
Finland	0.683	1.84	-64.55	-15.80	-1.44	-0.46	-37.62
France	0.112	-78.19	-91.84	-16.39	-0.52	0.00	-82.35
Germany	0.853	-11.92	-19.65	-17.82	-17.01	-4.45	-8.18
Greece	0.055	-86.03	-97.39	-37.66	-7.13	0.00	-70.88
Ireland	0.321	-46.58	-74.79	-12.24	-5.30	0.00	-17.53
Italy	0.207	-81.28	-88.20	-21.18	-9.87	-8.12	-74.42
Latvia	1.015	0.57	-4.42	-12.63	-1.77	**-11.91**	-3.67
Lithuania	0.478	-48.36	-45.41	-11.50	-23.49	-7.57	-36.63
Malta	0.076	-14.96	-55.30	-7.03	-6.20	1219.29	-5.82
Netherlands	0.239	-77.78	-51.48	-6.32	-7.79	0.00	-63.92
Poland	0.497	-8.82	-74.78	-7.33	-0.03	-0.55	-76.82
Portugal	0.115	-69.74	-95.61	-18.44	0.00	0.00	-78.23
Romania	1.489	20.41	-21.04	-19.03	0.00	0.00	-21.15
Slovenia	1.748	73.41	147.10	-9.52	-2.71	0.00	3.25
Spain	0.719	-26.12	-28.11	-14.63	-21.16	-3.82	-25.06
Sweden	0.402	-35.53	-66.14	-12.12	-2.12	0.00	-23.52
United Kingdom	0.181	-73.17	-86.73	-13.69	-1.16	0.00	-56.39
Average	**0.540**	**-33.34**	**-47.61**	**-14.73**	**-6.16**	**95.35**	**-35.65**

Source: authors' calculations in the software Max Dea.

The achieved results regarding Cyprus and Malta in the good output (catch) can be considered as outliers. Both of them are countries with the lowest catch volumes in comparison with the rest of EU countries and their catch volumes technically can have the large space to significantly increase.

The interpretation of inputs and bad outputs is the reverse. Negative slack means that a given input should be reduced, and positive slack means that efficiency can be maintained even if input usage increases. The interpretation of results, on the example of Belgium, is as follows: To maintain a full efficiency state in fisheries, greenhouse gas emissions should be reduced by almost 91%. Furthermore, Belgium should decrease the vessel tonnage by 82.4%, the number of fishermen by 70.0%, energy costs by almost 7%, and consumed fuel amount by over 7%. For Belgium, there is no room to expand or decrease the number of catches. Large slack values are connected with low average efficiency levels. In other words, the Belgian fishery sector is highly ineffective, and the inputs are far too high in comparison to the catch level. This excessive use of inputs is particularly clear for vessel tonnage and the number of fishermen employed.

Another remarkable result concerns the slack value for employees in Slovenia. This country had the highest average efficiency score in the sample, which was above 1. It means that the fishery sector of this country was super-efficient. This implies that some inputs (including, in particular, the number of employees) could even be increased while full efficiency would be maintained.

On average, sample countries could reduce their GT by over one-third, the number of fishermen by almost 50%, reduce the amount of fuel consumed by almost one-seventh and reduce costs by over 6%. Surprisingly, theoretically, there is 5% room to increase the number of catches; however, the reason behind that is two outliers: the smallest countries in terms of fisheries, Malta and Cyprus. Finally, countries could decrease their GHG emissions, on average, by over one-third.

Among the inputs, the biggest average slack was related to the number of employees, second to the GT of the vessels. This means that, on average, the fisheries sector deals with the problem of overstaffing. Another issue is that vessels are too big in relation to the real needs. The other important issue is related to GHG emissions. If all the studied countries achieve efficiency, emissions can be reduced by around one-third.

This study has some limitations. First, the number of DMUs, as well as the variables used in this study, was rather small in comparison with other previously mentioned analyses (Avadí et al., 2014; Avadí & Acosta-Alba, 2021; Vázquez-Rowe et al., 2010; González-García et al., 2015). Second, the countries used for this study (e.g., Spain and Malta) are subject to similar policies, but they differ a lot in their structures of the fisheries sector, especially in terms of catch volumes. The best way to deal with this problem is to repeat this study on a slightly smaller number of countries but with a more homogeneous fisheries profile over a longer period of time. Potential outliers such as island countries or very small countries could be excluded. Alternatively, this study could be repeated on a larger sample of countries, but in this case, the metafrontier approach should be employed.

Conclusions

In this research, two research goals were pursued. First, we assessed the dynamics of the eco-efficiency of fisheries in EU countries and its components. Second, we have identified potential sources of inefficiencies and efficiency surpluses through slack analysis. To achieve these goals, we used a hybrid DEA model with Slack analysis for the 2008-2019 research period.

We found that in 11 countries, progress towards eco-efficiency (the average value of the Malmquist index is above 1) could be observed. The highest rate was found in Cyprus, Finland and Croatia. At the same time, in 11 countries, average negative changes were observed. It shows that changes in fisheries of EU countries regarding the problem of eco-efficiency are highly differentiated. The main reason for these differences was related to changes in technical efficiency, which is associated with internal factors. In other words, in some countries the resources are not used in an optimal way, and this process continued over the research period. However, there were also countries where efficiency change was positive, such as Cyprus, Finland and Croatia.

Thanks to the slack analysis, we have also found that significant improvements could be made regarding resource management. Particularly high savings could be made regarding the number of employees and gross tonnage of vessels, suggesting that EU fisheries faced the problem of overinvestment and overstaffing. This led to the conclusion that important changes in the sector should be made to make it more sustainable.

The conclusion to be drawn from the results of this study is that, through its policy, the EU still has much work to do to improve the state of its fisheries since, in half of the studied countries, a negative tendency in eco-efficiency was observed. Policymakers should consider whether it is necessary to make policy adjustments in a situation where the sustainability of fisheries had not changed spectacularly (average value of MI index), despite huge efforts that were made. Particularly strong efforts should be directed towards supporting the retraining of fishermen in those countries where the problem of overstaffing is particularly pronounced. In addition, investment should be strongly encouraged so that fishermen can replace their boats with smaller but more efficient ones.

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The contribution of the authors

Conception, Ł.K. and K.P.; literature review, Ł.K. and K.P.; acquisition of data, Ł.K. and K.P.; analysis and interpretation of data, Ł.K. and K.P.

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EKOEFEKTYWNOŚĆ RYBOŁÓWSTWA W KRAJACH UNII EUROPEJSKIEJ

STRESZCZENIE: Głównym celem niniejszego artykułu była (1) ocena dynamiki eko-efektywności rybołówstwa w krajach UE i jej komponentów oraz (2) identyfikacja potencjalnych źródeł nieefektywności i nadwyżek efektywności poprzez analizę luzu. Zastosowano hybrydowy model analizy obwiedni danych (DEA) dla okresu 2008-2019. Postęp w zakresie eko-efektywności stwierdzono wśród 11 krajów (z 23), ale średni wskaźnik eko-efektywności dla próby wyniósł 0,988. Różnice w poziomach i dynamice eko-efektywności pomiędzy badanymi krajami wynikały głównie z komponentu zmiany efektywności, tj. czynników wewnętrznych. Największy potencjał w zakresie redukcji nakładów stwierdzono w odniesieniu do liczby pracowników i pojemności brutto statku, co sugeruje, że badane kraje borykają się z problemem przeinwestowania i nadmiernego zatrudnienia. Stwierdziliśmy również, że emisję gazów cieplarnianych można zmniejszyć o około jedną trzecią.

SŁOWA KLUCZOWE: zrównoważony rozwój, rybołówstwo, zasoby morskie, obwiedniowa analiza danych

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