



Implications of the WTO and EU fuel taxation reforms for a European fishing fleet: effects, side-effects and alternative approaches from an input–output analysis of the Galician (northwest Spain) fleet

Gonzalo Rodríguez-Rodríguez^{1,2} · Eduardo Sánchez-Llamas¹ · Helena Martínez-Cabrera¹ · Hugo M. Ballesteros¹

Received: 23 June 2023 / Accepted: 16 May 2024
© The Author(s) 2024

Abstract

The World Trade Organization (WTO) and European Union (EU) have both put forward tax reforms that impact fisheries' fuel costs, which are similar in the object of taxation but quite different in the externalities addressed, goals, scope, exemptions or tax rates, creating an opportunity to compare the effects and discuss the alternatives. These proposals are the result of long and intense debates in political, social and academic spheres. However, certain aspects remain unclear. First of all, the number of empirical studies is still limited, particularly considering that fisheries governance is subject to heterogeneous management systems and institutional contexts creating room for different potential outputs. Second, coastal states have no fiscal competence beyond 12 miles, which limits the scope of the reforms to small scale fleets (SSF). All in all, the economic consequences for the fleets remain unclear. To this end, we will build on the Galician fishing sector (NW Spain) input–output tables to discuss the direct impacts, effects and side effects of these reforms on a representative European fleet. Flaws identified in both initiatives mean that targeted externalities will not be corrected and, moreover, additional ones, such as distributional effects penalising SSF or fuel spillovers, could be boosted. Alternative policy approaches are discussed.

Keywords Fuel subsidies · Input–output · Economic impact · Fisheries management

Introduction

Fisheries subsidies, particularly fuel-related ones, have been a significant debate over the last three decades. Recently, this debate has been brought to the fore due to the World Trade Organization (WTO) and European Union (EU) initiatives. Both are similar in the object of taxation but quite different in the externalities addressed, goals, scope, exemptions or tax rate, and this creates an opportunity to compare the effects and discuss the alternatives.

After the Uruguay round, fisheries subsidies were included within the scope of the WTO Agreement on Subsidies and Countervailing Measures; as a result, in 2001, at the Doha Ministerial Conference, the WTO started negotiations on subsidising fisheries. Subsequently, target 14.6 of the Sustainable Development Goals (SDGs) of the 2030 Sustainable Development Agenda, approved by the Member States of the United Nations in 2015, recognised the specific role of the WTO negotiations to deal with this issue. Specifically, target 14.6, by 2020, aims to 'prohibit certain forms

✉ Gonzalo Rodríguez-Rodríguez
gonzalo.rodriguez@usc.es

Eduardo Sánchez-Llamas
edu.sanchez@usc.es

Helena Martínez-Cabrera
helena.martinez.c@usc.es

Hugo M. Ballesteros
victorhugo.martinez@usc.es

¹ Fisheries Economics and Natural Resources Research Unit, Faculty of Economics and Business Administration, University of Santiago, Av. Burgo das Nacións S/N, 15782 Santiago de Compostela, A Coruña, Spain

² Galician Studies and Development Institute (IDEGA), University of Santiago de Compostela Chalet Dos Catedráticos, 1. Avda. das Ciencias S/N, Campus Vida, 15782 Santiago de Compostela, A Coruña, Spain

of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognising that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation' (Sustainable Development Solutions Network). The agreement (WTO 2022) was adopted at the 12th Ministerial Conference (MC12) on 17 June 2022 and establishes that no member shall grant or maintain subsidies for fishing (including those that cover or reduce the cost of fuel) or fishing related activities regarding an overfished stock unless such subsidies or other measures are implemented to rebuild the stock to a biologically sustainable level.

The WTO reform is based on economic theory suggesting that capacity-enhancing subsidies lead to overcapacity and overfishing, contributing to overexploited stocks (Cisneros-Montemayor et al. 2022) when no sound biological control is in place (Sakai 2017; Sakai et al. 2019; Wang et al. 2023), the large segments being those that increase the share of the harvest with respect to the small-scale fleets when fuel subsidies are in place (Martini and Innes 2018). In the mid to long term, it is assumed that initial fishing profit 'losses' from subsidy elimination would be more than offset by gains in fishery catches as overexploited populations recovered (Sumaila 2004). In short, a reduction in fishing effort is expected, especially in industrial fleets.

In parallel, on 14 July 2021, the Commission adopted a proposal for revising the Energy Taxation Directive, aimed at aligning the taxation of energy products with EU energy and climate policies, promoting clean technologies and removing outdated exemptions and reduced rates that currently encourage the use of fossil fuels. Specifically, it aims to achieve a 55% net reduction of greenhouse gases by 2030 by setting up minimum levels of taxation applicable to motor fuels of 0.9 euros (€)/gigajoule (European Commission 2021), which means 0.035€/l in the case of marine fuel. It is worth pointing out that these two proposals are not mutually exclusive or alternatives but rather additive so that both can eventually be added to the market price of fuel.

The health of marine and coastal ecosystems is undoubtedly the basis not only for the sustainable development of coastal areas but also for the preservation of the biodiversity of the seas. The resources available in the oceans nourish the flow of food, energy and medicine, and they contribute to the creation of culture, opportunities for tourism and leisure and help regulate the climate and favour the nutrient cycle and so on. Given the relevance of these resources for humanity, there is also a far-reaching social consensus regarding the need to guarantee long-term sustainability, specifically among scientists, Non-governmental organizations (NGOs), fishers and political decision-makers (deReynier et al. 2010).

As a result of this interest, the debate about fuel taxation in general and, specifically, about marine fuel subsidies has become intense and extensive (Porter 2001; Cisneros-Montemayor et al. 2016; Peltovuori 2017; Owusu and Adjei 2021). However, certain aspects remain unclear. First of all, the number of empirical studies is still limited (Sakai et al. 2019). Specifically, more case studies are needed as fisheries governance is subject to highly heterogeneous management systems and institutional contexts (Wang et al. 2023) creating room for different potential outputs. Second, a particularly relevant regulatory feature that can affect the reforms' expected outputs is the absence of fiscal competence of the coastal states beyond 12 miles. All in all, the economic consequences for the fleets remain unclear (Roll et al. 2022).

This work aims to contribute to this debate with research into the economic impact of a rise in fuel costs for the different Galician fleets. It is worth pointing out that the Galician fleet is not only one of the largest in Europe, but it is also distinguished by its diversity, so it was possible to address the effects on fleets that range from artisanal fishing to high-seas industrial fishing, assessing several fishing practices: purse seine, longline, trawling, etc. Consequently, the results can be regarded as representative and make it possible to fill the existing gap in the debate and in literature.

To this end, the input–output framework provides an adequate tool to analyse the impacts of changes on the production function of economic activities. Based on Leontief's (1936) seminal contribution, the use of input–output models has become widespread and is currently a key component of several types of economic analyses; in fact, it is one of the most widely used methods in applied economics (Baumol 2000) in general and in the marine sector in particular (Morrissey and O'Donoghue 2013; Rodríguez-Rodríguez et al. 2019). Specifically regarding the Galician fishing sector, four editions of the input–output tables of the Galician fishing–canning sector have been published (García-Negro [Dir.] 1997; García-Negro [Dir.] 2003; García-Negro [Dir.] 2016; Rodríguez-Rodríguez et al. 2022). These publications, in turn, have supported a wide range of additional input–output analyses, such as the comparison of management scenarios (Surís-Regueiro and Santiago 2018), the economic impacts of TAC regulation (Fernández-Macho et al. 2008; Santiago and Surís-Regueiro 2018), the economic impacts of the discard ban (Rodríguez-Rodríguez et al. 2019), etc. Therefore, they are a solid and verified reference for a detailed analysis of the Galician fishing sector (Franquesa Artés 2006).

Materials and methods

Methodology

Surveys and sampling

The data regarding the structure of the Galician extractive fishing sector used in this work were compiled during the preparation of the Input–Output Tables of Galician Fisheries and Processed Seafood Products 2019 (TIOFP19) and were gathered mainly by means of questionnaires.

The study population comprises all the ships that make up the Galician fishing fleet. The sampling unit census used in this work was prepared using the data provided by the General Secretariat of the Sea, an organisation which depends on the Regional Government (Xunta de Galicia), and proposes and implements the government's general directives regarding issues related to fishing and the marine environment¹. Fishermen's Associations, professional associations, fisheries producers' organisations (OFPs) and sectorial groups of the Galician fishing subsectors were also consulted to obtain key information in those cases where the main source of information did not include all the relevant data regarding the characteristics of the productive units (ships). The compiled directory contained a total of 4334 ships (Table 1). These were divided into four large groups (strata), in which the ships were classified depending on their gross tonnage (GT) (Table 1). In turn, these strata were divided into sub-strata depending on the type of fishing used by each production unit. The size, the main stocks exploited for each fleet and the sustainability status of the stocks are also presented in Table 1. More information about the Galician fishing fleet and the characteristics of the aforementioned strata is included in Online Resource, ANNEX I: Methodology.

The sampling selection process was carried out following a stratified optimal random sampling design (Neyman optimal allocation), establishing a minimum sample size of 20 units and a maximum error of 8% with a 95% confidence interval. A total of 110 ships were surveyed (26 artisanal vessels, 19 coastal vessels, 30 European western waters ships and 48 long-distance waters ships). The field work was carried out between June 2020 and May 2021; the time schedule was affected by travel restrictions imposed during the coronavirus disease 2019 (COVID-19) lockdown periods and by the effects on the sector. All the questionnaires were carried out in person, lasting approximately 1.5 h. Informed consent was obtained from all participants. In specific cases, due to the high volume of information requested from the respondents, the surveys were completed over the phone, by consulting the companies' accounting ledgers or by checking

with staff or their consultants. The complete structure of the survey is available in Online Resource, ANNEX IV: Extractive Fishing Questionnaire. Once the sampling was completed or there were no more substitute production units available in the census, extensive analyses of the data were carried out. The outliers were eliminated following the inter-quartile range (IQR)² method during the statistical processing and macroeconomic variables were estimated following standard procedures (Eurostat 2008). Detailed information on the methodology is available in the *Galician input–output tables of the fishing sector and seafood industry* (Rodríguez-Rodríguez et al. 2022).

Galician fishing activity is regulated at European, national and regional levels. The EU sets up the total allowable catch (TAC) based on scientific advice from International Council for the Exploration of the Sea (ICES), which are then assigned to the Spanish fleet by the Spanish government. In the case of the artisanal fleet, most of the species are not subject to TACs but regulated by the regional government, including input and output controls. The status of the main stocks has been presented in Table 1.

Input–output framework

The main purpose of the input–output tables is to represent the flows of products from each industrial sector, considered as a producer, to each of the sectors, itself and others, considered as consumers (Miller and Blair 2009). In short, the standard input–output (I–O) model can be represented by the following expression:

$$\text{Intermediate goods} + \text{Final demand} = \text{Total output} \quad (1)$$

The basic information of an input–output model is contained in an interindustry transactions table, where the rows describe the distribution of a producer's output throughout the economy and the columns describe the composition of inputs required by a particular industry to produce its output. This interindustry exchanges of goods and services is what is contained in the Symmetrix matrix of the Galician Fishing sector (Rodríguez-Rodríguez et al. 2022) presented for the sake of brevity of the main text in Online Resource, Annex II: Input–Output Tables. It should be noted that the TIOFP19 are designed from the fishing sector point of view, with the specific purpose of capturing the production function of the different fishing segments, being the industry-products approach an adequate way of doing so. The additional rows represent the value added and account for the other (non-industrial) inputs to production, such as employee's

¹ <https://mar.xunta.gal/es>

² IQR is the range between the first and the third quartiles namely Q1 and Q3: $\text{IQR} = \text{Q3} - \text{Q1}$. The data points which fall below $\text{Q1} - 1.5 \text{ IQR}$ or above $\text{Q3} + 1.5 \text{ IQR}$ are outliers.

Table 1 Structure of the strata and substrata which comprise the ‘extractive fishing’ stratum and sustainability status of the main species

Strata	Substrata	Number vessels	Stocks	Sustainability status			
				Biomass	Harvest rate		
Artisanal fishing (0–40 GTs)		3.953	OCC	–	–		
			CTC	–	–		
			JDV	–	–		
			CKJ	–	–		
Coastal fishing (40–100 GTs)	Longline	9	HKE (8c9a)	Above trigger	Appropriate		
			POA	Unknown	Unknown		
			Purse seine	64	PIL (8c9a)	Above trigger	Above limits
					PIL (8abd)	Below trigger	Above limits
	PIL (7)	Unknown			Unknown		
	HOM (9a)	Above trigger			Appropriate		
				HOM (2a4a5b6a7a-ce-k8)	Below trigger	Above limits	
				MAC (nea)	Above trigger	Above limits	
				ANE (8)	Undefined	Full rep. capacity	
				ANE (9a)	Undefined	Reduced rep. capacity	
	Others	19		HKE (8c9a)	Above trigger	Appropriate	
				MAC (nea)	Above trigger	Above limits	
European western waters fishing (100–250 GTs)	Trawling	45	HKE (27.3a46-8abd)	Above trigger	Appropriate		
			WHE	–	–		
			MEG (7b-k8abd)	Above trigger	Appropriate		
			ANK	Above trigger	Appropriate		
			Longline	83	HKE (27.3a46-8abd)	Above trigger	Appropriate
	Others	11			HOM (9a)	Above trigger	Appropriate
					MAC (nea)	Above trigger	Above limits
	Long distance waters fishing (> 250 GTs)	Trawling	63	HKE (27.3a46-8abd)	Above trigger	Appropriate	
				WHE	Unknown	Unknown	
				MEG (7b-k8abd)	Above trigger	Appropriate	
ANK (78abd)				Above trigger	Appropriate		
Longline		85	SWO (Atl N)	Below trigger	Appropriate		
			SWO (Atl S)	Below trigger	Above limits		
			BSH (N)	Below trigger	Appropriate		
			BSH (S)	Below trigger	Appropriate		
			SMA	Status unknown (ICCAT) and vulnerable (IUCN)			

Each of the chosen strata (artisanal, coastal, European western waters and long-distance high seas fishing) were divided into substrata depending on tonnage and type of fishing gear used by each production unit

Stocks are classified following Regulation (EC) No 218/2009 of the European Parliament and of the Council of 11 March 2009 on the submission of nominal catch statistics by Member States fishing in the north-east Atlantic. Includes FAO’s ASFIS Alpha3_code for fish species & the ICES (International Council for the Exploration of the Sea) advisory areas when applicable

remuneration, capital remuneration, taxes and subsidies. The matrix of final demand is not presented in this case, as it is not necessary for the objectives of this paper but in case of interest can be found in Rodríguez-Rodríguez et al. (2022)

For further formalisation (Brito et al. 2024), we can use X to represent the total output, which can be divided into intermediated goods (AX , where $0 < A < 1$) and final demand (Y), so that Eq. (1) can be written as:

$$AX + Y = X \tag{2}$$

, where A is an ($n \times n$) matrix of technological coefficients; X is an ($n \times 1$) vector of gross output and Y is an ($n \times 1$) vector of final demand. The elements of the matrix of technological coefficients (A) are obtained by dividing each element X_{ij} (representing the intermediate demand for inputs between sector i and supply sector j) by the total output of sector j , X_j : (X_{ij}/X_j). Each element of this division represents the

proportion of the value produced by sector j that is attributed to the consumption of product i . For instance, instance, the proportion of fuel needed for each unit of total fishing production that can be calculated from Online Resource, Annex II: Input–Output Table. More detailed explanations of the input–output framework can be found in Miller and Blair (2009).

Using this model, it is possible to determine not only the structure of the production function but also the impact of external shocks, political measures, changes in demand and so on (Venegas 1994), and it can, therefore, be considered an appropriate tool to assess the direct impact of changes in input prices and, specifically, of diesel oil.

The main advantages of the input–output analysis include: (1) it provides an accurate quantitative perspective of the economic activity, (2) the model is inherently scalable and, therefore, can be applied to many different levels of consumption and production (Wiedmann 2009) and (3) it is worth mentioning the unambiguous link between inputs use and output production. On the other hand, it also presents certain limitations. First, it is not an adequate tool for modelling the transition to a new state. Second, and linked to the fixed production patterns assumption (Bess and Ambargis 2011), as no changes in the production function are allowed in the model, impacts are measured under current conditions (routines, technologies, equipment, etc.), which tends to reflect the ‘worst case’ cost scenario (Rodríguez-Rodríguez et al. 2019). Thus, the results of this research express impacts under present fixed conditions, while eventual alternatives and implications are considered in the discussion.

Projection of scenarios and hypothetical cases to calculate the impact on fuel cost

The primary inputs matrix was recalculated simulating three different scenarios:

- Scenario 1 (S1) assesses the effects of implementing the European Commission's proposal to increase the cost of a litre of fuel by 3 cents per litre. In this case, the impact of adding 3 cents over the 2019 average price (0.481€/l)⁽³⁾
- Scenario 2 (S2) represents the intermediate scenario. As fuel prices were relatively low in 2019, we checked the impact of the evolution of market prices of marine fuel over recent years by considering the average monthly price between January 2019 and July 2023 (the last available date in EUMOFA): 0.63€/l. The intuition behind this scenario is that the reforms could be based on cheap fuel era visions, while the future is more likely to be charac-

terised by higher prices, increasing the uncertainty about the impacts of the reform.

- Scenario 3 (S3) calculates the effects on the sector if the price of marine fuel were the same as the end user price for Standard Diesel Fuel at 2019 prices (1.212€/l), that is, the elimination of marine fuel subsidies as proposed by the WTO in the case of overfished stocks.

In all three scenarios, it is understood that the volume of fuel consumed is the same (*ceteris paribus*), as a matter of fact, the own price elasticities show a clearly inelastic response to changes in fuel price (Roll et al. 2022), the only variation being the input taxes (scenarios 1 and 3) and the input taxes and the cost of fuel (scenario 2). That is, in the first and third cases it is only necessary to adjust the net tax per product line item, whereas in the second it is also necessary to adjust the value of the ‘refined petroleum products and others’ line item.

Profit margin, that is, the variable that synthesises the impact in cost variation, can be defined as the percentage of profit earned by a company or a sector in relation to its revenue.

When using standard input–output notation, to facilitate replication, $PM = 100 \times (\text{profit/revenue})$ can be written as:

$$PM = 100 \cdot ((h + i)/l) \tag{3}$$

h being the mixed income, i the gross operating surplus (GOS) and l the revenue.

Furthermore, the operating profit ($h + i$) is calculated as follows:

$$(h + i)^0 = l^0 - (c^0 + e^0 + g^0) \tag{4}$$

c being the total inputs cost at purchasing prices, d the compensation of employees and g other net taxes on production⁽⁴⁾, with the superscript denoting the correspondent scenario. Corresponding data for this variables can be found in the Online Resource, ANNEX III: Table III.

In scenarios 1 and 3, impacts stem from increases in fuel taxes (Δb) and can be calculated as:

$$\Delta b = b^0 + \frac{z_{27}}{P_{27}} \partial \tag{5}$$

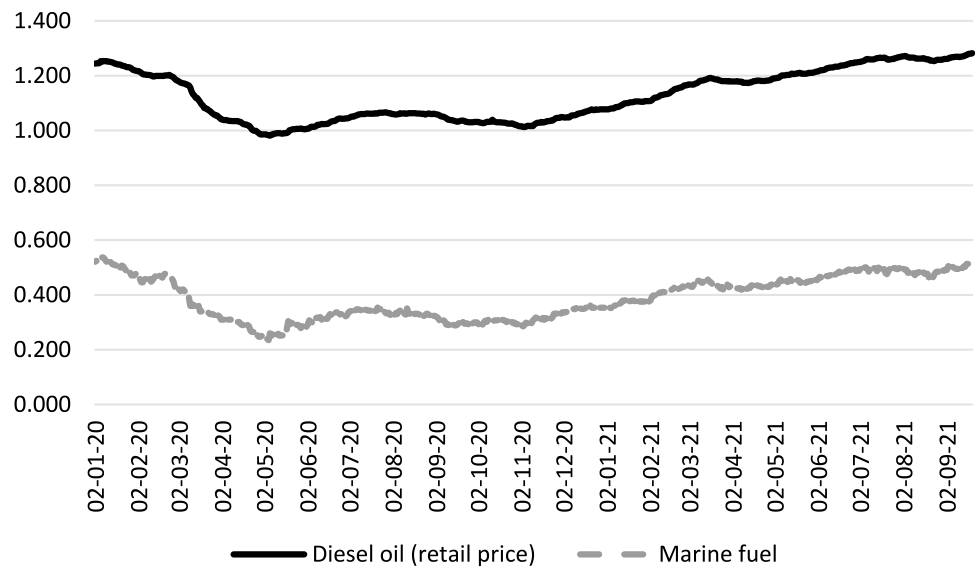
with the symbol Δ denoting ‘change in’ and b the net taxes on products⁽⁵⁾, z_{27} the total consumption in euros of input 27 (fuel), P_{27} the price of fuel and ∂ being = 0.03 in scenario

³ It should be acknowledged that in the case of this initiative, an exemption has been established for boats of less than 5000 gross registered tonnes, which includes all fishing boats, that will be revised in 2028.

⁴ Taxes less subsidies on production.

⁵ Tax on products are taxes that are payable per unit of some good or service produced or transacted, including VAT, special taxes on fuel and others. Net tax on products are defined as the difference between tax on products less subsidies on products.

Fig. 1 Daily evolution of standard diesel fuel and marine fuel (€). Source: Comisión Nacional de los Mercados y la Competencia (National Commission of Markets and Competition) (2021)



1.1 and 0.5 in scenario 2, that is, the same as equalising the price of marine diesel with the price of petrol or, in other words, removing exemptions. Downstream variables in the primary inputs matrix should be recalculated next. This means, first, recalculating the intermediate consumption at purchaser’s prices (*c*), which is basically the intermediate consumption at basic prices (*a*) plus the net taxes on products (**b**). Since inputs values at basic prices do not change, only the taxes on fuel, this can be done following Eq. (6). As compensation of employees is not affected, the operating profit (*h + i*) can be recalculated next with Eq. (4):

$$\Delta c = a^0 + \Delta b \tag{6}$$

In the case of scenario 2, changes are captured both in *b* and in z_{27} input (cost of fuel at basic prices), so to calculate the impact on profit (*h + i*) we also need to calculate the variation in *a*, which can be done as follows:

$$a^{1,2} = a^0 + \Delta z_{27} \tag{7}$$

$$\text{where } \Delta z_{27} = z_{27}^0 - \frac{z_{27}^0}{P_{27}^0} P_{27}^2 \tag{8}$$

P is the price of fuel in the base scenario or in scenario 2 denoted by the superscript. Substituting the correspondent values in (4) and then in (3) renders the operating profit under the three scenarios considered. In all three scenarios, production is assumed not to vary, that is to say, impact is calculated for the business-as-usual production level.

It is worth pointing out that the increase in taxation put forward by the EU and the elimination of tax exemptions

proposed by the WTO are addressed in this paper as alternative scenarios to isolate their individual effect. Nevertheless, they are additive and independent.

This process allows us to isolate the impact of the change in the cost of fuel within the fleets’ production function, given that it is calculated considering everything else as constant. In this regard, it is worth underlining that to date there are no alternative energies or technologies to substitute the use of diesel in the short term, and furthermore, there has been no significant renovation of the fleet since 2019. Therefore, the fixed technology assumption, typical of input–output models (Bess and Ambargis 2011), is not a limitation in this case but rather a characteristic of this activity.

Among the hypotheses typically included in input–output models, there is also ‘industry homogeneity’, that is, all the firms within the same industry are characterised by a common production process (Bess and Ambargis 2011). In this case, as mentioned above, the fishing ‘industry’ as a whole was divided into several strata in accordance with the ships’ tonnage, given that this is the stratifying variable that displays the least variance. To this end, the division into nine subsectors allows us to understand differences based not only on the differences in tonnage but also on the diverse fishing grounds and types so that fuel consumption is representative of the specific condition of each fleet.

It should be noted that all the scenarios were proposed to carry out the minimum possible transformations based on the 2019 production function from the questionnaires

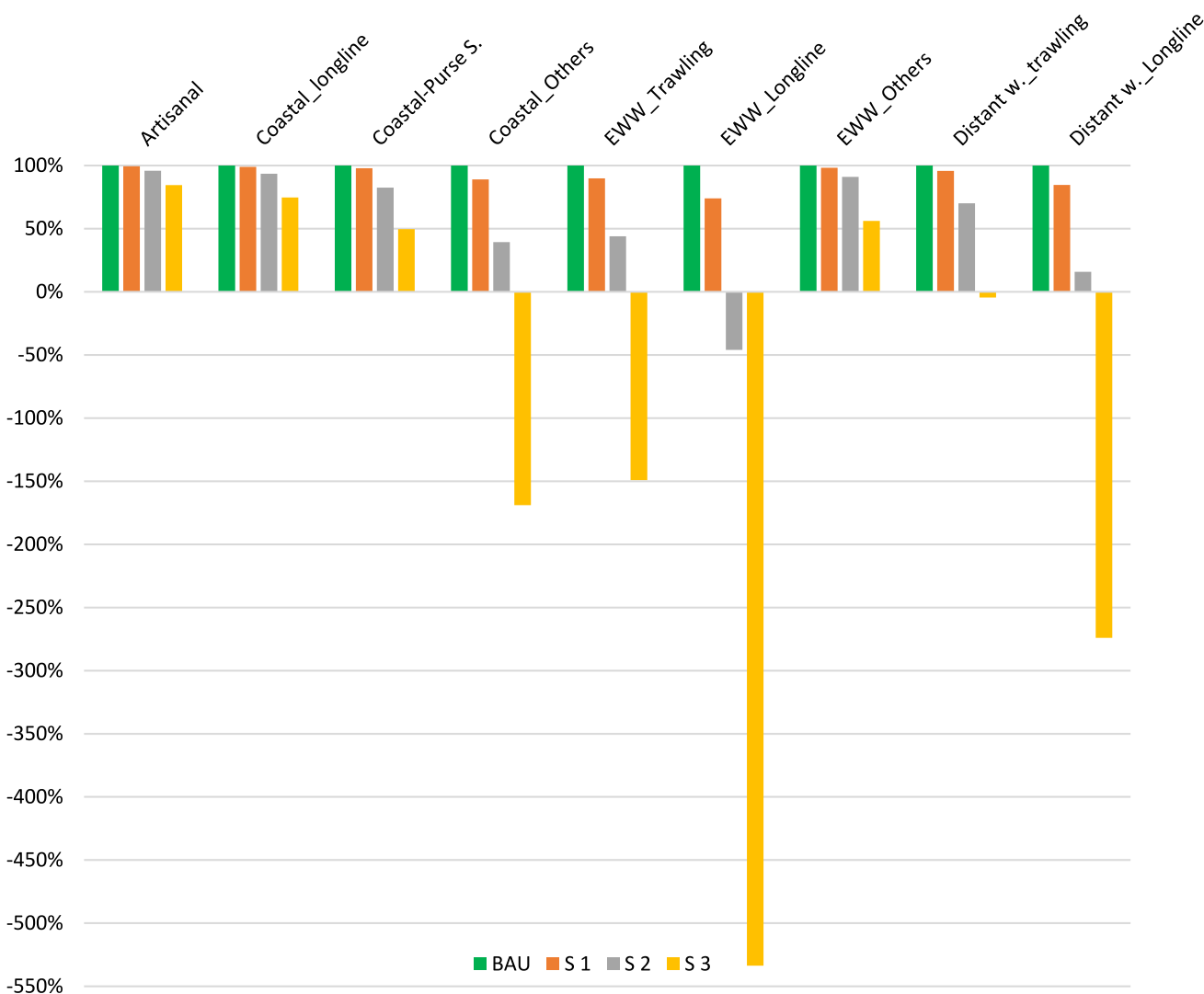


Fig. 2 Impact of increased taxation on marine fuel: changes to operating profits (GOS + mixed income)

performed for said year, as more recent equivalent data are unavailable.

Data

A main input to project the different scenarios proposed in this paper is the price of fuel. To this regard and merely to illustrate the relationship between marine diesel oil and standard diesel fuel, we have obtained a list of daily prices, made up of 430 entries between 2 January 2020 and 20

September 2021⁽⁶⁾, that has been compared with the daily diesel oil price data from standard pumps (Fig. 1).

Figure 1 illustrates how marine diesel oil and standard diesel are part of the same market, defined as the area within which the price of a commodity tends to uniformity, with allowance being made for transportation costs (Stigler 1966). The two series follow symmetrical movements through time, proving that we are dealing with the same product, except for the taxes applied in either case.

Furthermore, it can be seen how, as of May 2020, prices begin an increasing trend that is maintained to date, until reaching the values registered at the beginning of the study period. In fact, the tendency is still maintained and available forecasts (US Energy Information Administration 2021) seem to indicate that this upward trend will continue until the end of 2021, and then, prices will level off at values slightly lower than those at the end of the year during 2022;

⁶ This list has been provided by a representative organisation of producers who wish to remain anonymous due to their commercial strategies.

Table 2 Galician fishing sector net taxes (2019)

		Net taxes on products (€)	Net taxes on production (€)	Production (€)	Weight of total net taxes
Artisanal fishing	Traditional fishing	27,887,252.99	1.637.020,78	183,874,050.96	7,86%
Coastal fishing	Trawling	1,190,049.87	135.000,00	5,871,395.24	8,70%
	Purse seine	11,056,154.50	4.361.581,01	43,654,452.29	25,95%
	Gillnetting	1,189,816.03	0,00	3,675,711.50	4,48%
European western waters fishing	Trawling	19,725,661.01	849.216,36	47,281,188.10	6,41%
	Longline	33,758,844.66	2.051.148,05	90,330,900.40	9,88%
	Others	816,398.80	0,00	6,622,000.00	0,00%
Long distance waters fishing	Trawling	64,621,950.56	215.955,99	166,108,485.27	15,53%
	Longline	51,037,853.99	887.252,03	125,674,375.35	6,81%

Table 3 Input–output tables of Galician fisheries and processed seafood products 2019

		Business and professional services (€)	Refined petroleum products (€)	Operating costs (€)	Profit margin	Weight of fuel on OC	Fuel expenditure per euro produced (€)
Artisanal fishing	Traditional fishing	9,729,429.91	7,823,118.38	106,708,189.80	41.97%	7.33%	0.043
Coastal fishing	Trawling	11,400.99	422,435.85	3,329,801.06	43.29%	12.69%	0.072
	Purse seine	323,287.64	2,120,548.94	37,252,208.54	14.,67%	5.69%	0.049
	Gillnetting	31,932.67	531,867.00	3,374,902.82	8.18%	15.76%	0.145
European western waters fishing	Trawling	152,038.93	9,099,813.36	41,724,033.45	11.75%	21.81%	0.192
	Longline	435,737.33	13,945,023.04	86,982,865.94	3.71%	16.03%	0.154
	Others	14,520.00	423,500.00	5,152,400.00	22.19%	8.22%	0.064
Long distant waters fishing	Trawling	267,626.75	20,249,188.57	136,630,558.49	17.75%	14.82%	0.122
	Longline	487,853.61	22,493,941.39	116,526,436.01	7.28%	19.30%	0.179

Summary of line-item data to calculate the impact of increasing diesel oil taxation

however, the invasion of Ukraine is likely to trigger an inflationary spiral in energy prices, and, as a matter of fact, marine diesel prices reached 1.05€/l in March 2022. In the face of this kind of shock even more abrupt price increases are not ruled out (Jefferson 2020).

On the other hand, if fuel prices tends to move up on the long term suggesting the end of the cheap oil era (Jakobsen et al. 2012) the fleet size is moving down, having gone from 13,331 units in 2006 to 8657 in 2022 (MAPA 2023a), pushed by the fleet adjustmet policy implemented by the EU (Dolder et al. 2015). According to economic theory, vessels leaving the fishery should be the more inefficient, particularly smaller and older vessels. So, current market forces and fisheries regulations already seem to be creating incentives to increase efficiency, whereas the average age of the European and the Spanish fleets, approximately 36 and 35 years, respectively (MAPA 2023b), suggests the existence of other possible barriers towards ecological transition that should be considered in policy making (Fig. 2).

On the whole, the dependency on subsidies is limited. On the one hand, the Organization for Economic Cooperation and Development (OECD) has estimated the subsidies for the Spanish fleets (OECD 2023) to be 2% of their revenue (Delpeuch 2023), one of the lowest levels of all OECD members. On the other hand, at a Galician level, the fleet can hardly be characterised as subsidy-dependent, as all subsectors except gillnetters are net-pay taxers (Table 2).

Table 3 presents the economic information that defines the fleets in the study and that will serve as the basis for calculating the increase in taxes on fuel. The information comes from the TIOPT2019, gathered using the questionnaires in Online Resource: Annex IV: Questionnaire. This information is modelled for the different fleets and types of fishing assessed in this work (artisanal fleet [traditional fishing], coastal [gillnetting, purse seine and longline], European western waters [trawling, longline and others] and long distance [trawling and longline]).

From this information, it is worth highlighting that the consumption of diesel oil corresponding to the line item

‘refined petroleum products and others’, constitutes the main intermediate consumption by value in fishing for the coastal, high seas and long-distance fleets. For artisanal fishing, diesel oil consumption is the second most important expense after ‘business and professional services’. This is because an important part of the associated costs of shellfish harvesting and traditional fishing are covered by the shellfishing associations and/or fishermen’s associations and not directly by the producers themselves; these costs are jointly channelled through the line item ‘business and professional services’, which is paid for with quotas paid by each individual member.

Correlating ‘refined petroleum products’ with production value, it can be seen that billing 1 euro of product requires 4 cents of fuel in the case of artisanal fishing and 19 cents in the case of high seas trawling, which is mainly carried out in Gran Sol. For the fleet as a whole, the average is 11 cents for every euro billed. In terms of weight in the operational costs (OC), the fuel expenditure ranges from 7.3% for artisanal fishing to 21.8% for high-seas trawling, the average being 13.5%.

Results and discussion

Results: analysis of the direct economic impact

As mentioned above, input–output models provide a detailed image of the economic flow between a specific economy (the Galician fishing sectors, in this case) and the rest of the economy, with regard not only to goods suppliers but also to consumers (Miller and Blair 2009). Given that the TIOPT2019 allow us to analyse the impact per fleet segment, for the sake of conciseness, the data related to intermediate inputs are presented as a whole, with the exception of the line item ‘refined petroleum products and others’. Nevertheless, and to contextualise the results, Online Resource: ANNEX II: Input–Output Tables includes a detailed outlook of the intermediate and primary inputs at basic prices. By way of illustration, it is enough to highlight that the various Galician fleets demand inputs from the rest of the economy at a value of 264 million euros, which are distributed between up to 50 different sectors, including primary sectors, industry, energy, services and administration.

Scenario 0 represents the current production function of each fleet in 2019, that is, prior to the application of additional taxes. Scenarios 1, 2 and 3 represent the impacts of

⁷ Mixed incomes are generated by businesses that are not set up as companies, that is, self-employed remuneration, and it is called mixed income because it includes not only work remuneration but also the profits earned as an individual business owner.

the increase in fuel taxes in that production structure, when all else remains constant. The value-added matrices resulting from these simulations can be found in Online Resource: Annex III: Scenario Modelling. The data used in this section come from them.

In particular, the consumption of fuel does not change and neither do other primary inputs, so the disaggregation of primary inputs is not included in the tables. The change comes about in the ‘net taxes on product’ line item, which includes the taxes that are levied on products in scenarios 1 and 3 and also the value of fuel consumption in scenario 2, directly affecting the shipowners’ remuneration, regardless of whether this is as mixed income⁽⁷⁾ or as GOS⁽⁸⁾ and, consequently, the gross value added. However, production (as well as employees’ salaries) would not be modified. The sum of the mixed income and GOS can be the same as profits; although, in practical terms, the main difference would be the amortisation. In any case, depending on the extent to which this represents the shipowners’ remuneration, be they natural persons (mixed income) or entities (GOS), its variation constitutes a core variable to represent the impact on production units.

Generally, any vulnerability to fuel price increases is related to pre-existing profitability and to fuel clout on the production function, which, in turn, stems from the distances that the different fleets have to cover, affecting more those fleets that operate further away.

As expected, the fleet that would suffer the least in any of the scenarios would be the artisanal ships, which in the worst case (scenario 3) would see their profits reduced to 84.6% of BAU scenario (Online Resource, ANNEX III Table VI). A similar, slightly less negative result would be that of coastal longline.

It is worth pointing out that, in the case of artisanal fishing, the profit for the shipowner (mixed income) was 19,520.84€ in the BAU scenario (Online Resource, ANNEX III Table III.), which is above the average net salary in Galicia, estimated at 17,941,3€⁽⁹⁾ for the same year. In the worst-case scenario, it would drop to 16,510.28€, making fishing a comparatively less attractive activity and complicating the generational changeover, which is currently an important challenge facing the sector.

⁸ Gross operating surplus is the surplus generated by operating activities after the labour factor input has been recompensed. It can be calculated from the value added at factor cost less the personnel costs. It is the balance available to the unit which allows it to recompense the providers of own funds and debt, to pay taxes and eventually to finance all or a part of its investment.

⁹ Based on an average gross salary of 22,177, 40€ and considering 14 annual payments, a general contract of a non-qualified worker and no dependants.

On the other side of the spectrum are the fleets operating further away from the coast; however, the most fuel-intensive fleets are not the most vulnerable to fuel cost increases (Table 3). European western waters trawlers are the most fuel-intensive fleet, requiring 0.192€ of fuel per euro of production, nevertheless, the most vulnerable fleet is European western waters longliners with a lower fuel intensity (0.154), followed by distant waters longliners. The cause is mainly the combination of fuel consumption with low profit margins (3.7% and 7.3% respectively). A key factor contributing to the comparatively lower profitability is the contribution of a specific cost of these fleets, as is bait, representing 8.5% and 9.28% of the inputs (contabilised in rows 1.1 to 1.4.2 of the symmetric table [Online Resource: ANNEX II: Input–Output tables]).

Consequently, the European western waters longliners fleet would see its profits cut to 74.02% of the BAU scenario just with the taxation proposed by the EU; it would incur structural losses in a scenario with the 2019–2023 average fuel prices, and losses would skyrocket if subsidies were completely eliminated, as proposed by the WTO. The long-distance longline fleet would suffer similar consequences, albeit less severe. For instance, in scenario 2 they are not yet in the red although at that fuel price profits plummet to 15.8% of the base scenario.

The remaining fleets made up of coastal purse seiners, other European western waters fleets (mainly purse seiners and gillnetters), and trawlers fishing in European western waters and long-distance waters would be at an intermediate level; simulating a 3-cent increase in 2019 prices would vary between a drop in profits of up to 98.2% of the original in the case of other European western waters fleets (mainly gillnetting) and a fall of up to 89.8% for European western waters trawling, the most vulnerable of this group (Online Resource, ANNEX III: Table IV). The average fuel prices between 2019–2023 would reduce profits to a third of BAU scenario levels in the case of coastal gillnetting and European western waters trawling and to almost below 90% in the case of European western waters gillnetting (a very small fleet) and purse seine fishing. The elimination of exemptions would have a severe impact in the case of long-distance trawling, which would incur losses, extremely severe ones in the case of European western waters trawling or coastal gillnetting; profits would be cut by approximately half in the case of purse seine and, to a lesser degree, in the case of European western waters gillnetting. Previous results are aligned with the few other available studies, such as Carvalho and Guillen (2021) and Isaksen et al. (2015), this sensitivity being a consequence of the specific weight of fuel on the production function structure.

All of the above illustrates vulnerability, in different degrees, to fuel cost increases, in line with policymakers' expected results for this kind of green taxing. However, a

key institutional factor seems to have been missed when designing the reforms: coastal states have no fiscal competence beyond 12 miles (UN General Assembly 1982; Carvalho and Guillen 2021), which means a totally divergent scenario. All the fleets, except the artisanal sector, can continue with the BAU scenario and avoid any fiscal rules by means of offshore bunkering, so that the proposed reforms simply become a fee on artisanal fleets.

It is worth noting that it is impossible to know the exact offer of barges or tankers for bunkering but, given that they are offering a perfect substitute at lower prices, it is safe to assume that this offer will be provided, especially because bunkering is already a common practice in many ports around the world.

Discussion

The previous analysis has shown the impact of fuel increases on the different types of fleets, observing that, as expected, large-scale vessels operating in distant waters are more vulnerable than small-scale and coastal ones. Economic theory suggests that cost increases will provide economic incentives to promote a reduction in overfishing and the efficient use of fuel, thereby reducing carbon emissions. Nevertheless, incentives are context dependent, and when applied in specific activities and circumstances, outputs can diverge from the expected.

First of all, the more vulnerable fleets are not necessarily the most fuel intensive (trawlers). In this case, longliners are the most penalised because of the higher costs associated with higher selectivity. These kinds of effects could be relevant for consideration in future policy making. Second, some institutional aspects seem to have been missed when designing the reforms, particularly, that coastal states do not have fiscal jurisdiction beyond 12 nautical miles (UN General Assembly 1982; Carvalho and Guillen 2021), which completely changes the expected effects. That is to say, in their current terms, the directives would not be applied to those fleets that operate near or beyond 12 miles, nor to those operating in nearby enclaves where these rules do not apply, such as Gibraltar or the Channel Islands, with regard to EU taxes.

Under these conditions, the fleets which are characterised by their higher energy intensity and are responsible for about three-quarters of world catches (Pauly and Zeller 2016), could refuel offshore by means of bunkering. Consequently, there would be no benefits in terms of reducing emissions that contribute to climate change, nor in achieving the objectives of curbing overfishing or over capitalisation. Moreover, this approach would generate additional negative externalities due to oil spills. In fact, most oil pollution is not

caused by oil transported as cargo but rather by leaks from bunkering fuel (Krata and Jachowski 2021).

On the other hand, it would be the fleets operating closer to the coast, basically the artisanal fleets with lower energy intensity, that would suffer higher costs and would face greater competition from coastal and high seas fleets; the more the target species coincide, the greater the impact. Economic theory has suggested that older and smaller vessels tend to be more dependent on subsidies (Wang et al. 2023), but in this case, the fleet subsidy rates are low and the distribution of quotas, determined by the Relative Stability System, combined with successive European fishing policies, have caused a reduction in the capacity of the fishing fleet (Fernández-González et al. 2022), where the more inefficient units had to be the first to leave, so the main impacts seem to be caused by a deficient policy design. Under these conditions, the possible benefits from the reform would be marginal, given that they would be concentrated in the less energy intensive fleets and, as one might expect, they would be accompanied by negative impacts in economic and social terms.

The scope of the agreement negotiated within the WTO framework would be limited not only by its applicability in international waters but also by its own exceptions. The WTO agreement sets out that the different subsidies, including those that cover fuel costs, would still be permitted if the grantor country demonstrates that measures are being applied to maintain fishing grounds at biologically sustainable levels. This could pose some isolated problems in the case of fleets operating in mixed fisheries or those combining species with healthy stocks and others that are not; however, generally speaking, it would permit the continuance of different subsidies within the EU, where there is a thorough control of the condition of fisheries; there are TACs in place in the Atlantic and management measures in the Mediterranean aimed at achieving sustainability. This would also occur in the North American and Australian fisheries (Rousseau et al. 2019). Given that in international waters it would have no effect either, it seems that its main area of influence would be small-scale or coastal fishing grounds in developing countries, where there has been a noticeable motorisation of artisanal fishing over recent decades (Rousseau et al. 2019). The positive environmental effect would also be modest in this case, and it would bring about additional externalities together with economic and social impacts.

Coping measures in high seas fleets will mainly be limited to bunkering and refuelling in offshore locations, while in small-scale and coastal fleets they could include changes in fishing grounds (Vilela et al. 2021), moving to those closer to the coast, to more productive areas, or ceasing activity altogether in less productive seasons or reductions in speed (Isaksen et al. 2015).

Thus, the fiscal instruments proposed are not likely to reduce the externalities addressed (overfishing and carbon emissions), but they can represent an obstacle to effective measures (Roll et al. 2022) so to achieve the proposed goals other alternatives should be considered. In the case of overfishing, current management measures are contributing to enhancing the sustainability of stocks; in fact, the scientific assessment and management of fisheries remain the most reliable tool for improving the stock status (Hilborn et al. 2020).

Similar considerations can be made in the case of the UE initiative, so that no relevant contributions to its goals (the reduction of carbon emissions) can be expected in the fishing sector. Furthermore, one of the most interesting aspects of the UE reform is that it includes all kinds of vessels, not only fishing vessels, but these measures towards technological change can also be neutralised by the 12-mile boundary, once again limiting enforcement only to small boats.

Considering the key characteristics of innovation in fisheries is decisive to designing effective policy measures. First of all, fishing companies are rarely involved in explicit technological innovation and tend to incorporate technology embedded in machinery and equipment developed by world-leading manufacturers (González-López 2012), which Pavitt's taxonomy typified as supplier-dominated sectors (Pavitt 1984). Second, because early adopters of new technologies tend to be large and well-established ship-owners with relatively newer vessels, while latecomers are mainly young and small ship-owners with relatively old vessels (Mäkitie et al. 2022). The first case typically corresponds with offshore and international cargo ship-owners, while fishing companies are a typical example of the latter, with fewer and older vessels. This is, in fact, characteristic of the European and the Galician fishing fleets, where small boats average 34.4 and 37 years, respectively, while larger vessels average 24.4 and 26 years (MAPA 2023c). Two main reasons could contribute to explaining this different behaviour; on the one hand, large companies renewing their fleet more frequently can more easily experiment with alternative fuels on a limited number of ships. On the other hand, this kind of firm has also more administrative, technological (Steen et al. 2019) and economic (Shefer and Frenkel 2005) capabilities when applying for public funding for R&D (Research and development). However, the WTO proposal, article 4.1, also bans any subsidies for construction, modernisation or vessel upgrades when operating in overfished stocks, which can prevent technological transition in certain fleets in the global north (because of the status of the stocks) and, more frequently, in the global south.

Given the costs and existing uncertainties, some authors (Hua and Wu 2011; Mallouppas and Yfantis 2021; Mäkitie et al. 2022) suggest that economic and political incentives will be necessary to make any progress in decarbonisation.

In fact, this problem corresponds to the Mission-Oriented Research and Innovation approach put forward by Mazzucato (2018) to specifically tackle the climate change challenge in Europe and foster cleaner technology development. This is particularly relevant since there is also a high degree of uncertainty concerning technologies able to replace marine diesel oil, given that some are promising in the long term, such as hydrogen or ammonia fuel cells, but are not yet mature enough, and others, such as biofuels, can be useful in the short term and are mature technologies (Simonsen et al. 2021) but would not be adequate in the long term if the objective is to move towards a zero emissions scenario.

Recent policy developments at different EU levels reflect a turn towards positive incentives. The agreement between the European Council and the European Parliament (Council of the European Union 2022) grants more time to fuel suppliers, maritime companies and operators to adapt to the new regulation and introduces measures to promote the use of renewable fuels of non-biological origin (RFNBO). In parallel, the European Maritime, Fisheries and Aquaculture Fund (EMFAF) 2021–2027 (European Commission 2023) funds the replacement of engines, particularly in fleets < 24 m, to speed up the achievement of carbon emission goals.

These measures are likely to create limited side effects since a significant increase in fuel support could increase effort by 1.2% in large-scale fleets when TACs are in place and no increase in effort for SSF (Martini and Innes 2018), even though results can vary at the country level depending on the specific mix of subsidies and policies (Yagi et al. 2008).

In essence and coinciding with other recent papers (Wang 2023; Roll 2023; Carvallo,; Noruega), not only in the case of the WTO reform but also in the case of the UE energy reform, the proposals, following the logic of one size fits all, can be inefficient and provoke side effects. All in all, an alternative policy which places environmental, social and economic objectives on an equal footing could encompass effective management measures preventing overfishing (such as TACs and quotas) (Hilborn et al. 2020) (Sakai 2017), public financial support for technological transition at the shipping sector level and specific incentives, such as programs linking the fishing licenses to effective adaptation to alternative fuels or energy sources (Mäkitie et al. 2022) in the case of the fishing vessels and, after a transition period, negative incentives for those still using undesired technologies. In certain cases, buyback programs could be considered to adapt the fleets capacity. It is also key to develop a portfolio of measures adaptable to different contexts (Wang et al 2023), keeping in mind that the implementation of any significant measures should also be carried out within the framework of a three-way debate, including administration, scientists and producers; this is not only because of the general need to adequately combine the economic and social

effects within scientific approaches (Röckmann et al. 2015; Rodríguez-Rodríguez et al. 2021) but also because of the need to specifically prevent extremely adverse economic effects that are not always reversible (Franquesa 2002), such as those which would eventually stem from some of the aforementioned scenarios.

Therefore, changing the focus of the incentives would be more in line with the climate, technological and fishing challenges facing Europe, promoting leadership in cleaner technologies, while preserving the economic and social contribution of fisheries, since, as is generally accepted, the aim of green taxation is to maintain the activity but in a sustainable and responsible manner (Larach 1998).

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s12562-024-01794-x>.

Acknowledgements Partial financial support was received from Xunta de Galicia (Regional Government), contract (2017-CP092) H.M.B.'s work has been funded by a Postdoctoral Research Contract from the Xunta de Galicia, project ED481D-2022-009.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by G.R.-R., E.S.-L., H.M.-C. and H.M.B. The first draft of the manuscript was written by G.R.-R. and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature.

Data availability All data that supports the findings of this study is available within the article and/or supplementary materials. Alternatively, the original source of the data can be found in the Galician language in the Galician Input–Output Tables of the Fishing Sector and Seafood Industry 2019 at https://www.researchgate.net/publication/376077574_Taboas_input-output_da_pesca-conserva_galegas_2019

Declarations

Conflict of interest The research was conducted in the absence of any commercial, laboural or financial relationships that could be construed as a potential conflict of interest, and it was conducted based on the principles of neutrality, rigour, and independency.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Baumol WJ (2000) Leontief's great leap forward: beyond Quesnay, Marx and von Bortkiewicz. *Econ Syst Res* 12:141–152. <https://doi.org/10.1080/09535310050005662>
- Bess R, Ambargis ZO (2011) Input–output models for impact analysis: Suggestions for practitioners using RIMS II multipliers. In: 50th Southern Regional Science Association Conference, Southern Regional Science Association Morgantown, WV, pp 23–27
- Brito JAF, Nguyen TV, Kristófersson DM (2024) Evaluating the sustainability and potential of the blue economy: a bioeconomic and input–output analysis of the fisheries sector in Cape Verde. *Ocean Coast Manag* 250:107042. <https://doi.org/10.1016/j.ocecoaman.2024.107042>
- Carvalho N, Guillen J (2021) Economic impact of eliminating the fuel tax exemption in the EU fishing fleet. *Sustain* 13:2
- Cisneros-Montemayor AM, Sanjurjo E, Munro GR, Hernández-Trejo V, Rashid Sumaila U (2016) Strategies and rationale for fishery subsidy reform. *Mar Policy* 69:229–236. <https://doi.org/10.1016/j.marpol.2015.10.001>
- Cisneros-Montemayor AM, Sinan H, Nguyen T, Da Rocha JM, Sumaila UR, Skerritt DJ, Schuhbauer A, Sanjurjo E, Bailey M (2022) A constructive critique of the World Trade Organization draft agreement on harmful fisheries subsidies. *Mar Policy* 135:104872. <https://doi.org/10.1016/j.marpol.2021.104872>
- Comisión Nacional de los Mercados y la Competencia (2021) Estadística de productos petrolíferos CNMC. In: Estadística Prod. Pet.—CNMC. <https://www.cnmc.es/estadistica/estadistica-de-productos-petroliferos-cnmc>. Accessed 26 Oct 2021
- European Commission (2021) Proposal for a Council Directive restructuring de Union framework for the taxation of energy products and electricity. COM (2021) 563 final. Brussels
- European Commission (2023) European Maritime, Fisheries and Aquaculture Fund (EMFAF)
- Council of the European Union (2022) Proposal for a Regulation of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport and amending Directive 2009/16/EC. Brussels
- Delpeuch C (2023) Current situation and latest developments in OECD work. In: EAFE Conference 2023 May 30–June 1. EAFE, Athens
- deReynier YL, Levin PS, Shoji NL (2010) Bringing stakeholders, scientists, and managers together through an integrated ecosystem assessment process. *Mar Policy* 34:534–540. <https://doi.org/10.1016/j.marpol.2009.10.010>
- Dolder PJ, Engelhard GH, García-Carreras B, Lynam CP, Mackinson S (2015) Effort reduction and the large fish indicator: spatial trends reveal positive impacts of recent European fleet reduction schemes. *Environ Conserv* 42:227–236. <https://doi.org/10.1017/S0376892915000077>
- Eurostat (2008) Eurostat Manual of Supply, Use and Input-Output Tables. Office for Official Publications of the European Communities, Luxembourg
- Fernández-González R, Pérez-Vas R, Pérez-Pérez M, Garza-Gil MD (2022) Brexit, common fisheries policy and discard ban: a financial analysis of the Spanish fleet in the Grand Sole. *Fish Res* 249:106264. <https://doi.org/10.1016/j.fishres.2022.106264>
- Fernández-Macho J, Gallastegui C, González P (2008) Economic impacts of TAC regulation: a supply-driven SAM approach. *Fish Res* 90:225–234. <https://doi.org/10.1016/j.fishres.2007.10.019>
- Franquesa Artés R (2006) Las tablas input-output de la pesca y conserva gallega, un instrumento de gestión útil y oportuno. *Rev Galega Econ* 15:2
- Franquesa R (2002) El comercio pesquero y la WTO. In: VI Foro Científico de la Pesca Española en el Mediterráneo. Palamos
- García-Negro (Dir.) MDC (2003) Input-output tables for the galician fishing and preserved fish sectors. Consellería de Pesca e Asuntos Marítimos, Santiago de Compostela
- García-Negro (Dir.) MDC (2016) Táboas input-output da pesca-conserva galegas 2011. Consellería de Mar, Xunta de Galicia, Santiago de Compostela
- García-Negro (Dir.) MDC (1997) Táboa Input Output Pesca-Conserva Galega 1995. Consellería de Pesca, Marisqueo e Acuicultura, Xunta de Galicia., Santiago de Compostela
- González-López M (2012) The Spanish cod fishing industry: radical production changes without significant changes in the innovation system. *J Entrep Manag Innov* 8:35–51
- Hilborn R, Amoroso RO, Anderson CM, Baum JK, Branch TA, Costello C, de Moor CL, Faraj A, Hively D, Jensen OP, Kurota H, Little LR, Mace P, McClanahan T, Melnychuk MC, Minto C, Osio GC, Parma AM, Pons M, Segurado S, Szuwalski CS, Wilson JR, Ye Y (2020) Effective fisheries management instrumental in improving fish stock status. *Proc Natl Acad Sci* 117:2218–2224. <https://doi.org/10.1073/pnas.1909726116>
- Hua J, Wu Y (2011) Implications of energy use for fishing fleet—Taiwan example. *Energy Policy* 39:2656–2668. <https://doi.org/10.1016/j.enpol.2011.02.034>
- Isaksen JR, Hermansen Ø, Flaaten O (2015) Stubborn fuel tax concessions: the case of fisheries in Norway. *Mar Policy* 52:85–92. <https://doi.org/10.1016/j.marpol.2014.10.028>
- Jakobsson K, Bentley R, Söderbergh B, Aleklett K (2012) The end of cheap oil: bottom-up economic and geologic modeling of aggregate oil production curves. *Energy Policy* 41:860–870. <https://doi.org/10.1016/j.enpol.2011.11.073>
- Jefferson M (2020) A crude future? COVID-19s challenges for oil demand, supply and prices. *Energy Res Soc Sci* 68:101669. <https://doi.org/10.1016/j.erss.2020.101669>
- Larach MA (1998) Comercio y medio ambiente en la Organización Mundial del Comercio (LC/L. 1127). Santiago Chile, Com Económica para América Lat y el Caribe
- Mäkitie T, Steen M, Saether EA, Bjørgum Ø, Poulsen RT (2022) Norwegian ship-owners' adoption of alternative fuels. *Energy Policy* 163:112869. <https://doi.org/10.1016/j.enpol.2022.112869>
- Mallouppas G, Yfantis EA (2021) Decarbonization in shipping industry: a review of research, technology development, and innovation proposals. *J Mar Sci Eng* 9:2
- MAPA (2023c) 05. Análisis de la flota española y europea. In: Estadísticas Pesq. Estadística la Flot. Pesq.
- MAPA (2023a) Situación de la flota pesquera española
- MAPA (2023b) 05. Análisis de la flota española y europea. In: Estadísticas Pesq. Estadística la Flot. Pesq. <https://www.mapa.gob.es/es/estadistica/temas/estadisticas-pesqueras/pesca-maritima/estadistica-flota-pesquera/>. Accessed 2 Oct 2023
- Martini R, Innes J (2018) Relative Effects of Fisheries Support Policies”, OECD Food, Agriculture and Fisheries Papers, No. 115. Paris
- Mazzucato M (2018) Mission-Oriented Research & Innovation in the European Union. A problem-solving approach to fuel innovation-led growth. Luxembourg
- Miller RE, Blair PD (2009) Input-output analysis: foundations and extensions. Cambridge University Press
- Morrissey K, O'Donoghue C (2013) The role of the marine sector in the Irish national economy: an input–output analysis. *Mar Policy* 37:230–238. <https://doi.org/10.1016/j.marpol.2012.05.004>
- OECD (2023) Fisheries support estimates. In: OECD Agric. Stat. <https://www.oecd-ilibrary.org/content/data/ade64fdc-en>. Accessed 12 Oct 2023
- Owusu V, Adjei M (2021) Politics, power and unequal access to fisheries subsidies among small-scale coastal fisherfolk in Ghana.

- Ocean Coast Manag 214:105920. <https://doi.org/10.1016/j.ocecoaman.2021.105920>
- Pauly D, Zeller D (2016) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nat Commun* 7:10244. <https://doi.org/10.1038/ncomms10244>
- Pavitt K (1984) Sectoral patterns of technical change: Towards a taxonomy and a theory. *Res Policy* 13:343–373. [https://doi.org/10.1016/0048-7333\(84\)90018-0](https://doi.org/10.1016/0048-7333(84)90018-0)
- Peltovuori V (2017) Fossil fuel subsidies in the Pacific island context: analysis of the case of Kiribati. *Energy Policy* 111:102–110. <https://doi.org/10.1016/j.enpol.2017.09.021>
- Porter G (2001) Fisheries subsidies and overfishing. Toward a structured discussion, Geneva
- Röckmann C, van Leeuwen J, Goldsborough D, Kraan M, Piet G (2015) The interaction triangle as a tool for understanding stakeholder interactions in marine ecosystem based management. *Mar Policy*. <https://doi.org/10.1016/j.marpol.2014.10.019>
- Rodríguez-Rodríguez G, Ballesteros VHM, Valeiras J, Bellido JM (2019) Input-output analysis of the economic impacts of the landing obligation: Snap-shot from the trawler fleet in Northern Iberian waters (Spain). *Ocean Coast Manag* 172:146–156. <https://doi.org/10.1016/j.ocecoaman.2019.02.006>
- Rodríguez-Rodríguez G, Ballesteros HM, Martínez-Cabrera H, Vilela R, Pennino MG, Bellido JM (2021) On the role of perception: understanding stakeholders' collaboration in natural resources management through the evolutionary theory of innovation. *Sustain* 13:1–11. <https://doi.org/10.3390/su13063564>
- Rodríguez-Rodríguez G, García-Negro M do C, Sánchez-Llamas E, Martínez-Cabrera H, Ballesteros VHM (2022) Táboas input-output da pesca-conserva galegas 2019. Xunta de Galicia, Consellería do Mar
- Roll KH, Asche F, Bjørndal T (2022) The effect of introducing fuel tax to the Norwegian fishery industry. *Mar Policy* 135:104829. <https://doi.org/10.1016/j.marpol.2021.104829>
- Rousseau Y, Watson RA, Blanchard JL, Fulton EA (2019) Evolution of global marine fishing fleets and the response of fished resources. *Proc Natl Acad Sci* 116:12238–12243. <https://doi.org/10.1073/pnas.1820344116>
- Sakai Y (2017) Subsidies, fisheries management, and stock depletion. *Land Econ* 93:165–178. <https://doi.org/10.3368/le.93.1.165>
- Sakai Y, Yagi N, Sumaila UR (2019) Fishery subsidies: the interaction between science and policy. *Fish Sci* 85:439–447. <https://doi.org/10.1007/s12562-019-01306-2>
- Santiago JL, Surís-Regueiro JC (2018) An applied method for assessing socioeconomic impacts of European fisheries quota-based management. *Fish Res* 206:150–162. <https://doi.org/10.1016/j.fishres.2018.05.010>
- Shefer D, Frenkel A (2005) R&D, firm size and innovation: an empirical analysis. *Technovation* 25:25–32. [https://doi.org/10.1016/S0166-4972\(03\)00152-4](https://doi.org/10.1016/S0166-4972(03)00152-4)
- Simonsen TI, Weiss ND, van Dyk S, van Thuijl E, Thomsen ST (2021) Progress towards biofuels for marine shipping Status and identification of barriers for utilization of advanced biofuels in the marine sector. IEA Bioenergy
- Steen M, Bach H, Bjørgum Ø, Hansen T, Kenzhegaliyeva A (2019) Greening the fleet: A technological innovation system (TIS) analysis of hydrogen, battery electric, liquefied biogas, and biodiesel in the maritime sector. SINTEF, Trondheim
- Stigler GJ (1966) The theory of price. Macmillan, New York
- Sumaila UR (2004) Intergenerational cost–benefit analysis and marine ecosystem restoration. *Fish Fish* 5:329–343. <https://doi.org/10.1111/j.1467-2679.2004.00166.x>
- Surís-Regueiro JC, Santiago JL (2018) Assessment of Socioeconomic Impacts through physical multipliers: the case of fishing activity in Galicia (Spain). *Ecol Econ* 147:276–297. <https://doi.org/10.1016/j.ecolecon.2018.01.020>
- Sustainable Development Solutions Network Indicators and a monitoring framework. Launching a data revolution for the Sustainable Development Goals. <https://indicators.report/targets/14-6/>. Accessed 6 Nov 2021
- UN General Assembly (1982) Convention on the Law of the Sea, 10 December 1982
- US Energy Information Administration (2021) Short-Term Energy Outlook. Forecast highlights
- Venegas J (1994) Una matriz insumo-producto inversa de la economía chilena 1986. *Ser Estud Económicos* NA 38
- Vilela R, Pennino MG, Rodríguez-Rodríguez G, Ballesteros HM, Bellido JM (2021) The use of a spatial model of economic efficiency to predict the most likely outcomes under different fishing strategy scenarios. *Mar Policy* 129:104499. <https://doi.org/10.1016/j.marpol.2021.104499>
- Wang K, Reimer MN, Wilen JE (2023) Fisheries subsidies reform in China. *Proc Natl Acad Sci* 120:e2300688120. <https://doi.org/10.1073/pnas.2300688120>
- Wiedmann T (2009) Editorial: carbon footprint and input–output analysis—an introduction. *Econ Syst Res* 21:175–186. <https://doi.org/10.1080/09535310903541256>
- WTO (2022) Agreement on fisheries subsidies. Ministerial decision of 17 June 2022. Geneva
- Yagi N, Senda Y, Arijji M (2008) Panel data analyses to examine effects of subsidies to fishery productions in OECD countries. *Fish Sci* 74:1229–1234

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.