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CARBON FOOTPRINT ASSESSMENT OF A SEABASS FARM ON THE MEDITERRANEAN MOROCCAN COAST

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ABSTRACT

The present study assesses the carbon footprint of the only operating marine fish farm in Morocco. Five years of data were used to assess its carbon footprint, following ISO/TS 14067 standard, the PAS 2050 and the IPCC 2006 guidelines. The obtained carbon footprint ranged from 2.34 to 2.85 kg CO_2e/kg. The emission value for 2017 is 38% lower than the highest value. Fish feed contributes most to the carbon footprint of the farm. Based on PAS 2050, the inshore cage farming product ranks in the same category as dairy products. Furthermore, the comparison showed that it is almost 67% lower than the carbon footprint of other protein production. This study evaluates some scenarios for reducing the carbon footprint of the fish farm, which can be a basis for further studies.

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INTRODUCTION

Every human activity generates a footprint on the environment (Čuček et al., 2015). Accumulating greenhouse gas (GHG) emissions from these activities, global warming is a normal reaction of the environment (Cox et al., 2000; Hansen et al., 2000; Solomon et al., 2007). Following the Intergovernmental Panel on Climate Change report, the atmospheric carbon dioxide over the last 150 years increased by around 40% (IPCC, 2014). To address the global warming challenges, the first step was to assess GHG emissions of each activity and their contribution to global warming (UNFCCC, 1997; Thomas et al., 2000; UNEP, 2012). So, it is important to know which activities have a greater impact on the global warming phenomenon and which specific parts of their working processes contribute most to GHG emissions. To address the challenge of global warming, each economic sector must contribute to the reduction of GHG emissions to achieve the targets set by the United Nations Framework Convention on Climate Change (UNFCCC, 2015).

Aquaculture is one of the fastest developing human activities in the last decade (FAO, 2018). Many studies have dealt with aquaculture impacts on the environment; few have assessed the carbon footprint (CF) of this activity, especially with respect to marine cage farming. It is important to shed light on the necessity of distinguishing between the carbon footprint of a product and other terminology that may be similar, such as corporate carbon footprint, ecological footprint or life cycle assessment. As reported by He et al. (2018), Penz and Polsa (2018) and Caro (2019), the CF of a product is the measure of total GHG emissions during the life stages of the product, while other terms may extend the meaning to the indirect use of resources or the activities of the entire company.

In Morocco, there is an untapped potential for marine aquaculture as defined by the studies of regional aquaculture development plans, the framework of the Halieutis Plan (MMAMF, 2009) and the Blue Belt Initiative (Nguyen et al., 2016; Oceans Action Day Bulletin COP 22, 2016). As a matter of fact, there is currently only one operating marine fish farm and about twenty small shellfish farms. Nevertheless, sustainability is a key point and an essential baseline in the Moroccan aquaculture development agenda (MMAMF, 2009).

Since environmental considerations and sustainability have become key factors in aquaculture development, the carbon footprint can be one of the tools to increase social awareness of environmental responsibility and the impact of GHG emissions. For that, it was necessary to assess the emissions of the only operating marine fish farm over a period that can offer a clear vision of its carbon footprint. All activities within the farm and those linked to the inputs used on this farm were listed and analysed to evaluate their GHG emissions.

The assessment of fish farming GHG emissions highlights what it absolutely and relatively contributes to global warming, providing information on the possible pathways for decision-making at the farm level, as well as at the policymaking level. Moreover, the carbon footprint can play the role of a vaccine for society to become aware of the contribution of each activity to global warming (Weidema et al., 2008) and to consider suitable corrections or adaptations according to their real benefits to the environment, society and economic welfare. Therefore, this study is aimed at issuing some recommendations for marine fish farming to contribute to the development of respectful ecological activities and to shed light on the carbon footprint as an indicator of environmental sustainability.

MATERIALS AND METHODS

Study area

The fish farm is situated in the south of M'diq Bay which is located in the western part of the Moroccan Mediterranean coast (Fig. 1). This company is rearing European seabass *Dicentrarchus labrax* in 14 inshore circular cages, each having 12 m in diameter and 10 m in net depth. The sea farm covers an area of around 5.5 ha. The cages are installed at a mean depth of 20 m. The central point of the fish farm has the following geographic coordinates: 35°41'27" N and 5°17'51" W. For carbon footprint calculation purposes, a description of the fish farm working process is needed. The fish farm land-based infrastructures are located in the M'diq harbour wharf and are composed of two workshop mobile containers and a building that includes an office, as well as a small packing plant located 300 m away from the workshop containers. These land-based facilities are 50 km away from the Tangier commercial harbour (TANGER-MED) and about 292 km from Morocco's capital (Rabat).

Data collection

Firstly, all aspects contributing to GHG emissions were listed. The maximum production capacity of the studied farm reaches 200 tons per year. The farming process starts with the importation of fish fingerlings from France to Morocco by a live fish truck. The load capacity of the truck is 24 tons and meets the Euro 5 emission standard (diesel). When fingerlings are about to arrive from overseas, the required cages for stocking are brought to the M'diq harbour. Fingerlings are kept in a protected area for their acclimation to local conditions. Later, cages are towed to the sea farm site and moored in. Until 2016, most of the feed used on the farm was supplied by a local fish feed factory (ca. 50 km from the farm site). Since 2016, most of the feed has been imported from northwestern European countries. The fish are fed twice a day, which requires two round trips by boat at maximum. The feed distribution is manual; however, a broadcast-feeding machine is used when the workload is too high.

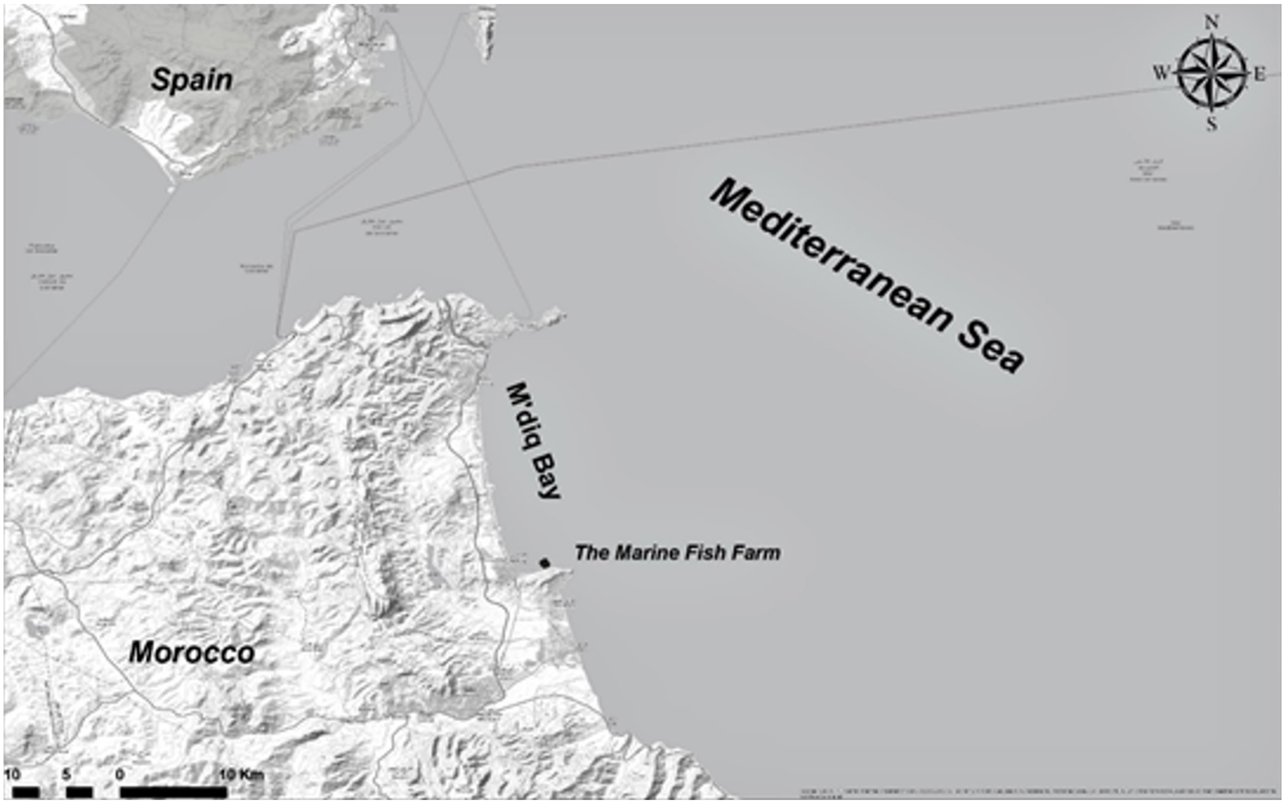

Fig 1. Location of the studied farm

Fish are harvested once a week. Two boats are required, a small and a larger one. They carry isotherm containers filled with seawater (70%) and ice (30%). After the harvest, the isotherm containers are transported from the harbour to the packaging unit using a diesel-powered forklift and a three-wheel cargo gasoline motorcycle. Fish is kept under ice conditions from the harvest to the packaging. Fish is stowed in an isothermal polystyrene box in superimposed layers covered with ice on top. Once the packaging process is completed, the product is kept in a 10 m² cold store. Generally, the product is sold ex-factory on the same day; that is, the customers come to transport their order directly. These emissions, generated by clients transporting products to their final destinations, were not included in the assessment of the product's carbon footprint.

Carbon footprint calculation

To estimate the carbon footprint of the fish farm, we followed the PAS 2050 emission factor (British Standards Institution, 2011) which has a life cycle greenhouse gas (GHG) assessment methodology that aligns with ISO/TS 14067 standard (ISO/TS 14067, 2013). Moreover, PAS 2050 offers more details and specifications on how to undertake the assessment, which makes product CF calculation easier to perceive and interpret.

The methodology is based on multiplying the GHG emission factor of a specific material by the quantity of the material used in the operation named in the PAS 2050 "activity data" using the following equation (1):

$$CF = EF \times MQ \quad (1)$$

CF: Carbon Footprint of a material (X kg CO_2e)

EF: Emission Factor of one unit of the material (x kg CO_2e / (1 kg, 1 L, 1 KWh, etc.))

MQ: Quantity of the Material used to achieve the whole operation (kg, L, KWh, etc.)

The emission factor references of the inputs and their use in the fish farm are listed in Table 1. Equation (1) applies to all the inputs listed in Table 1, except for the ice which was not available in the dataset and for which data were not provided by the ice producer. Instead, ice CF was calculated based on the amount of electricity consumed to produce the needed quantity of ice, then transformed into the emission factor.

The fish fingerling emissions were estimated based on the calculation of the elements used in their production, where the used input was communicated from a local scientific hatchery.

As mentioned earlier, the differences in fish feed imply different footprints. The feed footprint was assessed based on the composition and percentages of various feeds (Table 2). The specification of each ingredient was taken into consideration, as well as its origin. Then, the CF of each fish feed was multiplied by the annual consumption, as described by equation (1).

In addition, according to the transport modes (Table 3) used for fish feed, fish fingerlings and packing boxes, we collected the transport characteristics for each of these items.

Table 1. The inputs used in the farm activities and their emission factor reference

Inputs	Used in			Used for	Emission factor references
	Sea Farm	Inland	Packaging		
Electricity		X	X	Maintenance work such as for cage /in the packing process	(Francophone Cluster Regional Workshop, 2017)
Gasoline	X	X		Boats / Motor tricycle	(IPCC, 2006)
Diesel	X			Small boat/ Forklift	(IPCC, 2006)
Cleaning detergents			X	Cleaning packaging unit	(British Standards Institution, 2011)
Refrigerant of cold store			X	Keeping the fish at a cool temperature	SimaPro 8.5
Polystyrene Boxes			X	For fish packaging	(Ruuska, 2013)
Ice	X		X	Used as ice slurry in fish harvesting (live chilling) Used for preserving fish in packaging boxes	(Griffiths-Sattenspiel and Wilson, 2009; Francophone Cluster Regional Workshop, 2017)
Water		X	X	Fishnet and packing pallet cleaning	(Griffiths-Sattenspiel and Wilson, 2009)
Fish feed	X			To feed the farmed fish	SimaPro 8.5
Fish fingerlings	X			To be growing on the farm	(Francophone Cluster Regional Workshop, 2017) SimaPro 8.5

Table 2. Fish feed composition used by the studied fish farm

Local feed	Imported feed 1	Imported feed 2
Fish meal	Fish meal	Fish meal
Soybean meal	Soybean meal	Soya oilcake
Wheat	Wheat	Wheat
Maize extruded	Maize gluten meal	Maize gluten meal
Wheat gluten	Sunflower protein concentrate	Wheat gluten
Soy	Wheat gluten meal	Rapeseed cake
Soy Oil	Rapeseed oil	Rapeseed oil
Fish Oil	Fish Oil	Fish oil

Table 3. Transport details

Transport of	Origin	Mode of transport	Clarification
Fish feed	Europe	Train Ship Truck	• Carbon footprint of the train was obtained from the Logistics company • Navigated distance and spent days by vessel were obtained from the loading port and the discharge port • Carbon footprint of truck and boat are calculated
Fish fingerling	Europe	Truck Ship	
Boxes	Morocco	Truck	Calculated based on formulas
Local fish feed	Morocco	Truck	

However, in the case where the transport company did not provide CF data, then the travelled distance and the consumed fuel per kilometre were calculated to estimate the total fuel consumption for one delivery.

The calculation of fish feed transport CF is based on IPCC 2006 Guidelines for Mobile Combustion and the Emission Inventory Guidebook 2006 of shipping activities (EEA, 2006). These references provide an average fuel consumption per day for each ship type, which is used to calculate the total fuel consumption of the container vessel. The total fuel consumption is multiplied by the emission factors provided by IPCC 2006 Mobile combustion to evaluate vessel GHG emissions, then converted to carbon emissions. Furthermore, the assessment of carbon emissions generated by one delivery is calculated by dividing the total emission amount of the ship by its total container number. The final result is equal to the total number of containers delivered to the fish farm multiplied by the carbon emissions generated by one container travel. In general, each order is comprised of two containers at maximum, and the annual sea transport footprint is calculated via the following equations:

$$\mathrm{ASTCF} = \sum \frac{\mathrm{FE} \times \mathrm{OC}}{\mathrm{VTC}} \tag{2}$$

ASTCF: Annual Sea Transport Carbon Footprint

FE: Fuel GHG Emissions

OC: Ordered Containers

VTC: Vessel Total Containers

$$\mathrm{FE} = \frac{\mathrm{TFC} \times \mathrm{EF}}{\mathrm{CI}} \tag{3}$$

FE: Fuel GHG Emissions

TFC: Total Fuel Consumption

EF: Emission Factors

CI: Converting Index to carbon

$$\mathrm{TFC} = \mathrm{DFC} \times \mathrm{Duration} \tag{4}$$

DFC: Daily Fuel Consumption

Fish farm waste is composed of fish feed bags that are reused by local fishermen, as well as wood pallets for feed transport that are sold. In fact, these wastes are raw materials for other activities.

We used data from 1 January 2013 to 31 December 2017 to characterise fish farm husbandry CF. Fish farm product CF is calculated following equation 5:

$$\mathrm{PCF} = \frac{\sum \mathrm{Tr} + \sum \mathrm{In} + \mathrm{Ff} + \mathrm{Ffi}}{\mathrm{Pf}} \tag{5}$$

PCF (kg CO_2e/kg): the Carbon Footprint of the Product, which reflects the annual amount of GHG emissions expressed in carbon dioxide divided by the kilogrammes of produced seabass

Tr: the annual total emissions from different transport methods (marine, road and rail)

In: the annual total emissions from the inputs in the production activity, which includes gasoline, electricity, etc.

Ff: the total fish feed emissions

Ffi: the fish fingerling emissions

Pf: the produced fish in each year

The average CF in the five studied years is the accumulation of GHG over this period, converted into carbon dioxide. The obtained result was divided by produced seabass quantity during the five years:

$$\mathrm{ACF} = \frac{\mathrm{TCE}_5}{\mathrm{TSP}_5} \tag{6}$$

ACF: Average Carbon Footprint in the assessed five years;

TCE_5: Total Carbon Emissions in the assessed five years;

TSP_5: Total Seabass Production in the assessed five years.

RESULTS AND DISCUSSION

Fish farm carbon footprint results

CF product assessment values ranged from 2.40 to 2.90 kg CO_2e per produced fish kg (Table 4). The value recorded in 2017 is 17.87% lower than that of 2013, and a gradual decrease is observed throughout the study period.

It should be noted that fish feed represents the largest part of CF, exceeding three-quarters (85.04±2.96%). On the other hand, the carbon emissions from fish feed were reduced by about 24.16% in 2017, compared to 2013. The PCF decreased over the five-year period, resulting from the change of fish feed supplier. The used fuel for the farming process is the second most important component of CF. However, it contributes only 7.77±1.55% to the CF of the farm. In fact, emissions from fuel increased by 68.34% from 2013 to 2017, due to the use of an additional boat with a gasoline engine. Also, the diminution of the part generated by fish feed in 2017 changed the percentage repartition and increased the fuel part. Over the years, the CF of fuel increased by less than 4%.

The transport modes are ranked third, they contribute less than 4% to total emissions and reached their maximum in 2016. Among the transport parts, the national transport contribution to carbon emissions during the five years did not exceed 1% (Table 5). Although the national transport emission percentage increased by ca. 11% from 2013 to 2017, its GHG emissions decreased in 2017 by about 31.46%, compared to 2013. The contribution of international transport to total carbon emissions almost doubled from 2013 to 2017. The increase was at its maximum in 2016.

Fish feed transport is the major element influencing transport emissions. The two elements have a high correlation coefficient, exceeding 0.9. The contribution of imported fish feed transport to carbon emissions more than doubled from 2013 to 2017. GHG emissions generated by fish feed transport increased by 136% from 2013 to 2017, and the emissions maximum was registered in 2016.

Table 4. Fish farm carbon footprint segmented into different generators

Carbon footprint generators	Year											
	2013		2014		2015		2016		2017			
	CF (kg CO_2e/kg)	%	CF (kg CO_2e/kg)	%	CF (kg CO_2e/kg)	%	CF (kg CO_2e/kg)	%	CF (kg CO_2e/kg)	%	CF Average	Percentage Average
Electricity	0.03	0.88	0.03	0.96	0.02	0.81	0.02	0.82	0.04	1.69	0.03±0.01	1.03±0.37%
Fuel	0.17	5.99	0.19	7.15	0.18	7.12	0.21	8.58	0.24	10.01	0.20±0.03	7.77±1.55%
Gasoline	0.04	1.28	0.03	1.23	0.04	1.49	0.09	3.52	0.10	4.21	0.06±0.03	2.35±1.41%
Diesel	0.14	4.71	0.16	5.92	0.14	5.63	0.13	5.06	0.14	5.79	0.14±0.01	5.42±0.52%
Cleaning detergents	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.03	0.00	0.05	0.00±0.00	0.04±0.01%
Refrigerant	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00	0.01	0.00±0.00	0.01±0.00%
Polystyrene boxes	0.01	0.34	0.01	0.33	0.01	0.40	0.01	0.31	0.01	0.40	0.01±0.00	0.36±0.04%
Ice	0.04	1.27	0.03	1.23	0.04	1.50	0.03	1.14	0.04	1.48	0.03±0.00	1.32±0.16%
Water	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.03	0.00±0.00	0.02±0.00%
Road Transport	0.06	1.91	0.05	1.84	0.05	2.03	0.05	2.03	0.05	2.14	0.05±0.00	1.99±0.12%
National	0.02	0.66	0.02	0.66	0.02	0.76	0.01	0.57	0.02	0.77	0.02±0.00	0.69±0.08%
Fish feed in Europe	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.15	0.00	0.02	0.00±0.00	0.04±0.06%
Fish fingerlings	0.04	1.25	0.03	1.13	0.03	1.27	0.03	1.30	0.03	1.34	0.03±0.00	1.26±0.08%
Maritime Transport	0.00	0.02	0.00	0.14	0.00	0.02	0.03	1.16	0.02	0.87	0.01±0.01	0.44±0.54%
Fish feed	0.00	0.00	0.00	0.12	0.00	0.00	0.03	1.14	0.02	0.85	0.01±0.01	0.42±0.54%
Fish fingerlings	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00±0.00	0.02±0.00%
Rail Transport	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.71	0.01	0.41	0.01±0.01	0.22±0.32%
Fish feed	2.55	87.90	2.23	86.74	2.13	86.45	2.08	83.45	1.94	80.63	2.20±0.24	85.04±2.96%
Fish fingerlings	0.05	1.63	0.04	1.55	0.04	1.62	0.04	1.75	0.05	2.28	0.05±0.01	1.77±0.3%
Total	2.90		2.65		2.46		2.5		2.40		2.58±0.20	

Table 5. Transport contribution percentages to **t**otal **c**arbon **e**missions (**TCE**)

Years	National transport percentage in TCE	International transport percentage in TCE	Local feed transport contribution in TCE	Imported feed transport contribution in TCE
2013	0.67%	1.29%	0.22%	0.00%
2014	0.66%	1.35%	0.20%	0.18%
2015	0.77%	1.31%	0.23%	0.00%
2016	0.49%	3.47%	0.08%	2.13%
2017	0.75%	2.75%	0.19%	1.36%

Emissions from fish fingerlings electricity, gasoline, diesel, cleaning detergents, refrigerant, polystyrene boxes, ice and water represent almost 12% of the farm's total emissions, with a maximum of 15.95% recorded in 2017.

To analyse which part of the fish farming process generates the most emissions, we regrouped the percentages according to three groups (Table 6). The majority of product CF was generated by sea farm activities. Noting that, fish feed CF dominates the cumulative percentage.

The inputs in sea activities apart from the fish feed have a cumulative percentage of 9.00±1.2%, and their CF is about 0.23 kg±0.02 CO_2e/kg.

Carbon footprint reduction

The studied coastal seabass farm has an average CF of 2.58 kg CO_2e/kg. Fish feed is the main contributor (86.95%), followed by fuel (Gasoline + Diesel), with an average of 7.70% (Fig. 2).

According to PAS 2050, the CF of the studied fish farm product is ranked in the same category as dairy products and rice. The seabass cage farm ranks low when compared to the CF of meat products.

This study has an objective to recommend measures to reduce CF; these measures need to consider production in normal years in which no exceptional events happened, such as a massive fish loss due to a storm. To achieve this objective, we propose a change according to six scenarios (Fig. 3):

- Feed CF
- The feed conversion ratio (FCR) and feed CF
- The fuel consumption and feed CF
- A sustainable electricity source and feed CF
- Local sourcing of fish fingerlings and feed CF

Since fish feed contributes most to product CF, we took the emissions recorded in 2015 and replaced feed emissions with the emissions of the European feed, as it was produced locally. The emissions related to its importation were also reduced; in that case, product CF will be around 1.9 kg CO_2e/kg, which signifies a diminution of 22.94%. Noting that, feed CF can be less than the European feed, where some ingredients have a lower CF than others (Hognes et al., 2011).

Furthermore, the FCR is an important aspect of reducing fish feed CF. If the studied farm were to reduce its FCR to 1.9, a normal value compared to other studies (Tacon and Metian, 2008; Türkmen et al., 2012; Magalhães et al., 2017; Eroldoğan et al., 2018; Gisbert et al., 2018), and keep a similar feed CF as for the imported one, CF would be reduced by 29.79%.

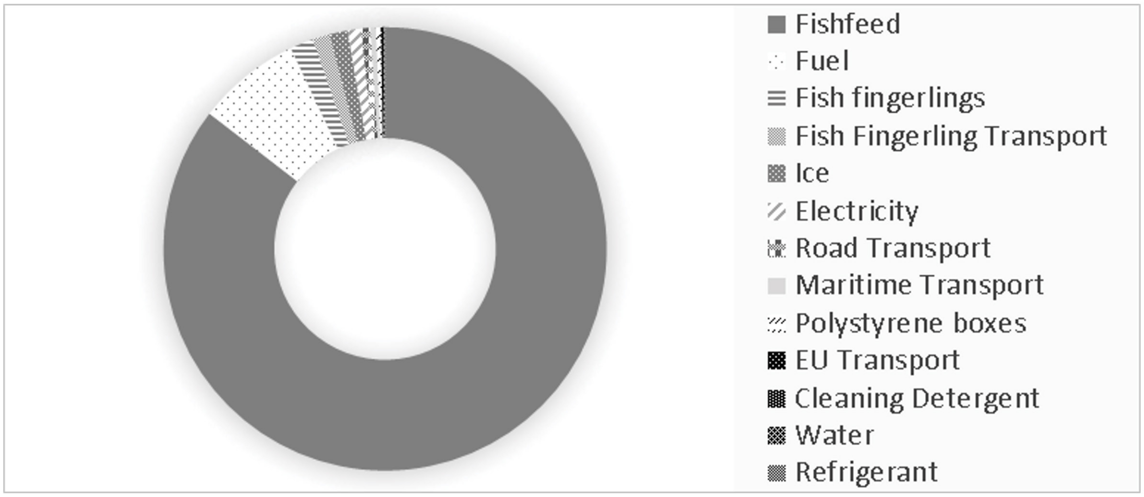

Fig 2. Proportions of carbon footprint generators (sorted in descending order)

Table 6. Carbon footprint contributions based on each activity group, in %

Carbon footprint generators	Sea farm activities						Farm inland activities						Packing plant					
	2013	2014	2015	2016	2017	Average	2013	2014	2015	2016	2017	Average	2013	2014	2015	2016	2017	Average
Electricity							0.66	0.70	0.26	0.28	0.82	0.54±0.26	0.22	0.26	0.54	0.54	0.87	0.49±0.26
Fuel	5.37	6.48	6.39	7.27	8.45	6.79±1.15												
Gasoline	0.89	0.86	1.04	2.47	2.95	1.64±0.99	0.38	0.37	0.45	1.06	1.26	0.70±0.42						
Diesel	4.47	5.62	5.35	4.80	5.50	5.15±0.49							0.24	0.30	0.28	0.25	0.29	0.27±0.03
Cleaning Detergent													0.03	0.03	0.03	0.03	0.05	0.04±0.01
Refrigerant													0.01	0.01	0.01	0.01	0.01	0.01±0.00
Polystyrene boxes													0.34	0.33	0.40	0.31	0.40	0.36±0.04
Ice	0.38	0.37	0.45	0.34	0.44	0.40±0.05							0.89	0.86	1.05	0.79	1.04	0.93±0.11
Water							0.00	0.00	0.00	0.00	0.01	0.01±0.00	0.01	0.01	0.01	0.01	0.02	0.01±0.00
Road Transport	1.47	1.38	1.49	1.62	1.60	1.51±0.10							0.45	0.46	0.54	0.41	0.54	0.48±0.06
National	0.21	0.20	0.22	0.17	0.23	0.21±0.03												
Fish feed transport in Europe	0.00	0.05	0.00	0.15	0.02	0.04±0.06												
Fish fingerlings transport	1.25	1.13	1.27	1.30	1.34	1.26±0.08												
Maritime Transport	0.02	0.14	0.02	1.16	0.87	0.44±0.54												
Fish Feed	0.00	0.12	0.00	1.14	0.85	0.42±0.54												
Fish fingerlings	0.02	0.02	0.02	0.02	0.02	0.02±0.00												
Rail Transport	0.00	0.00	0.00	0.71	0.41	0.22±0.32												
Fish feed	87.90	86.74	86.45	83.45	80.63	85.04±2.96												
Fish fingerlings	1.63	1.87	1.89	1.96	1.72	1.81±0.14												
Cumulative percentage	96.98	97.19	96.91	96.68	94.35	96.42±1.17	1.05	1.08	0.72	1.34	2.09	1.25±0.52	2.19	2.26	2.87	2.36	3.22	2.58±0.45

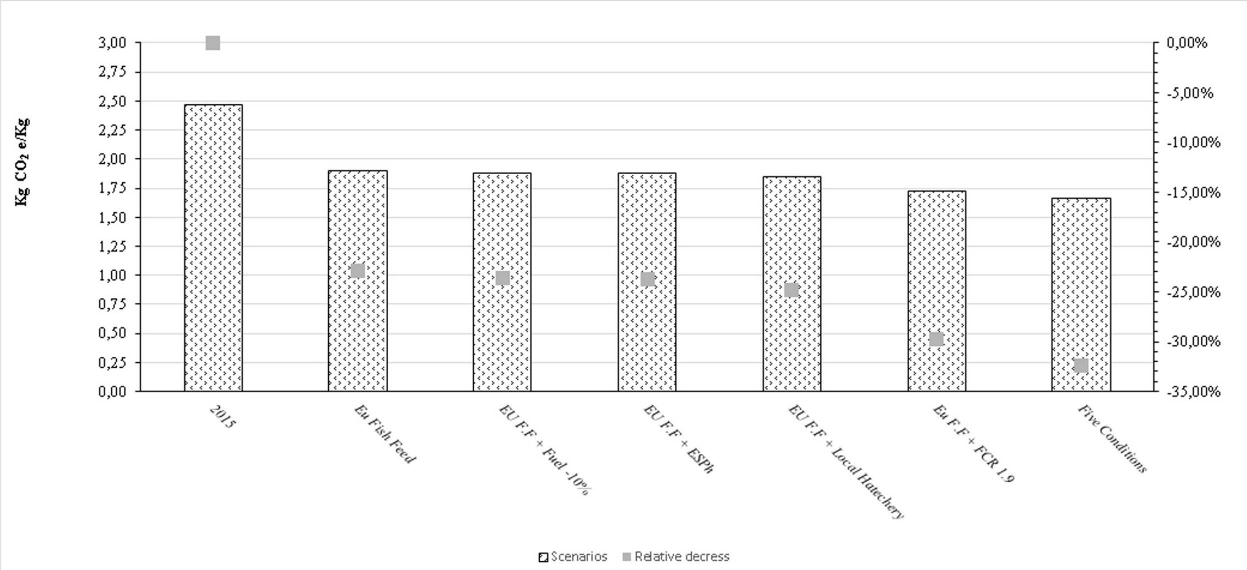

Fig 3. Carbon footprint amelioration scenarios compared to the studied farm carbon footprint in 2015. The grey square represents the relative decrease percentage

The third scenario is to reduce the fuel consumption of the studied fish farm by 10%, in addition to the fish feed CF described scenario; the PCF would be reduced by 23.65% accordingly. Moreover, if the fish farm uses a sustainable electricity source, such as a photovoltaic one in addition to the described situation for fish feed, CF would be reduced by 23.70%; noting that electricity from a photovoltaic source has a CF of 35 g CO2/KWh in southern Europe (POST, 2006).

By the same logic, if the fish farm uses seabass fingerlings produced by a local hatchery in an area not farther than 220 km, adding to it the uses of a local fish feed with a similar CF as the imported one, then CF would be reduced by 24.84%.

In the end, if all five conditions (a local feed with a similar CF to the imported one, plus an FCR of 1.9, plus reducing the use of fuel by 10%, plus a near seabass hatchery, plus electricity from a sustainable source such as photovoltaic one) were to be applied, the studied seabass CF would be around 1.66 kg CO_2e/kg. This value is smaller than the CF registered by the fish farm in 2015 by almost 33%.

The six scenarios are remarkably different from the obtained value in 2015, so we can assume that any chosen scenarios from the proposed ones will be effective and create a significant change in the fish farm product CF.

Slika 3

Carbon footprint comparison

The average annual fish farm CF for the five years is about 2.58 kg CO_2e/kg with a standard deviation of 0.2. To situate the current study CF in a general context, firstly we compared it to the CF of other protein food sources at the farm gate level (Fig. 4). This comparison was based on the averages of the CF of other protein sources (Hamerschlag and Venkat, 2011). As shown in Fig. 4, the studied farm seabass CF is 69% lower than the average CF of other food protein sources. The studied product CF is greater than whole milk CF by about 129% and lower than lamb CF by about 9 times or 894%.

Furthermore, we compared our results with other fish farms (Fig. 5), both seawater and freshwater. Due to the lack of raw data, we calculated the CF of these farms. The life cycle of gilthead seabream *Sparus aurata*, a species of equal importance in the Mediterranean as seabass, has been studied by García et al. (2016); we took feed emissions and the fuel used on the farm for comparison.

We compared our study PCF to three Atlantic salmon carbon footprints (Liu et al., 2016)

by adding the CF of the product at the farm gate level to the packaging and ice carbon footprints. The first system is a Norwegian open-net pen (ONP) farming system. The second system is a land-based closed containment (LBCC) using a recirculating aquaculture system (RAS) and running on a typical electricity mix (a combination of coal, gas, nuclear, wind and hydropower). The third is an LBCC-RAS system running on electricity generated predominantly by hydropower.

Further, a comparison was made with a Norwegian farmed salmon CF elaborated by Hognes et al. (2011) for their five studied diets (referred to as 2010, 2010HMI, 2010NAMI, 2020VEG and 2020LAP).

For seabass *Dicentrarchus labrax*, trout *Oncorhynchus mykiss* and turbot *Scophthalmus maximus* in Aubin et al. (2009), we compared carbon emissions based on feed and energy. The comparison with turbot *Scophthalmus maximus* CF assessed by Gonzalez-Garcia et al. (2018) was based on an intensive growth phase, carried out in land-based facilities (RAS).

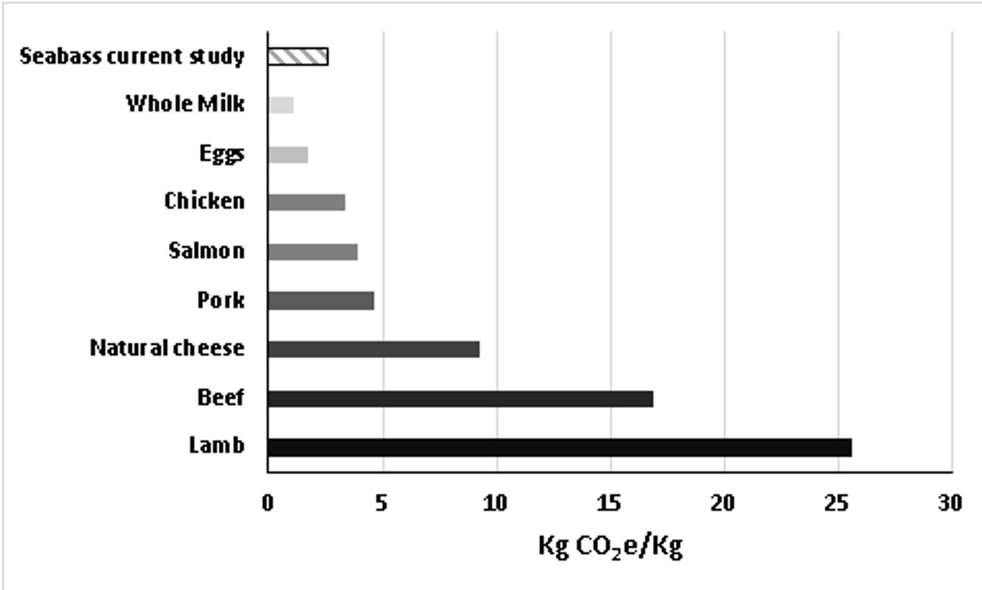

Fig 4. Comparison of the carbon footprint of various protein sources

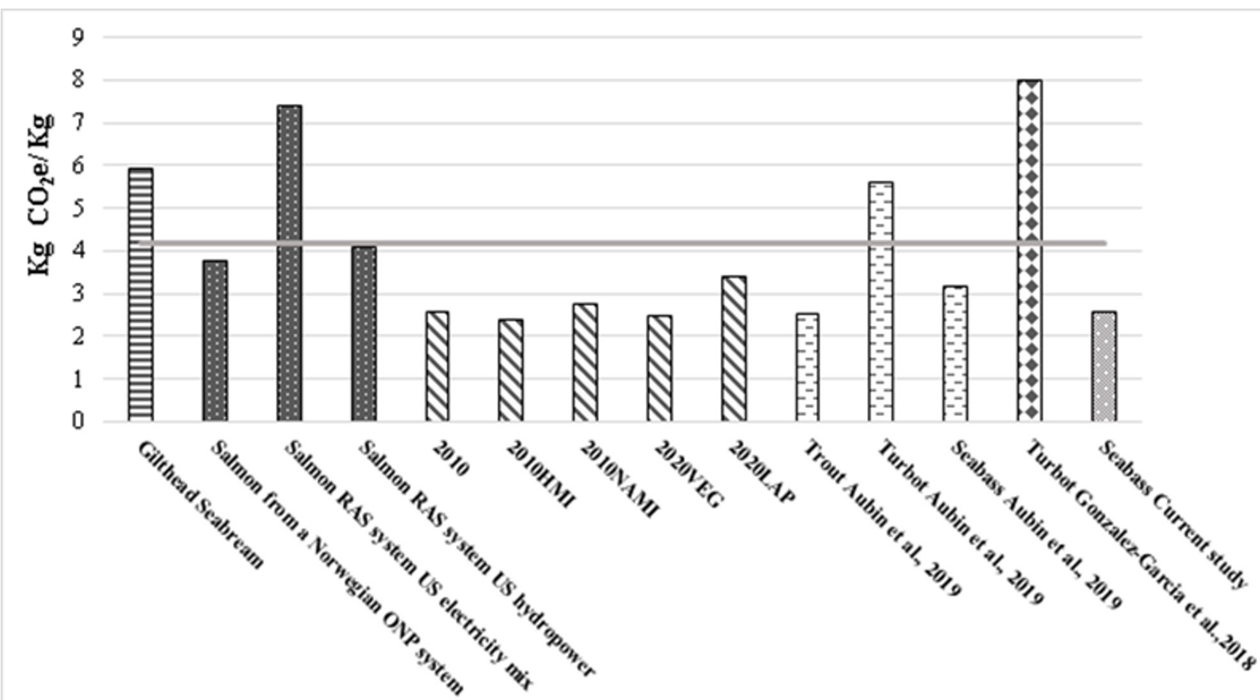

Fig 5. Comparison of the carbon footprint of fish farming products with the current study (the grey line represents the average of the compared product)

The studied farm product CF is less than the average CF of the other farmed fish by about 38%. One-third of the fish's carbon footprint is less than the studied seabass CF. In addition to the footprint assessed in the publications cited above, other publications (Ziegler et al., 2013; Abualtaher and Bar, 2020) conclude that fish feed is the main GHG generator. This means that the variation of the CF of farmed fish is related to the CF of the feed used: the larger the footprint of the feed, the larger the footprint of the farm.

Moreover, as reported by Cataudella et al. (2005), the link between aquaculture and fishing in people's minds is so strong that the interactions between the two sectors can be ambiguous. So, to illustrate the difference between the two sectors, we compared the footprint of the studied farm to marine captured fish. For lack of local data, we used those reported by Iribarren et al. (2010) (Fig. 6) from fishing areas close to the site of the studied farm.

The CF of the current study is lower than the results of 17 of the 19 captured fish species, and also 60% lower than

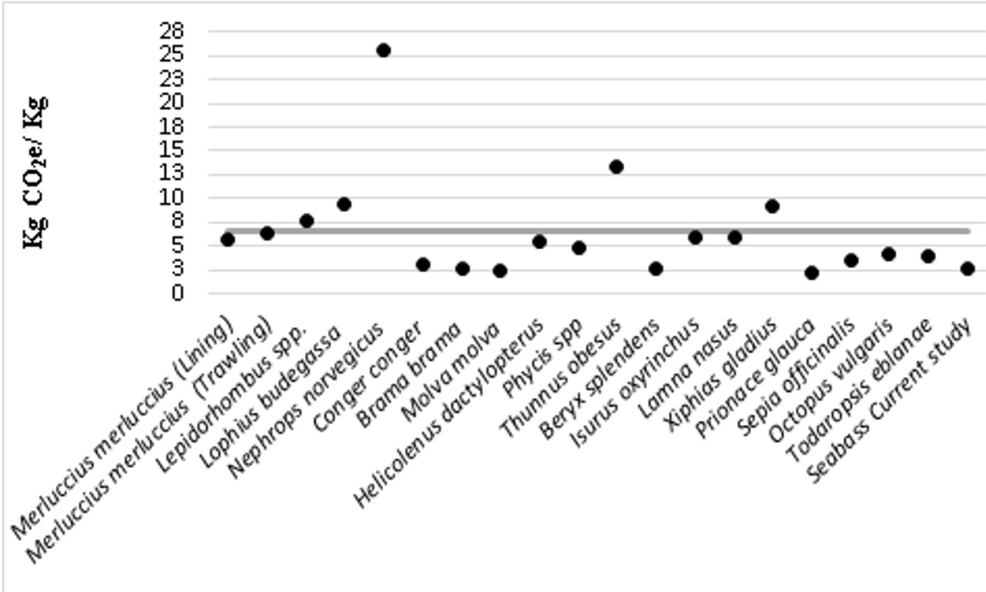

Fig 6. Comparison between the CF of 19 captured species and that of the studied fish farm product. The grey line represents the average of the compared products

their average CF. The relative difference between the CF of the farm and the minimum CF of the 19 fish species does not exceed 15.2%.

CONCLUSION

Described as "process efficiency" by PAS 2050, appropriate resource management is one of the keys to reducing the carbon footprint. In the fish farming case, feed loss is an inevitable situation; however, it should be reduced as much as possible to a minimum level by applying the optimal feed distribution mechanism, such as slow feed distribution or the use of a subsea feed distributor. According to Abdou et al. (2017) and Ballester-Moltó et al. (2017), the uneaten fish feed can vary from 5 to 50%. The product CF methodology does not integrate this activity specification, so for a better and more realistic evaluation it is important to highlight the necessity of integrating the specification of fish sea-farming activities into the product CF evaluation procedure and/or adapt such activities to it. Additionally, in marine aquaculture, some ecological solutions could contribute to the reduction of GHG emissions, such as integrated multitrophic aquaculture and artificial reefs used as biofilters, which allow improved assimilation of the carbon issued from the uneaten feed and fish faeces. This case needs to be studied and assessed as a CF reduction procedure and could give some information on how to mitigate fish farming CF, particularly in its intensive system production.

PROCJENA UGLJIČNOG OTISKA FARME UZGOJA BRANCINA NA SREDOZEMNOJ MAROKANSKOJ OBALI

SAŽETAK

Ova studija procjenjuje ugljični otisak (CF) jedinog uzgajališta morske ribe u Maroku. Petogodišnji podaci korišteni su za procjenu ugljičnog otiska farme, prema standardima ISO/TS 14067, PAS 2050 i IPCC 2006. Dobiveni ugljični otisak kretao se od 2,34 do 2,85 kg CO_2 e/kg. Vrijednost emisije za 2017. godinu niža je za 38% od najviše vrijednosti. Hrana za ribe najviše pridonosi ugljičnom otisku proizvoda s farme. Na temelju PAS 2050, proizvod s obalnih kaveznih farmi svrstava se u istu kategoriju kao i mliječni proizvodi. Nadalje, usporedba je pokazala da je niži za gotovo 67% od ugljičnog otiska ostalih proteinskih proizvoda. Studija procjenjuje neke scenarije za smanjenje ugljičnog otiska ribogojilišta, što može biti osnova za druge studije.

Ključne riječi: procjena ugljičnog otiska, uzgajalište morske ribe, brancin, smanjenje emisije stakleničkih plinova (GHG)

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