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Abstract

In the context of climate change, the diet is a key driver of environmental impacts. Previous research emphasized the environmental benefit to increase fisheries and aquaculture products (FAPs) consumption in European diets. However, increasing the share of FAPs could lead to a transfer of environmental damage from earth to sea. It is thus important to evaluate the environmental impacts of FAPs considering marine eco-systems and global scale. We constructed an original database to map the origin of FAPs, and we matched it with environmental indicators. The exploration of the database investigates the environmental impact of FAPs in regards of French consumption. We found some heterogeneity across species, meaning that the pattern of consumption across the FAPs does influence the environmental footprint. Furthermore, the choice of methods of production largely affects the global impact. Thus, relevant public policy could decrease the environmental impact of FAPs despite a standstill level of consumption.

Keywords: environmental impact, climate change, LCA, seafood consumption

JEL classification: Q22, Q54, D10

L'impact environnemental de la consommation de produits de la pêche et de l'aquaculture en France

Résumé

Dans le contexte du changement climatique, l'impact environnemental de l'alimentation joue un rôle central. Les avantages environnementaux lié à l'augmentation de la consommation de produits de la pêche et de l'aquaculture (FAP) dans les régimes alimentaires européens ont été mis en avant dans de précédents travaux. Néanmoins, augmenter la part des FAP dans le régime alimentaire pourrait entraîner un transfert des dommages environnementaux de la terre à la mer. Il est donc important d'évaluer, en complémentarité des impacts environnementaux globaux, les impacts environnementaux spécifiques des FAP liés aux écosystèmes aquatiques. Nous avons construit une base de données originale pour cartographier l'origine des FAP, et nous l'avons couplée à des indicateurs environnementaux. Cela nous permet d'évaluer l'impact environnemental de la consommation de FAP en France au regard de plusieurs indicateurs environnementaux. Nous avons trouvé une certaine hétérogénéité entre les espèces, ce qui signifie que la structure de la consommation de FAP, c'est–à–dire la répartition de la consommation entre espèces, influence l'empreinte environnementale. En outre, le choix des méthodes de production affecte largement l'impact mondial. Ainsi, les politiques publiques pertinentes pourraient réduire l'impact environnemental des FAP tout en maintenant le niveau de consommation.

Mots-clefs : impact environnemental, changement climatique, ACV, consommation des produits de la pêche et de l'aquaculture

Classification JEL: Q22, Q54, D10

The environmental impact of consumption of fisheries and aquaculture products in France

1. Introduction

The environmental impact of the food system is a major concern in the context of global environmental change and biodiversity crisis (IPBES, 2019). Diet-level assessments in several countries (Macdiarmid et *al*., 2012; Green et *al*., 2015; Vieux et *al*., 2018; Westhoek et *al*., 2014; Carlsson-Kanyama and Gonzales, 2009) have produced relevant recommendations to decrease the environmental impacts of food consumption. In particular, decreasing meat consumption has been found to have a positive influence on the overall environmental state, while raising consumption of fish generates health and environmental benefits (Westhoek et *al*., 2014; Vieux et *al*., 2018; Scarborough et *al*., 2014). Still, the environmental gains from the increased share of fisheries and aquaculture products (FAPs) in the European diet raise the possibility that the environmental damage will simply be transferred from earth to sea rather than being reduced, as the assessment conducted to date have important limitations.

First, most of papers use aggregate indicators to compare environmental impact of FAPs and other foods. The most popular method used to propose environmental profiles of agrifood sector is Life Cycle Assessment (LCA) (Van der Werf et *al*., 2014). It proposes a set of environmental objectives calculated through the whole product life cycle, and permits to compare different products performances. Greenhouse gas (GHG) emissions are often lower for FAPs (Hartikainen and Pulkkinen, 2016; Poore and Nemecek, 2018), but important caveats are in order. FAPs' contribution to global warming is usually compared to that of meat products considering aggregated categories.

However, intra-category heterogeneity in climate impact is large for both meat products and FAPs, as documented for the latter category in the French AGRIBALYSE database[1]. Meat production varies from 2.03 kg CO2e live weight for some chicken to 21.74 for some beef, and FAPs production. Data available in the AGRIBALYSE database show variation from 2.96 kg CO2e live weight for some trout to 4.43 for some seabass and seabream. Thus, considering the whole category hides some food-level specificities, which are relevant when seeking options to decrease the environmental impact of the diet. Hence, 74% of FAPs consumed in the EU

[1] https://www.ademe.fr/expertises/produire-autrement/production-agricole/passer-a-laction/dossier/levaluation-environnementale-agriculture/loutil-agribalyser

originates from wild fisheries (EUMOFA, 2019), and the environmental impact of FAPs production industry will be influenced by the consumption volume and its composition. Thus quantifying the total environmental impact of FAPs consumption requires both to weight the environmental impact of each FAPs category using detailed consumption data, and to have a detailed environmental data at the species level.

Second, even if FAPs have lower greenhouse gas emissions than some meat categories, other environmental impacts (e.g., on the marine ecosystem for FAPs) should be considered as well. Indeed, to allow comparison between food categories, common indicators have to be used. Greenhouse gas emissions, which can be evaluated for all foods, are thus relevant indicators of global warming, but the environmental impact of fisheries or aquaculture extends beyond global warming (Carlsson-Kanyama and Gonzales, 2009). The production of FAPs has an impact on the marine food webs, either directly (fisheries) or indirectly (aquaculture of carnivore species), through the catching of wild resources. The impact will differ depending on the species' level in the food web. Furthermore, fish production influences eco-systems through the choice of fishing gear, causing in some case large bycatch or seabed damages (Jennings et *al*., 2001). To evaluate the environmental impact of FAPs accurately, it is therefore necessary to take into account specific indicators measuring the impact of FAPs production on the marine eco-system also (Abdou et *al*., 2020).

The aim of this paper is to fill the gap in current research on the real impact of FAPs consumption on the environment, considering both global impact and marine eco-systems impact. To do so, we need to establish a picture of the impact of French FAPs consumption. Combining several existing database and through a literature review, we have constructed an original database mapping the origin of FAPs and linked it to consumption patterns. Thus, our measure of environmental impact accounts for differences in species of geographical origin and production method (type of gear, wild versus farmed) through appropriate weighting. This method allowed us to draw an up-to-date and accurate picture of the environmental impact of FAPs consumption in France.

Based on this database, we will investigate the various impacts of FAPs while disaggregated and weighted by consumption entry. We will evaluate the relevance of specific environmental indicators for FAPs. Analysis by species may also underline potential heterogeneity between species, and if so allowing refinement of the message to consumer to improve the sustainability of the sector. The paper is organized as follows: the next section presents the data and methodology, while section 3 discusses the results. A short conclusion follows in section 4.

2. Data and methodology

First, an original database mapping the origin of FAPs has been constructed by combining trade and production data from several sources. The trade data describe volumes of commercial exchanges of FAPs between France and other countries. Second, we matched this information on origin with environmental data, extracted from FishBase, the international database on fish built from the scientific literature (Froese and Pauly, 2019).

2.1. Origin of FAPs

For the trade data, the apparent market is used to represent the overall consumption of seafood products in France. All market data are from year 2012. The apparent market (AP) by species *i* is constructed as follows:

$$AP_i = P_i + M_i - X_i \qquad (1)$$

where P_i is the French production for species i, M_i imports of species *i* in France, and X_i French exports. Production data were gathered from FAO production data through the FishStat J software. Those data cover all French production, not only for human consumption. For imports and exports data, we used the Eurostat database Comext (BDD COMEXT - Eurostat, 2019)[2]. Forty-five species across 90 partner countries were identified (see table A.1).

In order to have the products' origin, we needed to go further than the Eurostat data because those data only identify trading countries which are not necessarily the producing countries as trade flows often involve multiple countries. In the case of France, BDD COMEXT attributes large amounts of FAPs trade to Belgium, Denmark and the Netherlands but it is clear that the products are often not produced in those countries.

To trace back to the producer country, we needed to make assumptions on the flow of products. When a country from which France imports was identified as a transit country (say country B), we considered that the composition by country of origin of imports of country B was the same as the composition by country of origin of its exports. As an example, if transit country B imports 30% of cod from country A, then 30% of cod exported from country B to France is assumed to originate from country A. We call this assumption linearity of flows. The entire

[2] The FAO data are expressed in live weight, thus Eurostat data have been converted to live weight using the conversion ratio reported on the EUMOFA website (Metadata 2 – Annex 7).

database has been constructed based on this assumption, which makes it possible to estimate the origin of FAPs consumed in France.

Furthermore, France is a transit country also, and for several species, exports can be higher than production. Eurostat database does not allow making the distinction between products that only go through one country ("transit product") from those produced in this country and then exported ("real exportation"). To address this issue, linearity assumption was used again. To evaluate the apparent market, exports were deducted in proportion to the contribution of each country of origin. For example, we call "French supply" the sum of French production and imports for one species. If France accounts for 20% and country B for 80% of "French supply", the calculation of the apparent market subtracts 20% of exports from the volume of French production, while 80% of French exports will be subtracted form French imports from country B. The total matches with equation (1).

Once the database on origin of FAPs was constructed, we constructed databases on production methods and zones of production. The Eurostat database does not distinguish between wild and farmed products and has no information on type of gear nor fishing zone of the fleets. To fill the gap, we used the STECF (Scientific, Technical and Economic Committee for Fisheries) database for European countries, and data from the literature for non-European countries[3]. For all wild fish products, this allows to identify the fishing gear used, according to STECF classification (Sup. Mat. A2). After matching fishing gears and zone of production for each species and country, we applied the assumption of linearity to connect this information with the apparent market in France. If a country produces 40% of a species through aquaculture and fishes the 60% remaining, thus the exportation of this country to France is composed for 40% of aquaculture products and at 60% of fisheries products. The same assumption holds for the zone of fishing and the type of gear used (see Appendix 2 for gear classification).

2.2. Environmental indicators of FAPs

In order to evaluate the environmental impact of FAPs consumption in France we matched the database on origin with five relevant indicators. First, we took into account the trophic level (TL) and the overall impact on the food web, through the Primary Production Required (PPR) indicator (Pauly and Christensen, 1995):

[3] Among others : htttps://www.fishsource.org/

$$PPR = \frac{Total\ consumption}{[0{,}1^{TL-1}]} \quad (2)$$

The total consumption is based on the apparent market (database on origin), while the TL is assessed for each species (based on the literature review and Fishbase). The TL is a measure of the place occupied by the species in the food chain, starting from 1 for primary producers (seaweeds and phytoplankton), then 2 for their consumers (primary consumers), 3 for their predators (secondary consumers) and so on. Therefore, the higher the trophic level, the higher the species is in the food chain (ending with top predator), and the larger the primary production from the sea required to sustain FAPs consumption. Value 0.1 used in equation (2) can be considered as a conventional measure of ratio of production between a predator and its prey.

Second, we introduced the mean maximum length (MML), calculated on average for all species included in the consumption, from the maximum length each species would reach at the theoretical maximum age the species can live. This indicator can be calculated for fish only, and it is not dependant of the method of production. The higher the MML, the more the FAPs consumption is based on large and thus usually long-lived and low turn-over species. TL and MML have been extracted from the ISSCAAP Troph software of Fishbase (FAO, 2019) and a literature review.

Third, we considered environmental impacts calculated by Life Cycle Assessment (LCA) method. LCA is a standardised method (ISO, 2006a, 2006b) conceived to assess the environmental impact of a service or a product all along its life duration, from the extraction of raw material up to its end of life or recycling. In our study, the boundaries of the studied system include the building of vessels and fishing gear, the use of fuel and consumable, and feeds and specific inputs for aquaculture. The fish is delivered to the dock or at the farm gate. We selected three impacts categories: climate impact (kg CO2eq./ton), which takes into account the different greenhouse gas emissions and is widely used to compare products; eutrophication potential (kg PO_4^3eq./ton), which takes into account the emissions of reactive nitrogen and phosphorus in the ecosystems; and the energy demand (MJ eq./ton), as proposed by Pelletier et *al*. (2007) for seafood products.

The calculation method of the impact categories refers mainly to CML2 method for eutrophication and climate change (Guinée et *al*., 2002), and to total cumulative energy demand (TCED) method (Frischknecht et *al*., 2004), as they were the main methods used in the literature in LCA of fisheries and aquaculture.

We used several sources for the values of those indicators in FAPs, including research results (ICVpêche[4]) and reviews of the literature (Eyjólfdóttir et *al*., 2003; Ziegler et *al*., 2003; Thrane, 2004; Hospido et Tyedmers, 2005; Schmidt and Thrane, 2006; Ziegler and Valentisson, 2008; Aubin et *al*., 2009; Pelletier et *al*., 2009; Sund et *al*., 2009; Cao et *al*., 2011; Iribarren et *al*., 2010; Bosma et *al*., 2011; Ramos et *al*., 2011; Vazquez-Rowe et *al*., 2011; ERM, 2012; Hilborn and Tellier, 2012; Tyedmers and Parker, 2012; Vazquez-Rowe et *al*., 2012; Chen et *al*., 2015; Ramos et *al*., 2014; Aubin et *al*. 2015; Driscoll et *al*. 2015; Pelletier et *al*., 2015; Santos et *al*., 2015; Abdou et *al*., 2017; Aubin et *al*. 2018). We obtained 420 combinations of species, fishing gears and production zones, some of which are unfortunately not covered by the previous evaluation of environmental impact of FAPs. In that case, we used proxies to evaluate missing values, based on proximity of species, type of gear and the fishing zone.

2.3. Principal component analysis on environmental indicators

To go further on the analysis of this original database, we use a principal component analysis (PCA) to highlight correlation between indicators. We have some global impact indicators, *i.e*. non-fish specifics, and marine ecosystem indicators, meanly TL-based, more specific to the FAPs sector. Statistical individuals are the 420 identified FAPs, *i.e.* combination of species, fishing gear and production zone (see table A.3 for descriptive data). PCA allows to draw groups of individuals inside our database to highlight some convergences between indicators if any. Factors of the analysis use climate change, eutrophication, energy demand and trophic level as active variables, whilst quantitative and qualitative illustrative variables are the volume of apparent market, the MML (due to null value for many individuals, as this indicator can only be used for fish), the species and the mode of production. Norwegian lobster and shrimp bottom trawled will be used as an illustration, meaning not included for calculation, considering the very significant effect of trawling for the shrimp and Norway lobster fisheries in a preliminary analysis.

2.4. Limitation on database

During the construction of this database, several issues have raised. First, the identification and traceability of some products is complicated, as commercial name can match several scientific

[4] https://www.ademe.fr/expertises/produire-autrement/production-agricole/passer-a-laction/dossier/levaluation-environnementale-agriculture/loutil-agribalyser

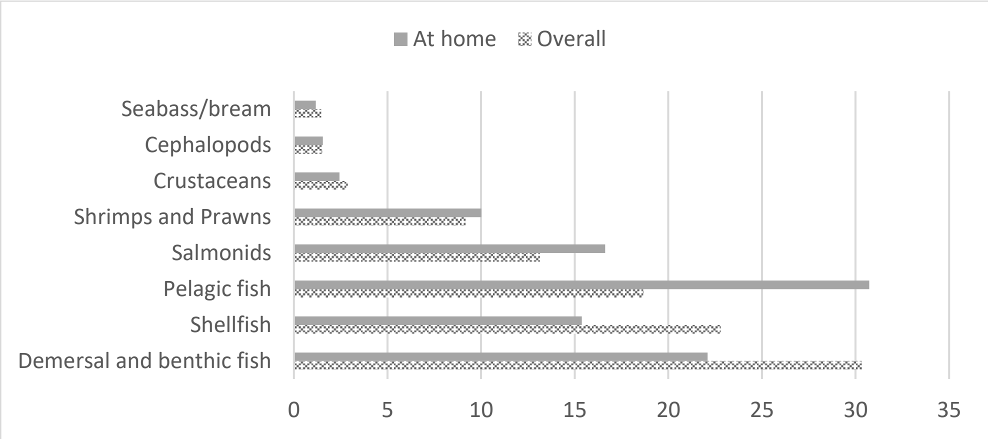
species. That is the case for scallop (*Pecten maximus, Pecten jacobeus, Aequipecten opercularis, Zygochlamys patagonica, Argopecten purpuratus*), tuna (*Sarda sarda, Thunnus albacares, Thunnus alalunga, Katsuwonus pelamis, Thunnus obesus, Thunnus thynnus*), pollock (*Theragra chalcogramma, Pollachius virens*) or rays (*Raja montagui, Leucoraja naevus, Raja clavata, Raja undulata, Raja brachyuran, Raja microocellata, Leucoraja circularis, Leucoraja fullonica*). For those species, the commercial name is identical regardless of the biological species, despite some very different origins, fishing methods or fish stock state. In this case, we try to weigh the species using all available information. For the flatfish category, 49% is classified as "undetermined species" in Eurostat (flatfish unspecified) thus, the construction of indicators (origin, fishing zone and type of gear) is based on the remaining apparent market of flatfish (51%). As a result, 25,756 tons are not taken into consideration in this analysis, namely 1.5% of the apparent market. For some other species, no information was found despite some consumption in France (e.g., for sea spider, whelk, carp, red mullet). However, as those are marginal species in volume, we considered the closest species as a proxy. Finally, it was impossible to identify the origin of some productions (1.8% of the apparent market), the most important shares of unknown origin being recorded for monkfish (16%).

3. Results and discussions

3.1. Characteristics of FAPs consumed in France

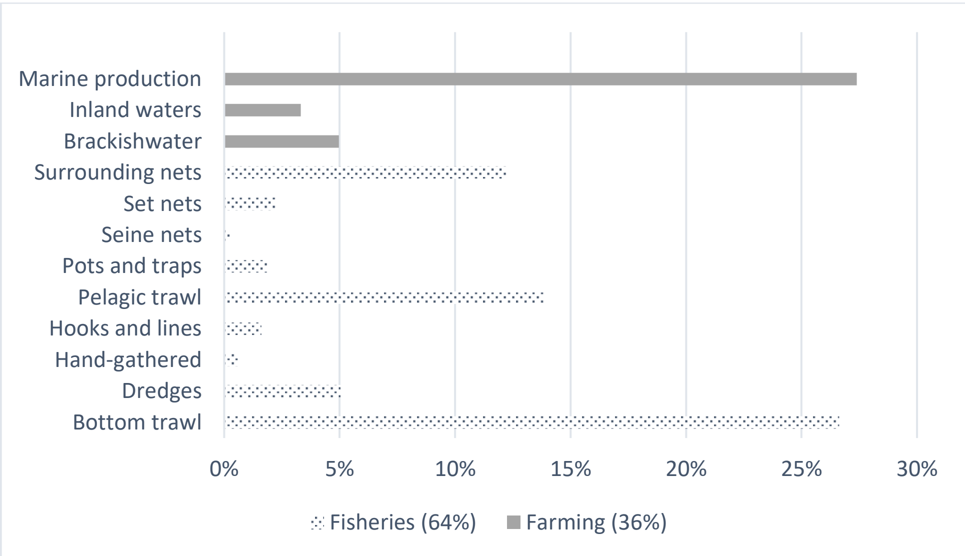
The unique database that we constructed allows us to trace products from water to plate, and to determine FAPs' origin, method of production and environmental impact. Our database corresponds to overall consumption, at home and away from home (meaning private and public catering), in French consumption. There is a slight difference between home and away from home consumption. In particular, shellfish, as well as demersal and benthic fish are relatively less consumed at home than away from home, while the opposite is true for Salmonidae and pelagic fish (Figure 1). Those results are in line with national data on French consumption (FranceAgriMer, 2013). The FAPs consumed in France originate from 90 different countries. Almost half comes from European Countries (47% without Norway and Faroe Island, 61% with those countries included) including 27% of FAPs coming from France. Thus, FAPs consumption in France is largely dependent on commercial trade within and outside of Europe.

Figure 1: At home consumption (full line) versus overall consumption (dotted line) of FAPs in France in 2012, % by species (repartition in volume – live weight).



Source: own elaboration

Figure 2: Methods of production of FAPs consumed in France. Undetermined type of gear represents less than 0.04%. See Table A.2 for gear categories.



Source: own elaboration

A majority of consumed FAPs comes from fisheries (64%, in volume, see Figure 2); bottom trawl being the most commonly used fishing gear, followed by pelagic trawl. Active gears[5] account for 58% of FAPs consumed in France, whilst passive gears account only 6% (in

[5] Active gears are mainly trawls and dredges, while passive gears are nets, lines and traps. See http://www.fao.org/3/y3427e/y3427e04.htm

volume). In terms of methods of production for aquaculture, 77% of farmed products consumed in France comes from marine production systems (27% of FAPs).

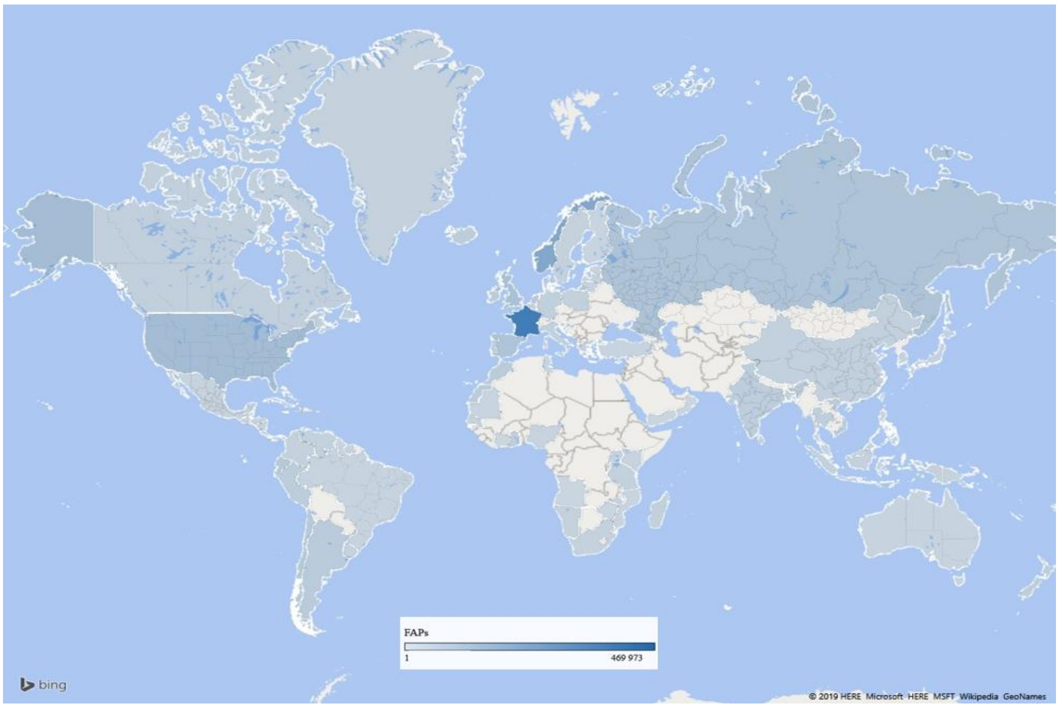
3.2 Environmental impact of FAPs consumption

3.2.1. Overall impact

First, fish related indicators allow us to characterize the environmental impact of FAPs consumption with regards to the aquatic ecosystem. The Primary Production Required and the mean maximum length are indicators specific to FAPs. They are relevant in this eco-systemic analysis but cannot be applied in other areas of the food system. While the total French consumption of FAPs is estimated about 1.7 million tonnes per year, the primary production required to sustain this production is 1,252 million tonnes per year[6]. This suggests the global impact on marine food webs could be much larger than the direct impact of harvesting seafood. The mean maximum length of French consumption of fish is 118 cm, what appears a very high value, related to a fish consumption dominated by large species (such as tuna, cod, salmon…). With respect to a more global indicator of environmental impact, overall consumption contributes to greenhouse gas emissions by an average 2.6 tons CO2 eq. per ton of FAPs (live weight at the dock). It is complicated to compare between species, which do not produce the same amount of edible food. Nonetheless, it gives the global impact of consumption. The climate change for beef systems is between 21.7 and 8.2 tons CO2 eq. per ton of live weight, depending on the farm system. Weighted by volume of consumption, FAPs still remain in average less damaging in terms of warming impact. Eutrophication reaches 17.8 kg of PO43- eq. per ton of FAPs in average and finally, the fish consumption in France requires 26,599 MJ eq. per ton of FAPs. (See Figure 3 & Table 2).

[6] In this version of the paper: Value subjects to caution, calculation of NT still undergoing for aquaculture species.

Figure 3: Origin of FAPs consumed in France in 2012[7]



Source: own elaboration

Table 2: Characteristics and environmental impact of FAPs consumption in France, consumption data of 2012

Apparent Market (live weight)	1,745,252 tons
Number of Country of Origin	90 countries
Top five (%)	France – 27%
	Norway – 13%
	USA – 7%
	UK – 5%
	Spain – 4%
Ecosystem indicators	
PPR (millions tons/years)	1,252
Mean Maximum length (MML)	118 cm
Life Cycle assessment impact categories (/ton of live-weight)	
kg CO2 eq.	2,622
	(*Min*:544 ; *Max*: 10,343 ; *s.e.*: 1,774)
kg PO43 eq.	18
	(*Min*:0.8 ; *Max*: 78 ; *s.e.*: 20)
MJ	26,604
	(*Min*:10,414 - *Max*: 132,906 *s.e.*: 10,902)

Min and Max for species categories, Standard error of weighted average: s.e.

Source: own elaboration

[7] Source of the empty map 2019 HERE Microsoft

3.2.2. Heterogeneity across species

Looking precisely into the species categories shows a large heterogeneity in environmental performance. Thus, consumer's choices with regards to species have an impact on the environmental externality of FAPs and it is possible to decrease the environmental impact of this consumption by choosing the favourable species.

In terms of ecosystem indicators, salmonidae (trout and salmon) and demersal and benthic (including colin[8], cod, flatfish[9], whiting, monkfish, and others demersal and benthic fish[10]) have the higher level of PPR (see table 3), while the lowest level is for crustaceans (excluded shrimps and prawns (S&P)) [11] and shellfish. The MML indicator holds only for fish, highlighting that all categories are dominated by large long-living species (able to reach more than 110 cm long on average). Therefore, except for the seabass and seabream category (merging smaller species that are both fished and farmed), little contrast is observed between categories, suggesting that FAPs fish production systems tend to select large predator species, rather than small prey species. However, in some categories, the average may mask large intra-category variabilities as it is likely the case for pelagic where small species such as herring or sardine are aggregated with tunas. We thus not only eat the largest top-predators of the sea.

For global environmental indicators, the species do not rank similarly. Despite good eco-system performances linked to their low trophic level, the global environmental impact of crustaceans (excl. S&P) per kg consumed is among the most important in terms of climate change and energy consumption. Shrimps and prawn have bad environmental performances, in terms of both climate change and marine ecosystem. Salmonidae do not affect global change more than average, even on the impact on the ecosystem due to an improved efficiency in fish-meal feeding (Kaushik and Troell, 2010). On the other side, the shellfish category has the best environmental performance, considering both global and ecosystem impacts. Pelagic category as well has good environmental performance compared to others categories, beside a relatively high PPR level.

However, despite bad environmental performances, crustaceans (excl. S&P) account for only 3% in volume of French FAPs consumption, while pelagic fish and shellfish account for 19% and 23% respectively. Thus, beyond the per unit environmental impact of consumption of a

[8] Alaska Pollack, Pollock, Saithe, and Hake.
[9] Flounder, Halibut, Plaice, Megrim, Sole, Turbot, Rays, and skates.
[10] Haddock, Ling, Dogfish, Redfish, and Bleu grenadier.
[11] Crab, Lobster, Norway Lobster, Rock lobster, and sea crawfish

species, it is fundamental to look at the total quantity consumed. The most important categories of fish consumed in France are the demersal and benthic fish. Most of the fish from this category are caught by bottom trawls or pelagic trawls (93%), resulting in a high energy demand of 27,962 MJ per ton of product (once weighted by consumption volume). At the same time, the greenhouse gas emissions level is slightly lower than the overall average (see table 3). However, while a 10% decrease in CO_2 eq. from crustaceans would reduce FAPs greenhouse gas emissions by 1% only, the same decrease for demersal and benthic fisheries would reduce the global emission of greenhouse gases from FAPs by about 3%.

It is interesting to look at the link between gears type and environmental impacts. The crustacean (excl. S&P) category has the highest level of energetic demand, but it is mainly due to the bottom trawls used by Norway lobster fisheries, which considerably increase climate change and eutrophication potential as well as energy demand. The substitution of bottom trawl by pots and traps to catch Norway lobster, for the same consumed amount of crustaceans, would decrease the environmental impact to 5,330 kg CO_2 eq. (- 48%), to 17 kg PO_4^3 eq. (- 50%) and to 71,840 MJ (- 46%), yet trawling accounts for only 25 % of crustaceans. In 2012, pots and traps were used for only 2% of Norway lobster consumed in France. Thus, type of gear choice does affect the global environmental impact of fisheries, while also strongly determines the impacts on the sea floor, even though it will not change the impact in term of PPR.

Table 3: Environmental impact and origin of FAPs by category

	Independence (%)			Eco-system indicators	
	France	UE	UE + Norway and Faroe	PPR (millions tons/years)	MML (cm)
Demersal and benthic	21	34	52	758	120
Shellfish	46	66	66	5	---
Pelagic	35	65	67	367	110
Salmonidae	13	28	89	68	131
Shrimps and Prawns	≈0	15	15	20	---
Crustaceans (excl. S&P)	24	65	66	3	---
Freshwater fish	1	5	5	9	118
Cephalopods	37	76	76	14	---
Seabass and seabream	43	96	96	8	72
Overall	27	47	61	1,783	118

	Global environmental indicators (/tons of live-weight)			Apparent market	
	kg CO2 eq.	kg PO43 eq.	MJ	Thousands tons	%
Demersal and benthic	2,368	8	27,961	530	30
Shellfish	545	1	10,414	398	23
Pelagic	1,155	3	17,917	326	19
Salmonidae	2,143	48	33,283	229	13
Shrimps and Prawns	10,344	78	34,446	125	7
Crustaceans (excl. S&P)	10,315	34	132,906	50	3
Freshwater fish	5,370	33	19,731	35	2
Cephalopods	6,094	14	47,953	27	2
Seabass and seabream	2,909	65	45,147	25	1
Overall	2,622	18	26,599	1,745	

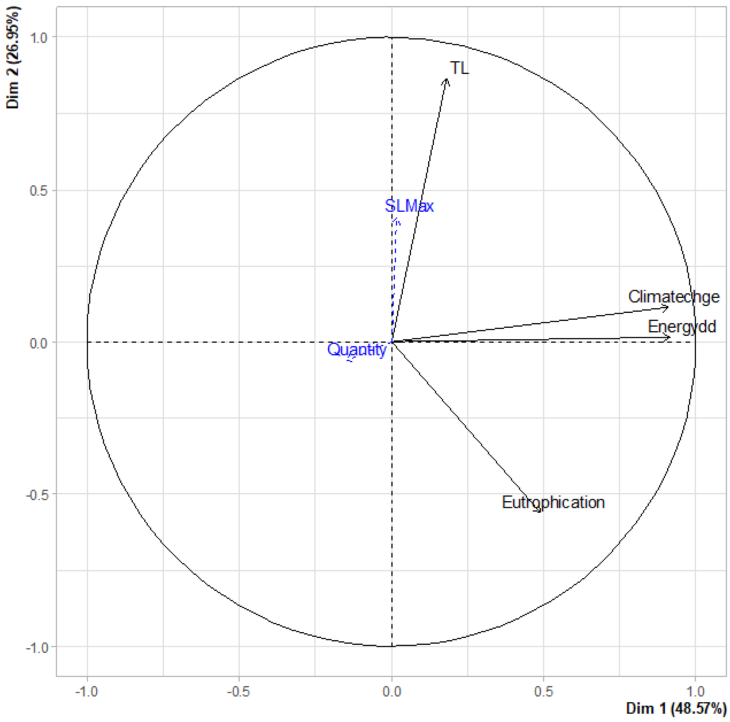
Source: Own elaboration

The LCA coefficients used are from the sea to the dock, thus it is interesting to look at the origin of products for two main reasons. First, transportation of FAPs after landing has an impact too. Shrimps and prawns are already among the worst species in terms of impact as measured by the LCA; and this result is reinforced whilst taking into account transportation, as almost 85% of this consumption originates from non-European countries. On the contrary, shellfish products are mostly produced in Europe, coupled with a low global environmental impact. Second, production taking place in Europe is subject to European regulations, meaning more leeway to implement policy to reduce environmental impact of FAPs.

3.3. PCA results

The results of PCA reinforce previous analysis in regards of correlation between climate change and energy demand, and between TL (used to calculate PPR) and MML. The horizontal axis D1 represents the impact in terms of climate change and energy demand, while the vertical axis D2 represents the trophic level (fig.4). The plane D1/D2 cover 75.52% of the variability.

Figure 4: Variable graphic of PCA – Dim 1 (48.75%)/Dim 2(26.95%)



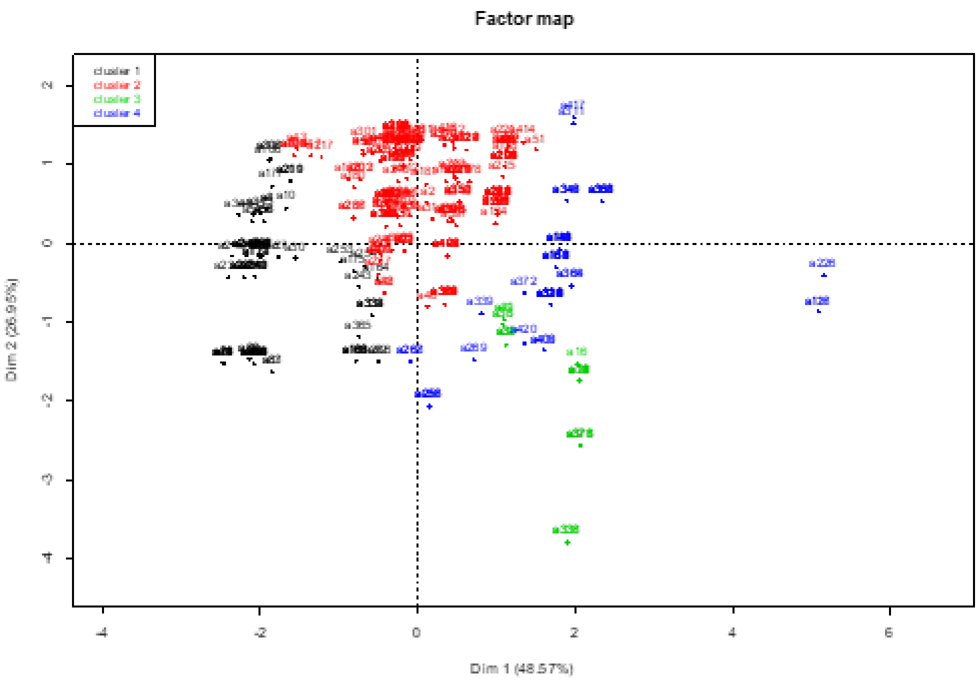
Nb of obs.: 404

Source: own elaboration

Four clusters have been selected by hierarchical analysis (see fig 5). The first cluster includes 98 products. In particular, it represents productions by pelagic trawl, dredges and surround nets. The key species are mussels, anchovy, sardines, and clams; these are mainly species with on average low trophic levels (2.9), and environmental impacts lower than the average in eutrophication (5.55), climate change (712), and energy demand (12,397). We found a convergence for this cluster between global impact and marine ecosystem TL-based indicators.

The second cluster is the most diverse group, with very heterogeneous production methods for 218 products (52% of the studied population). It represents most specifically the productions by bottom trawl, hook lines, and set nets. The key species are ling, rays, swordfish, sole, whiting, tuna. The global environmental performances (climate change and energy demand) are close to average but marine ecosystem TL-based indicators show higher values (TL – 3.97 and MML - 85.8) while eutrophication values are lower on average (9.46).

Figure 5: Factor map of PCA



Nb of obs.= 404

Source: own elaboration

The third cluster is the Aquaculture group composed of 26 products. We unsurprisingly find in this group trout, shrimp, seabass, seabream as key species. It is marked by a much higher level than the average for eutrophication (104 versus 18) and higher than the average for energy demand (51,180). Variables values are higher for marine ecosystem indicator too.

Crustacean and cephalopod mainly compose the fourth cluster, as it is the group of production by pots and traps. It includes 62 individuals. This group has low trophic levels TL (2.94), but high impacts in climate change (5,244) and energy demand (68,430).

We can consider a fifth cluster, composed by individuals non-used for the PCA. This is the production group of shrimp and Norwegian lobster by bottom trawl. They are 16 individuals.

They have impacts on energy demand (170,563), climate change (27,800) and eutrophication (77) several times above the average, but a TL (2.66) below the average.

Overall, we can observe that if we have a correlation between climate change and energy demand, we do not find convergence through cluster between global impact or non-fish specific indicators, and marine TL-based indicators. If in the larger cluster (2), eutrophication is better than average, marine indicators we used are worst, while in others cases lower marine ecosystem impact can be associated with higher values for climate change and energy demand (cluster 4 and 5). The only convergence holds for cluster 1, mainly composed by species produced by the use of pelagic trawl, dredges and surround nets, in which case both environmental indicators show better performances. Only surround nets and pelagic trawl used to fish tuna do not belong to this cluster. Despite being pelagic species, tuna fisheries worsen the marine eco-system indicators, while better in non-fish specifics indicators.

Thus, as the correlation between global impact and marine ecosystem impact is not systematic, it is thus relevant to evaluate environmental impact FAPs using specific environmental indicators. It will avoid simply transferring environmental damage from earth to sea, without taking care of specific damage on marine ecosystems. The analysis by species underlined heterogeneity between species, and furthermore between production methods. Those specificities have to be taken into account to refine the message to consumers to improve the sustainability of the sector. The message to consumers, in order to be efficient, needs to focus on species together with both their fishing and production methods. In addition, in our study we only use a limited number of ecosystem indicators, but some impacts should be considered to clarify some clusters having many heterogeneous environmental impact that we did not catch in our analysis (as impact on the seabed or by catch species).

4. Discussion and Conclusion

If the environmental impacts of food systems is a major concern in the context of global change and biodiversity crisis, the environmental gains from increased share of FAPs in the European diet raises the question of a transfer from earth to sea of this impact. In this context, we looked more precisely at the impact of FAPs consumption in the ecosystem as well as the global environmental level.

The environmental impact of FAPs consumption depends on the pattern of consumption. Depending of the species, the environmental footprint can widely vary. Trawled crustaceans, and farm shrimps or prawns are the worst in terms of global warming, beside good performances regarding TL-based ecosystem indicators. However, this assessment worsens since it is mostly non-European products, meaning transportation may increase environmental impacts also. From another side, shellfish registers the weakest footprint, in global as well as in ecosystem scales, whilst it is mainly produced at the European scale. Nevertheless, the worst species in terms of environmental impact do not necessarily match with the largest share of consumption. On the contrary, two of the top three species categories consumed in France are the less damaging for the environment (pelagic and shellfish). Furthermore, global and marine specific impacts may differ making the interpretation of environmental impact of FAPs more complex but underling the necessity to work at the FAPs at a desegregate level.

Two solutions can be implemented to decrease the environmental footprint of FAPs without changing the global volume consumed. First, improving the environmental impact by species favouring the less damaging gears or production methods. Second, favouring the consumption of categories that minimize the environmental footprint. In that end, establishing a strong labelling policy is needed, allowing consumer to have, and to understand, the information on species jointly with the origin and the method of production on all the FAPs, regardless of the degree of transformation of the final product. If indeed, our objective is for consumer to make the "sustainable" choice, detailed information is required.

Nevertheless, consumer behaviour in terms of substitution between species needs to be looked after to be able to implement efficient policy. In undergoing work, this database will be matched with demand system estimated with the Kantar Database (real purchase database). Matching our original database with demand elasticity will allow us to take into account the consumers preferences, and thus being able to recommend efficient policy to improve the environmental impact of FAPs consumption.

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Appendix:

Table A.1: Trade with France: Species, partner countries, and zone of fishing (own elaboration)

Countries	Angola, Argentina, Armenia, Australia, Bahamas, Bangladesh, Belgium, Belize, Brazil, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cuba, Cyprus, Denmark, Ecuador, Estonia, Faroe islands, Fiji, Finland, French Polynesia, French Southern Territories, Gambia, Germany, Ghana, Greece, Greenland, Guatemala, Guyana, Honduras, Iceland, India, Indonesia, Ireland, Italy, Ivory Coast, Jamaica, Japan, Kenya, Korea (Republic of), Latvia, Lithuania, Madagascar, Malaysia, Maldives, Mauritania, Mexico, Morocco, Mozambique, Namibia, Netherland, New Caledonia, New Zealand, Nicaragua, Nigeria, Norway, Oman, Panama, Papua New Guinea, Peru, Philippines, Poland, Portugal, Russia, Senegal, Seychelles, Singapore, Slovenia, South Africa, Spain, Sri Lanka, St Pierre and Miquelon, Suriname, Sweden, Taiwan, Tanzania, Thailand, Tunisia, Turkey, Uganda, United Kingdom, United States of America, Uruguay, Venezuela, Vietnam, Yemen, Zimbabwe, Indeterminate
Species	Alaska Pollack, Anchovy, Blue grenadier, Cephalopods, Clam, Cod, Crab, Dogfish, Flounder, Freshwater crayfish, Freshwater catfish, Haddock, Hake, Halibut, Herring, Jack and horse mackerel, Ling, Lobster, Mackerel, Megrim, Monkfish, Mussel, Nile perch, Norway lobster, Oyster, Plaice, Pollack, Rays and skates, Redfish, Rock lobster and sea crawfish, Saithe, Salmon, Sardine, Scallop, Seabass, Seabream, Sea urchins, Shrimps and prawns, Sole, Swordfish, Tilapia, Trout, Tuna, Turbot, Whiting,
Zone of fishing	Atlantic Iberian waters; Barents Sea and Norwegian Sea; Bay of Biscay; Bay of Biscay and Atlantic Iberian waters; Belts and sounds; Black Sea; Bristol Channel; Cantabrian Sea and Atlantic Iberian waters; Celtic Sea; Celtic Sea and West of Ireland; Celtic Sea, West of Ireland, English Channel and Bay of Biscay; Eastern Central Atlantic; Eastern Central Pacific; Eastern Channel; Eastern English Channel; Eastern Indian Ocean; English Channel; Faroe grounds; Faroe Plateau Ecosystem; Gulf of Lions; Iceland and East Greenland; Iceland grounds; Indian Ocean; Irish Sea; Irish Sea, Celtic Sea, English Channel, southern North Sea; Lake Victoria; Mediterranean and Black sea; Mediterranean Sea; NE Atlantic / N Stock; North Pacific; North Sea; North Sea and West of Scotland; North Sea, Eastern channel and Skagerrak; North Sea, Skagerrak and Kattegat; Northeast Atlantic; Northeast Pacific; Northern Adriatic; Northern stock; Northwest Atlantic; Northwest Pacific; Norwegian Sea and Barents Sea; Pacific southeast; Porcupine Bank; Portuguese waters; Rockall; Skagerrak and Kattegat; Southeast Atlantic; Southeast Pacific; Southern Celtic Sea and the English Channel; Southern stock; Southwest Atlantic; Southwest of Ireland; Southwest Pacific; West of Ireland; West of Scotland; Western Central Atlantic; Western Channel; Western English Channel; Western Indian Ocean

Table A.2: Gear classification (source: STECF, 2018)

Code STECF	Description STECF	Gear Paper
PS	Purse seines	SURROUNDING NETS
LA SDN SSC SPR	Lampara nets Danish seines Scottish seines Pair seines	SEINE NETS
TBB OTB PTB OTT	Beam trawl Bottom otter trawl Bottom pair trawl Otter twin trawl	BOTTOM TRAWL
OTM PTM	Midwater otter trawl Pelagic pair trawl	PELAGIC TRAWL
DRB DRH HMD	Boat dredges Hand dredges Mechanised dredges including suction dredges	DREDGES
GNS GND GNC GTR GTN	Set gillnets (anchored) Driftnets Encircling gillnets Trammel nets Combined gillnets-trammel nets	NETS
LHP LHM LLS LLD LTL	Handlines and pole-lines (hand-operated) Handlines and pole-lines (mechanised) Set longlines Drifting longlines Troll lines	HOOKS AND LINES
FPO FYK FPN	Pots Fyke nets Stationary uncovered pound nets	POTS AND TRAPS
HAR SV SB LNB LNS	Harpoons Beach and boat seine Beach seines Boat-operated lift nets Shore-operated stationary lift nets	OTHER GEARS
NK NO MIS	Gear not know or not specified No gear Miscellaneous Gear	INDETERMINATE

Table A.3: Quantitative data description for ACP

Parameters	Min.	1st Quartile	Median	**Mean**	3rd Quartile	Max.
Quantity (Volume consumed in tons)	3.0	210.5	681.5	**4,130.4**	2,499.0	143,616.0
Climate change (kg CO2 eq.)	10	17.59	2,804	**3,662**	3,840	27,800
Eutrophication (kg PO43 eq.)	-0.74	5.89	7.30	**17.88**	11.2	150.0
Energy demand (MJ)	2,175	24,078	37,788	**43,489**	54,656	325,000
Trophic level	2.10	3.05	3.60	**3.494**	4.20	4.50
Mean Maximum Length	0	0	0	**53.8**	92	455

Source: own elaboration

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