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The carbon footprint of the hake supply chain in Spain: Accounting for fisheries, international transportation and domestic distribution

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ABSTRACT

Climate change mitigation depends to a large extent on economic sectors modifying their production processes to significantly reduce their greenhouse gas emissions, particularly CO_2. However, greenhouse gas emission assessments are usually excluded from management of capture fisheries. Traditionally, hake (*Merluccius* ssp.) has been an important food for the population of Western Europe, and remains one of the most consumed fish in Spain's gastronomic culture. This paper reconstructs, for the first time, the hake seafood chain in Spain with the aim of estimating the carbon footprint of its extraction (fishing), transport and distribution. Our results show that total greenhouse gas emissions from the hake production and value chain in 2017 were 681 kt CO_2e, with an emission intensity of 4.42 $kgCO_2e\ kg^{-1}$ of whole fish. From these total emissions, those related to fishing operations represent 67% (456 kt CO_2e), with the remaining 33% (225 kt CO_2e) associated with transport (maritime, air or road). Air transport was the highest in terms of emission intensity per kilogram of hake transported (15.85 $kgCO_2e\ kg^{-1}$), and contributed to the largest share (72%) of transport emissions. Maritime transport presented the least emission intensity (0.33 $kgCO_2e\ kg^{-1}$) and predominated for hake caught outside the EU (e.g., Argentina, Namibia), offsetting the long distances the hake had to travel with greater transport efficiency. Our study highlights the importance of including greenhouse gas emissions analysis in the operationalization of the ecosystem-based fisheries management in the European Common Fisheries Policy as well as other regulations such as the Marine Strategy Framework Directive as a key tool for decision makers to appropriately address climate change impacts. The evidence provided by our study highlights the importance of finding a balance between healthy fish consumption patterns and their associated environmental impacts.

1. Introduction

The current globalization of the economy has led to an increasing volume of international trade. An interconnected network of suppliers, producers, traders and consumers across the globe has increased the distances between the production and consumption sites (Kastner and Haberl, 2014; Watson et al., 2015, Farmery et al., 2015). This global supply chain may raise living standards and help alleviate poverty, but it also places great demands on ecosystems and natural resources (Wible et al., 2014; Tilman and Clark, 2014). Reducing greenhouse gas (GHG) emissions to mitigate climate change (CC) requires increasing our knowledge about which sectors generate the largest contributions to GHG emissions and where and how reduction strategies can be effectively implemented. In particular, offshoring processes should be taken into consideration, as they lessen impact indicators in consumer countries at the expense of natural resources from all over the world (Barrett et al., 2013).

Recent studies point out that food system emissions, from production to consumption, including processing, transport and packaging, represent a third of global anthropogenic GHG emissions (Crippa et al., 2021;

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Xu et al., 2021). This indicates a clear difference in GHG emissions between food categories, with grains, fruit and vegetables having the lowest impact and meat from ruminants having the highest impact (Clune et al., 2017; Poore and Nemecek, 2018). Some examples are the impacts related to feed production in the European meat sector (e.g., Weiss and Leip, 2012), or emissions related to synthetic nitrogen fertilizers in Spanish agriculture (e.g., Aguilera et al., 2021). Even more, transport impacts should also be taken into consideration, particularly in countries such as Spain, where dependence on food imports has increased in the last decades (Pérez-Neira et al., 2016). Overall, the emissions of the Spanish population account for 3.5 Mg CO_2e cap^{-1} yr^{-1} related to their consumption patterns, 45% of which is related to animal food (Aguilera et al., 2020).

Previous studies found that the fisheries sector emits between 112 and 179 million tonnes of CO_2 into the atmosphere annually, which accounts for ca 0.5% of total GHG emissions and represents about 4% of global emissions from food production (Tyedmers et al., 2005; Parker et al., 2018; Greer et al., 2019). Despite recent advances, marine capture fisheries are often excluded from global GHG assessments or, in the best of cases, policy recommendations are usually made based on a limited number of case studies, thus not taking into account the large variability in emissions among fisheries that target a wide range of species using different fishing gears (Parker et al., 2018). GHG assessments applied to fisheries show that transport and fuel consumption of the fishing activity commonly constitute the most important impacts (Hospido and Tyedmers, 2005; Vázquez-Rowe et al., 2010, 2011).

Under this context, Spain is among the 25 largest seafood producers in the world and hosts the largest fishing industry in the European Union (EU) (STECF, 2021). In 2019, Spain produced around 850,000 tons of seafood, 29% of the total EU fleet landings, and accounted for nearly 1700 million euros in landing value (STECF, 2021). In Spain, Iribarren et al. (2011) were the first scholars who assessed the carbon footprint of fishing activities, reporting GHG emissions of 888,620 t CO_2e $year^{-1}$ by the Galician fleet. Vázquez-Rowe et al. (2011) also evaluated the environmental impacts related to the extraction, processing and consumption of the northern stock hake in European waters caught by Galician trawlers and longliners, showing considerably lower environmental impacts for fresh fillets of European hake from longline vessels compared to trawlers, mainly due to the high energy demand of the trawlers analysed.

Hake has been an important food for the people of Western Europe throughout history, and it remains as one of the most consumed seafood products in Spain. It is also important for the domestic market and particularly relevant for the economy of the fishing sector and food security, accounting in 2017 for 15% of the total value caught by the Spanish fleet (MAPAMA, 2017a; STECF, 2021). However, there is no evidence available on the carbon footprint of the hake supply chain in Spain as a whole. Therefore, by using the life cycle-oriented indicator of the carbon footprint (Finkbeiner, 2009; Vázques-Rowe et al., 2016), we have assessed, for the first time, the GHG emissions for: (a) Spanish vessels targeting hake landed at domestic ports; b) Spanish vessels targeting hake landed at international ports; (c) hake imports destined for Spain, including GHG emissions from fishing vessels in the countries of origin; and (d) the transport modes and routes (sea, air and land) used for transport to Spain and distribution routes (roads) within the Spanish territory. We also compared the carbon footprint for fresh or chilled hake and frozen hake, which includes only frozen fillets and meat.

2. Material and methods

The system analysed includes extraction (fishing), international transport to Spain, and domestic distribution within Spanish territory for the year 2017. The fleet consumption of fuel included all fishing operations (Supplementary Material, Figure SM1), while imports included international transport as well as emissions from fishing fleet operations in the countries of origin. We accounted for the different types of transport (land, sea and air) and the diverse routes that landings follow from ports to retailers distributed in Spain, following intermodal transport supply chains from abroad up to the final distribution in each Spanish province. The domestic distribution included the recirculation[1] of hake within the national territory and between the logistics centres of the different provinces in order to cover the demand for domestic consumption (Supplementary Material, Figures SM2, SM4, SM5, SM6 and Table SM5).

Some components of the supply chain have been excluded from the analysis: a) all post-retail emissions, including transport, storage, cooking and waste, b) the volume of hake marketed as “canned and processed”, because it represents a minimal amount of the total hake marketed in Spain, c) carbon emissions during trawling operations due to the resuspension of seabed sediments, although recent studies suggest that this remineralisation could be an important source of CO_2 emissions (Sala et al., 2021), d) GHG emissions related to the transport and distribution of exports to third countries, because our aim is to understand the emission intensity and impacts of the food chain supply associated with hake consumption in Spain (It should be noted that exports have only been considered for calculating the net availability of hake for consumption in Spain), and e) emissions from cooling agents in fishing operations (Iribarren et al., 2011).

The hake landings of the Spanish fleet were obtained from the vessels' logbook records (Data Collection Framework, Regulation (EU) Nº 2017/1004). These records include information on the number of landings, fishing zones and sub-zones according to the codes used by the Food and Agriculture Organization of the United Nations (FAO), the port and country of landing, and the vessels' engine power. International seafood trade flows of hake were obtained from the official database of the Spanish Secretary of State for Foreign Trade Statistics (DataComex, 2017), which includes information on countries of origin, Spanish provinces of destination, volume transported and types of transport (road, maritime and air). We assumed that landings of the Spanish fleet in international ports followed the same transport routes as imports, using the same cargo areas and logistics centres. We also assumed that hake landed at Spanish ports followed the same supply chain transport routes as other foods.

The difference between the net availability of hake for human consumption within each Spanish province, i. e., the difference between landings, plus imports minus exports, and the volume of consumption in each province allowed us to identify the existence of recirculation of a product between them, from those provinces with a production surplus to those with a deficit, to cover their domestic consumption (Supplementary Material). The volume of hake consumption in each Spanish province was obtained from the Food Consumption Panel data (MAPAMA, 2017c). To compute the volume of hake received by the provinces with deficits, we assumed that they received a proportional contribution of the aggregate total national surplus from provinces with surplus, according to the market shares of large distributing wholesalers in Spain (Supplementary Material, Table SM1). After estimating the hake flows a proportional contribution of the aggregate domestic total from the fishing zones and the net imports to retail in each province, we computed the international transport and the domestic distribution routes with the associated means of transport in each case, as well as the distances travelled.

2.1. Calculating the carbon footprint

To obtain the carbon footprint we converted the fleet fuel consumption and the distances covered by the different types of transport at the different stages of the entire hake supply chain into GHG emissions. In this study we considered a functional unit (FU) as the amount of CO_2

[1] Transport of hake between provinces with a surplus to provinces with a deficit.

equivalent (CO_2e) emitted per kilogram of whole hake, and we applied a series of converters widely used in this type of studies following the ReCiPe (H) 2016 v.1.04 methodology (Huijbregts et al., 2016) (Supplementary Material, Figure SM3).

2.2. Greenhouse gas emissions from fishing

The GHG emissions from hake catches were calculated based on fuel consumption by fishing vessels, including fishing, transport from the fishing zone to the landing port and the outward journey with an empty vessel, assuming it represents the vast majority of GHG emissions (Vázquez-Rowe et al., 2011). Data on fuel consumption were extracted from the Scientific, Technical and Economic Committee for Fisheries (STECF, 2019), which provides a detailed consumption profile for each fleet segment of different fishing areas. As fleet segments catch more than one species, it was necessary to allocate fuel consumption in a weighted manner between the volumes of the different species caught, using a mass allocation approach[2] (see the Supplementary Material). Finally, GHG emissions related to fuel consumption (KgCO_2 eq. t^{-1}. km^{-1}) were calculated following the methodology and converters developed by Aguilera et al. (2019) (Eq. (1), and Supplementary Material, Table SM2):

$$GHG_{fishing=}\frac{V_{diesel}}{M_{hake}}x\, M_{hake}\; x\; GCV\; x\; GHG_{diesel} \tag{1}$$

where *Vdiesel/MHake denotes* the volume of diesel consumption per tonne of hake caught, *Mhake* means the mass of hake caught, *GCV* (gross calorific value) is the energy contained in each unit of mass or volume of diesel, and *GHG* diesel denotes the value of GHG emissions per MJ of diesel for the year 2010, including fuel production and direct emissions from fuel combustion.

2.3. Greenhouse gas emissions from transport

The GHG emissions associated with the different transport types were calculated using converters for each of the types of transport used in the hake supply chain in Spain obtained through a literature review (Supplementary Material, Table SM3). We complemented this information with the Ecoinvent 3.7.1 database (Ecoinvent, 2019). The choice of a particular transport type and the use of refrigeration was made based on the information available in the scientific literature and on expert knowledge (Fitzgerald et al., 2011; Meneghetti and Ceschia, 2020; Parajuli et al., 2021). Measuring the emissions from these transports in Kg CO_2e per tonne per kilometre (Kg CO_2 eq.t^{-1}.km^{-1}), makes it possible to estimate the emissions derived from transport by multiplying the distance travelled and the volume transported by the values of the converters (Supplementary Material). Transport routes of the net volume of hake marketed were reconstructed by breaking down the distances travelled for each of the transport types. The application of the selected converters allowed us to calculate the impact of each of the routes from the volume transported and the distance travelled between the origin and the destination (Eq. (2)):

$$GHG_{transp} = \sum(GHG_{md}x\; distance\; xM_{Hake}) \tag{2}$$

Emissions from transport (*GHGtransp*) are calculated through the converters (Supplementary Material, Table SM3) for each mode of transport (*GHGmd*), multiplied by the estimated distance and the mass of hake transported (*Mhake*).

[2] The application of efficiency to the volume captured in each sub-zone allows us to estimate the amount of diesel attributable to the hake captures for each segment.

3. Results

3.1. Total supply, net availability and origin of hake

The term 'hake' encompasses a group of demersal fish species (genus *Merluccius*) that inhabit all seas and oceans, usually at depths between 150 and 600 m and close to the bottom. Of the 12 different species belonging to this genus worldwide, 8 are marketed in Spain (Supplementary Material, Table SM4) (MAPAMA, 2017b). Among them, European hake (*Merluccius merluccius)* and Argentine hake (*Merluccius hubbsi*) were responsible for 83% of the total catches of hake of the Spanish fleet (STECF, 2017). Regarding imports, the main species of hake marketed in Spain are Cape hake (*Merluccius capensis*), Argentine hake and Southern hake (*Merluccius australis*). Henceforth in this paper, references 'hake' include the 8 species marketed in Spain.

The Spanish fleet caught 98,206 t of hake in 2017. Of this total 30,134 t came from Spanish vessels landing their catch in domestic ports, of which 12,789 t were caught in national fishing zones and 17,345 t in international fishing zones (Fig. 1). The remaining 68,072 t came from Spanish vessels fishing exclusively in international fishing zones, and landing their catches at international ports. Imports reached a volume of 121,032 t, which when added to the catch yield produced a total availability of 219,239 t. From this total availability we deducted the volume of hake exported (65,305 t), resulting in a net availability of 153,934 t of hake, which is the volume that ultimately reached the retail sector for consumption in Spain (Fig. 1). It is worth highlighting that of all the hake available for consumption in Spain, only 8% is caught by the Spanish fleet in national fishing zones.

Spanish vessels harvesting hake operate regularly in 5 major FAO fishing zones. The FAO 41 (Southwest Atlantic) is the fishing zone with the highest volume of catches (46,000 t; 47%); 93% of these catches were landed at international ports (mainly Argentina and Uruguay) while only 7% were landed at Spanish ports (Fig. 2). The second FAO zone with the highest catches was FAO 27 (North-East Atlantic) (more than 33,000 t; 33%), 76% of the volume was landed at Spanish ports, while the remaining 24% was landed at international ports (Ireland and France), and then transported to Spain. These two zones (41 and 27) together account for 80% of the total hake caught by the Spanish fleet (Fig. 2a; Supplementary Material, Table SM4).

Most of the hake available in Spain (55%) relies on imports, with Namibia being the country from which the most hake was imported (40,000 t), representing 30% of the total volume of imports. Of the hake imported from Namibia, 96% was transported to Spain frozen. The second most important country was France (24,000 t), representing 17% of the total. Unlike Namibia, almost all of the hake imported from France arrived in Spain fresh (98%). Argentina was the third country, with more than 15,000 t of hake, all of which was marketed frozen (Fig. 2b).

The hake imported and landed by Spanish vessels in international ports travels long distances to be sold in Spain. Fig. 3 shows the weighted average distance (km) of hake transported by each country of origin. South American countries (Chile, Argentina, Uruguay) and the Islas Malvinas/Falkland Islands led the ranking of weighted average distances. Chile was the country with the longest journey per ton of hake caught and transported to Spain, while in the opposite position ranked Portugal, with a weighted average distance of less than 850 km. France, the United Kingdom, Ireland and Denmark also showed very similar figures when comparing the weighted average distance travelled for landings of catches in international ports and imports. Hake transported from Germany, Denmark, South Africa, the United States, Canada and Chile came mainly from imports, while hake transported from Uruguay, Mauritania, Senegal, Morocco, Portugal, Guinea, Italy and Angola came exclusively from catches landed by Spanish vessels in international ports (Fig. 3).

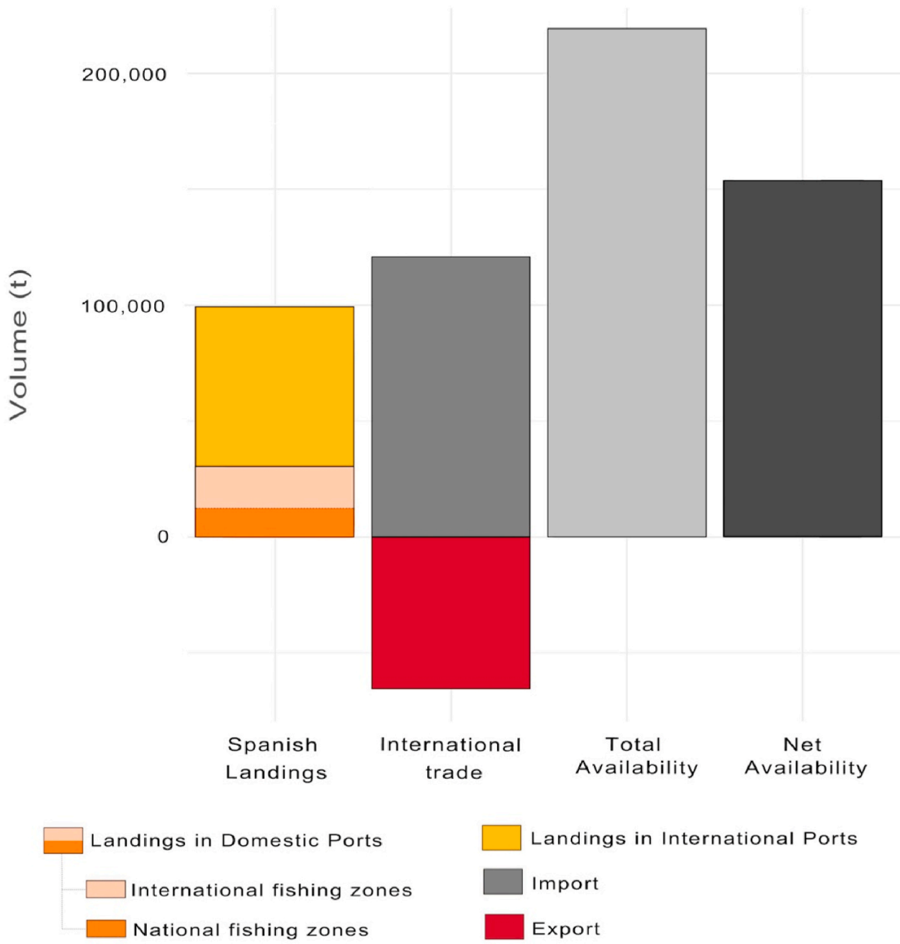

Fig. 1. Availability of hake in the Spanish supply chain. Total availability includes the sum of all hake entering Spanish territory, and Net availability refers to the hake actually available to consumers in Spain after subtracting exports from total availability.

3.2. Greenhouse gas emissions (GHG) of the hake supply chain

The total GHG emissions of the hake supply chain were 681 kt CO_2e, with fishing accounting for 456 kt CO_2e (67%), and transport accounting for 225 kt CO_2e (33%) (Fig. 4; Supplementary material, Table SM6). Emissions associated with imported hake were 356 kt CO_2e, accounting for more than half of total emissions (52%), with fishing being responsible for 231 kt CO_2e (65%), and transport for 124 kt CO_2e (35%). In the second place, we found hake from vessels landing their catches at international ports, with an amount of 216 kt CO_2e, and representing 32% of total GHG emissions. In this case, fishing was responsible for emissions estimated at 119 kt CO_2e (65%), and transport for 97 kt CO_2e (55%). Finally, hake from vessels landing their catches at domestic ports emitted 109 kt CO_2e, representing 16% of total emissions, with fishing accounting for 97% and transport for the remaining 3%. Of landings made at domestic ports, hake caught in national fishing zones presented an emission of 57 kt CO_2e, while hake caught in international fishing zones reached 52 kt CO_2e. In both cases, emissions associated with fishing accounted for more than 95% (Fig. 4; Supplementary Material, Table SM6). All hake landed at international ports and from imports was caught in international fishing zones.

Considering only emissions by product presentation (fresh and frozen), emissions from fresh hake accounted for 541 kt CO_2e, 79.5% of total GHG emissions, with fishing accounting for 337 kt CO_2e (62% of emissions from this presentation), and transportation represented 204 kt CO_2e (38% of emissions from fresh hake) (Fig. 4; Supplementary Material, Table SM6). Our results also indicate that frozen hake was responsible for lower emissions than fresh hake due to the lower volume caught and transported, reaching a total amount of emissions estimated at 139 kt CO_2e. Emissions related to the fishing of frozen hake were 118 kt CO_2e (85%), and those from transportation were 21 kt CO_2e (15%) (Fig. 4; Supplementary Material, Table SM6).

The Emission Intensity (EI) of hake in Spain was 4.42 kg CO_2e/kg of whole fish (Fig. 5). The imported hake showed the highest EI (4.88 kg CO_2e/kg), followed by the hake landed at international ports (4.09 kg CO_2e/kg), while hake landed at domestic ports presented the lowest emission intensity ratio (3.86 kg CO_2e/kg). It is important to highlight that hake landed at domestic ports are caught in both national and international fishing zones: while hake caught in international zones showed an EI of 3.22 kgCO_2e kg^{-1}, hake caught in national zones showed a higher EI, with a value of 4.74 kgCO_2e kg^{-1} (Fig. 5). Fresh hake also showed a higher EI when compared to frozen hake, reaching an amount of 4.62 kgCO_2e kg^{-1}, while the EI for frozen hake was 3.78 kg CO_2e/kg (Fig. 5).

The associated emissions from international and domestic hake transport alone amounted to 225 kt CO_2e (Fig. 6; Supplementary Material, Table SM6). The transport mode with the highest volume of emissions was air transport, with a volume of 165 kt CO_2e, representing 73% of emissions related to hake transport, despite only accounting for 14% of the total volume transported. In second place we found sea transport, with 34 kt CO_2e, 15% of the total emissions, and 45% of the total volume transported and finally road transport which presented 26 kt CO_2e, 10% of transport-related emissions being responsible for 41% of the total volume transported (Fig. 6; Supplementary Material, Table SM6). Air transport also showed the highest emissions intensity, valuing 7.70 kgCO_2e kg^{-1}, far above the other modes of transport, sea

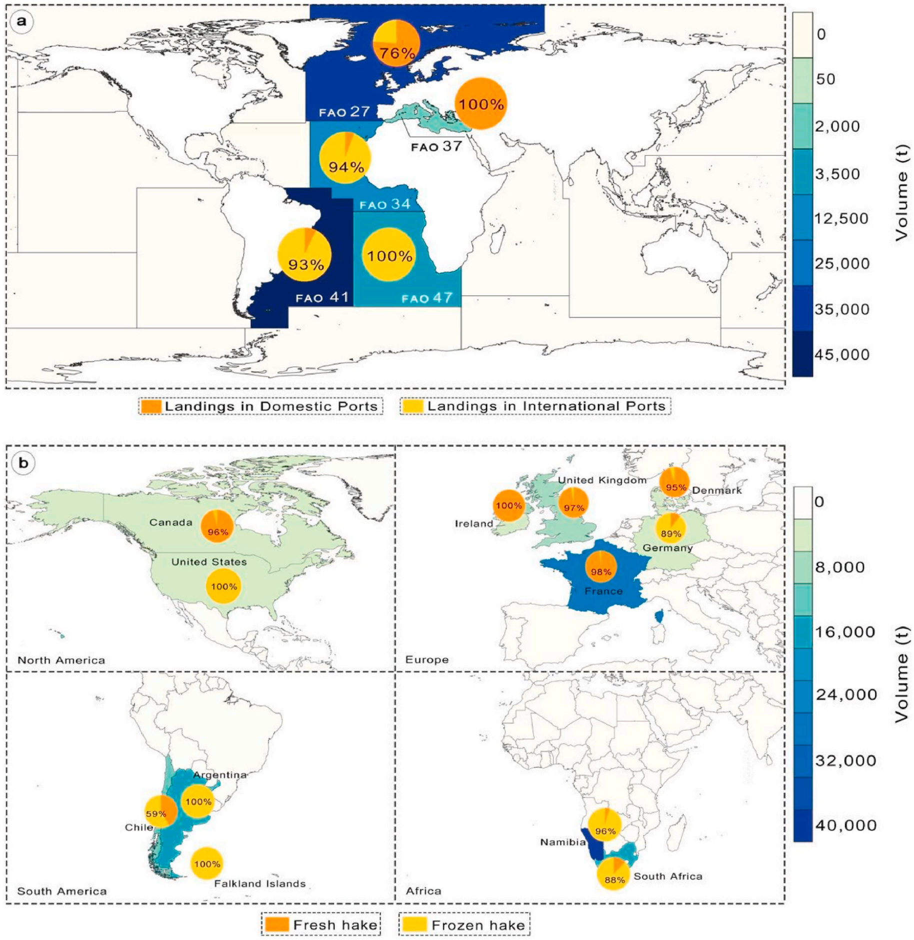

Fig. 2. a) Volume of hake catches in tonnes (t, colour scale) and percentage of catches landed on Spanish territory and in third countries by FAO area. Catches landed by Spanish vessels in Spanish ports are differentiated from those catches landed by Spanish vessels in international ports. b) Volume of hake imports in tonnes (t, colour scale) and percentage of imports of fresh and frozen hake.

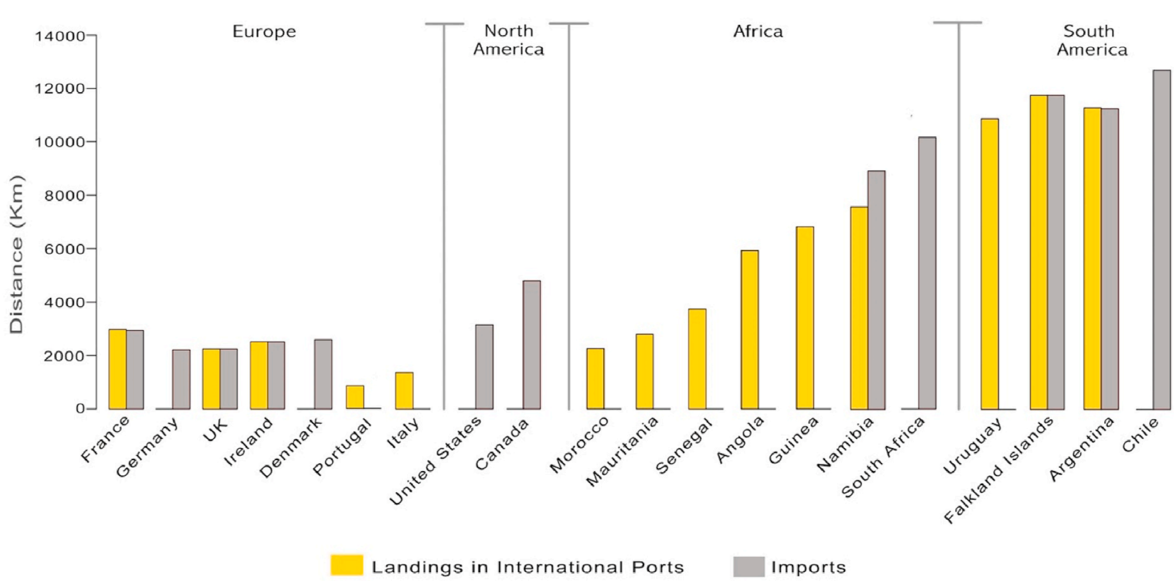

Fig. 3. Weighted average distance (in km) per tonne transported by country of origin. The yellow bars refer to hake caught by Spanish vessels and landed at international ports. The grey bars refer to hake caught by vessels from third countries and imported to Spain as international seafood trade flows. The distances include the transport routes from the country of landing to retail in Spanish provinces.

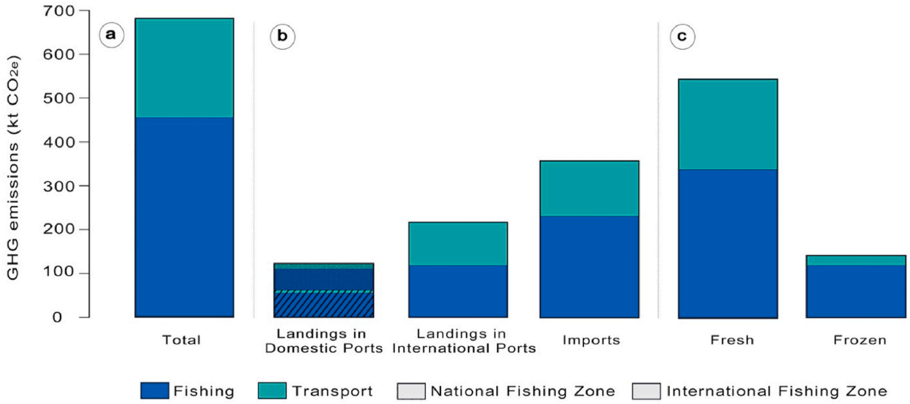

Fig. 4. Total Greenhouse gas emissions (GHG) (kt CO_2e) for: **a)** the hake supply chain with breakdown of emissions between fishing and transport to retail, **b)** by origin of hake considering the catches landed by Spanish vessels in Spanish ports, the catches landed by Spanish vessels in international ports and imports, as well as transportation associated with these categories (the catches landed by Spanish vessels in Spanish ports are divided into catches made in "National fishing zones" and in "International fishing zones"), **c)** by presentation of hake (fresh and frozen) with breakdown of emissions between fishing and transport to retail.

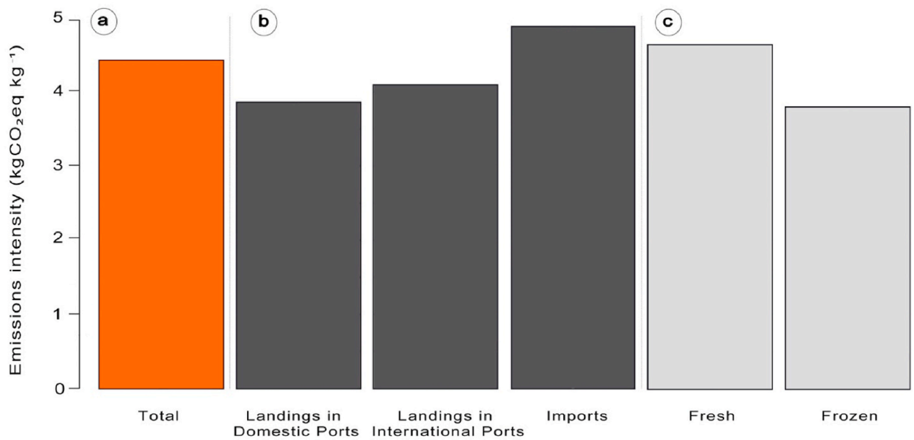

Fig. 5. The Emission Intensity (kgCO_2e kg^{-1}): **a)** of the hake supply chain; **b)** by origin of hake considering the catches landed by Spanish vessels at Spanish ports, the catches landed by Spanish vessels at international ports and imports; **c)** by presentation of hake (fresh and frozen).

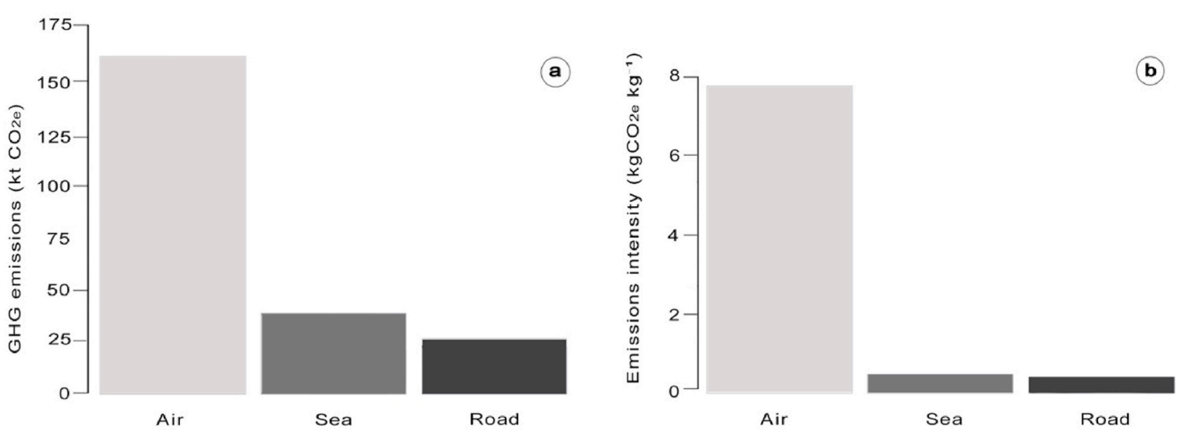

Fig. 6. **a)** GHG emissions (kt CO_2e) by transport mode for the hake food chain, **b)** Emission intensity (kgCO_2e kg^{-1}) by transport mode for the hake food chain. Neither penal includes emissions from fishing operations.

transport presented an EI 0.50 kgCO_2e kg^{-1}, and road transport was the most efficient compared to air and road transport, with an EI 0.42 kgCO_2e kg^{-1}.

4. Discussion

The fishing industry has become increasingly interconnected on a global scale (Hilborn, 2013). Travelling to the deepest waters of the oceans is now a common practice (Swartz et al., 2010), and subsequent transport to the final destination market may require hundreds or thousands of miles of travel by sea and air (Madin and Macreadie, 2015). The dependence on consumption of hake from international sources fuels the debate on the environmental impacts that transport has on the seafood supply chain. This debate exists for a wide range of food products, which is based precisely on the dependence of food chains on various factors such as the location of logistical distribution nodes, the means of transport used or the production systems, with production systems being the factor that generally has the greatest environmental impact (Infante-Amate et al., 2018; Pérez Neira et al., 2020). As mentioned earlier (section material and methods), this study did not include the emissions related to leakage of cooling agents in the production system (fishing), although some studies indicate that this source can increase the total value of GHG. For example, according to Iribarren et al. (2011) GHG emissions increased by 13% due to refrigerant leakage. However, the *R22* refrigerant used at the time has been gradually replaced by other less harmful materials and if we were to count the GHG emissions associated with *R22*, we would overestimate the weight of the GHG emission in our calculations.

From the science-policy interface, the results of this study have implications in terms of fisheries management in several key directions, contributing to: (a) advancing the management of hake fisheries, (b) advancing the reduction of environmental impacts from fishing in order to mitigate the effects of climate change, and (c) articulating innovative actions with the potential to foster sustainability transformations of the Spanish food system in general and for the consumption of hake in particular.

The latest reform of the EU's Common Fisheries Policy (CFP) highlighted the need to move away from traditional single-stock fisheries management and towards operationalising the ecosystem approach to fisheries (EAF) (Prellezo and Curtin, 2015). Within the CFP, achieving the Maximum Sustainable Yield (MSY) does not require considering the climate change impacts through the incorporation of GHG emissions and the retained carbon sequestration of catches (Mariani et al., 2020). While recent findings indicate that marine resources throughout their life cycle contribute to processes that sequester considerable amounts of carbon (Blue Carbon Initiative, 2021), the MSY-based management objective does not take that into account, as it is limited only to promoting optimal commercial fish harvest. Thus, although the new CFP advocates the implementation of some form of EAF, it is still unclear how to implement conservation objectives within the management measures such as the GHG emissions and carbon sequestration of species.

In terms of fisheries management, taking actions towards GHG emissions and climate change considerations would require reconsidering the current MSY reference point moving towards ocean management instead of fisheries management, thus promoting climate services from the oceans (Aragão et al., 2021). Indeed, Mariani et al. (2020) recently showed that commercial fishing activities reduced the carbon sequestration of the oceans by decreasing the biomass of fish stocks, particularly regarding top predators (i.e., adult hake), and highlighted the importance of measures to promote the rebuilding of fish stocks, thus increasing their capacity for sequestering blue carbon.

In terms of mitigating environmental and climate change, it is worth noting that the fishing industry has a significant carbon footprint (Chassot et al., 2021; Hilborn et al., 2018; Ziegler et al., 2013). However, seafood carbon footprints are rarely integrated into sustainability assessments in commercial fisheries management, either through eco-labels or through sustainability certification or sustainability guides for consumer seafood products. Thus, environmental analyses of fishing activity generally focus on certain biological concerns such as resource availability and stock conservation, while underestimating other impacts caused by fishing activities (Hospido and Tyedmers, 2005; Vázquez-Rowe et al., 2010). Energy and material use by fishing vessels can generate significant environmental impacts, mainly related to fuel consumption (Hospido and Tyedmers, 2005). These analyses, however, generally do not consider the impacts associated with the entire food chain, thus preventing a holistic understanding of the environmental footprint associated with a population's food consumption patterns. Therefore, improving fisheries management should not only be linked to efforts to reduce overfishing, bycatch and discards, the disturbances created in benthic communities by trawling and other types of gear, or altered trophic dynamics (Fonseca et al., 2005), but also to the analysis and mitigation of the impacts of fisheries and the organization of their food chain on GHG emissions and the resulting global warming.

From the consumer perspective, including the carbon footprint in seafood awareness campaigns could also generate a number of key benefits for both the consumer and the seafood producer (Madin and Macreadie, 2015). Providing consumers and businesses (e.g., restaurants) with information on the relative contribution to climate change associated with one product compared to another can promote products with a lower carbon footprint (e.g., by shifting purchases to locally produced seafood), or serve as an indicator for improving the steps in the food chain with the greatest impacts in order to move towards more sustainable scenarios (Altiok et al., 2021). Therefore, a more powerful effort is needed to increase the social acceptance of low-carbon products by consumers (Bryant, 2019).

The limited evidence suggests that giving stakeholders access to information on other aspects of seafood sustainability may lead to preferential purchase of products with lower environmental impact (Teisl et al., 2002). The existence of legislation linked to ecosocial transition may also contribute to the consumption of products with lower environmental impacts, but other factors such as the price of the labelled product influence consumer choice (Aoki and Akai, 2013; Grebitus et al., 2013; Elofsson et al., 2016). Another approach could be directed at limiting consumer choice by distributing seafood products that fulfil specific environmental criteria (Panzone et al., 2011). To our knowledge, there are few initiatives at an international level to raise awareness about sustainable seafood. One example would be Friend of the Sea, which explicitly incorporates carbon footprint into its selection criteria, or the Swedish national eco-label KRAV for small-scale seafood products (Ziegler et al., 2013). Thus, both the generation of legislative frameworks capable of promoting the adoption of practices that mitigate climate change in this context, and the promotion and awareness-raising of consumers and operators in the food chain through labelling should be options to combine for achieving the sustainability objectives in the global action frameworks.

Unhealthy diets represent a serious challenge for Spanish society, given that the country has one of the highest rates of obesity in adults and young people among OECD countries (OECD, 2019). In addition, today's consumers are also increasingly concerned about the origin and environmental impact of the food they eat and value the good quality of the natural environments. In terms of seafood, there is strong evidence of the benefits of fish consumption for human health, such as contributing to reducing cardiovascular problems (Whelton et al., 2004), improving neurodevelopment in pregnant women and children during pregnancy, improving mental health, and helping with stress, depression and anxiety while preventing cancer, autoimmune diseases, asthma, multiple sclerosis and diabetes (EUPHA, 2017). There is also robust scientific evidence linking diets to human health and environmental sustainability (MacDiarmid, 2013).

However, the absence of scientific studies conducted at global and national levels for simultaneously assessing healthy and sustainable diets has hampered coordinated efforts to transform the food system (Willett et al., 2019). In this sense, this paper on GHG emissions from the hake supply chain provides new evidence to link sustainability issues to other studies addressing the health effects derived from fish consumption by the Spanish population. The high dependence on imports and catches in international fishing zones, while only 8% of the hake consumed in Spain comes from national fishing zones, and the entire carbon footprint associated with intensive fishing and its associated international transport make the current volumes of hake consumption by the Spanish population alarming. Furthermore, neither simplistic approaches based on large-scale fishing efficiency in international fisheries, nor the human health of diets based on current hake consumption volumes should underpin decision-making and legislative frameworks. A combination of recommendations for sustainable and healthy fish consumption should take both aspects into account on an equal footing, i.e., encouraging the transformation of the food supply chain by moving to more efficient and sustainable practices without undermining the positive nature of hake consumption in Spanish diets. For this same reason, the fishing industry, policy makers and society at large must work together to achieve significant transformative changes in sustainable and healthy food production and consumption patterns.

To build a new narrative for ocean healing (Lubchenco and Gaines, 2019) and align with the UN Decade of Oceans for Sustainable Development from 2021 (Claudet et al., 2020), new nature-based solutions are needed to reduce the impact on oceans. Unlocking current barriers to transformative change towards sustainable oceans and healthy diets in line with the UN Sustainable Development Goals for 2030 requires innovative solutions (Rosa, 2017). This highlights the importance of educating society through effective communication efforts about the real value of food for human health and to promote environmental sustainability (Medawar et al., 2019; Nelson et al., 2016; Tomova et al., 2019).

5. Conclusions

This study provides scientific evidence and new insights that can be helpful for the design of possible solutions to help managing hake exploitation at sustainable production levels (both outside and within the European Union), thus supporting climate change mitigation and healthy diets. The framework of this study presents a sound proposal on how to consider the ecosystem impacts not only of fisheries, but also of the entire food chain supplying a country, which would contribute to improving the approach to be adopted in the forthcoming review of the CFP regulatory framework, as well as other regulations such as the Marine Strategy Framework Directive. Evidence suggests the need for striking a balance between healthy fish consumption patterns and associated environmental impacts.

There are great opportunities available for promoting the transformation of food systems towards a shared vision of the Planet's health and people's health. The scientific targets set by the EAT-Lancet Commission on dietary change, sustainable production and food loss and waste will enable Spanish companies to create science-based solutions that can support food system transformation (Willett et al., 2019). To lead this transformation and ensure the success and continuity of the fisheries sector, we advocate for business leadership and public policies aimed at adopting innovative solutions along the entire value chain, such as (a) reducing GHG emissions in operations and supply chains using nature-based climate solutions, (b) extending and standardising food labelling to include information on the health and sustainability implications of food products, (c) supporting the fisheries sector in this transition with training and development, assistance and recognition, (d) encouraging transparent marketing practices that promote healthy and sustainable food consumption, (e) helping consumers reduce food waste with ideas for leftovers and portion sizes, and (f) adopting a diverse and sustainable protein mix by increasing diverse plant-based protein sources. The future of current and future generations depends on our ability to create a food system that supports healthy people and a healthy Planet.

Data availability

The data underlying this article will be shared upon reasonable requests to the corresponding author.

CRediT authorship contribution statement

Guilherme Martins Aragão: Conceptualization, Writing – original draft, Data curation, Writing – review & editing. **Pablo Saralegui-Díez:** Methodology, Validation. **Sebastián Villasante:** Conceptualization, Writing – review & editing, Validation. **Lucía López-López:** Conceptualization, Validation. **Eduardo Aguilera:** Validation. **Joan Moranta:** Conceptualization, Writing – review & editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Corrigendum to “The carbon footprint of the hake supply chain in Spain: Accounting for fisheries, international transportation and domestic distribution” [J. Clean. Prod. 360 (2022) 131979]

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The version of this article that was originally published online contains an error in the abstract. This error does not change the results of the calculation used in this paper, but the paragraph between lines 10–13 of the abstract referred to the air transportation should read as follows:

Abstract Lines 10 to 13: Air transport was the highest in terms of emission intensity per kilogram of hake transported, valuing 7.70 kgCO$_2$e kg¯1, far above the other modes of transport, sea transport presented an EI 0.50 kgCO$_2$e kg¯1, and road transport was the most efficient compared to air and road transport, with an EI 0.42 kgCO$_2$e kg¯1.”

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