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Towards an environmentally sustainable and healthy Atlantic dietary pattern: life cycle carbon footprint and nutritional quality

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Abstract

Production and consumption of food has a significant effect on climate change. The effect of different consumption habits on the environment should not be under estimated, as there are different studies that mention the environmental impact associated with different foods, especially those of animal origin. The analysis of the Atlantic Diet (AD), as the most common dietary pattern in Northwestern Spain, serves as an example of a diet with a high consumption of local, fresh and seasonal products, home cooking and low-processed foods. The evaluation was carried out by quantifying the carbon footprint following the Life Cycle Analysis methodology and identifying its nutritional quality according to the value of the Nutrient-rich Dietary index (NRD9.3.). According to the main results, the consumption of livestock products and shellfish is responsible for most GHG emissions (70% of the total). The basic ingredients of the AD, such as vegetables and legumes, make a relatively minor contribution (with an impact of 30% of the total) to the total carbon footprint of 3.01 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$. As regards nutritional quality, AD has a high nutritional score (474), mainly due to the low intake of sodium, added sugars and saturated fats (nutrients to be limited in healthy diets). In general, both the carbon footprint and the nutritional index score are consistent with those of other studies on the Mediterranean diet, which has been recognised as beneficial. Therefore, it can be concluded that the AD may be recommended from a nutritional and environmental point of view, mainly due to the high intake of fish and vegetables. The communication of this valuable environmental and nutritional information to consumers should be taken into account when considering strategic actions for the adoption of healthy and sustainable dietary patterns.

Keywords: Atlantic diet; Daily diet; LCA; Meals; Nutritional value; Sustainable diet

1. Introduction

Nutrition is a basic human need and access to adequate nutrition depends on numerous social, political and economic factors (Heller et al., 2013). Balanced and complete nutrition affects human health and well-being. The effects of nutritional patterns on overweight, cardiovascular disease and other diet-related health problems are widely known (Coelho et al., 2016; Risku-Norja, 2011). The selection of one type of food versus another entails direct consequences in the supply chain, as well as environmental, economic and social impacts associated with the production process (Cencic and Chingwaru, 2010). In particular, food chains that support diets are linked to environmental issues such as greenhouse gas (GHG) emissions, embedded energy consumption and land use (Irz et al., 2016; Castañé and Antón, 2017). Therefore, environmental pressures on food systems are relevant to public health agendas (Sáez-Almendros et al., 2013).

Food production ranges from agricultural and farming activities to manufacturing, refrigeration, retailing, storage, cooking and final disposal of waste (Garnett, 2011; Sáez-Almendros et al., 2013). According to Garnett (2011) and Irz et al. (2016), 15-30% of total GHG emissions in developed countries are derived from food production, distribution and consumption, and agriculture is responsible for 70-80% of water consumption (Heller et al., 2013). In this regard, researchers are evaluating the sustainability of food production and eating patterns (Baroni et al., 2007; Donati et al., 2016). According to these studies, lactoovovegetarian or plant-based diets are more environmentally sustainable than those containing resource-intensive products (e.g., meat-rich diets) (Baroni et al., 2007; Risku-Norja, 2011). Of special interest is the development of methodologies to analyse the environmental impact of a product or food system with the most objective approach. (Aleksandrowicz et al., 2016; Duchin, 2005; van de Kamp et al., 2018; Van Kernebeek et al., 2014). The environmental footprints of some diets (e.g., omnivorous, vegetarian, vegan, omega-3 fatty acids enriched) have been quantified according to the Life Cycle Assessment – LCA methodology (Pimentel and Pimentel, 2003; Coelho et al., 2016). In this sense, numerous studies can be found in the literature in which the relationship between European diets, nutritional quality and environmental aspects are evaluated in detail (Aleksandrowicz et al., 2016; Duchin, 2005; van de Kamp et al., 2018; Van Kernebeek et al., 2014).

Several studies can be found in the literature where the food trends of Swedish homemade menus were analysed proposing dietary guidelines, with special attention to organic food (Carlsson-Kanyama et al., 2003; Carlsson-Kanyama and Faist, 2000; Carlsson-Kanyama and Linden, 2001). In these studies, the energy needs throughout the life cycle of Swedish diets were estimated with the aim of planning home-cooked meals that were nutritionally rich but included products that were less energy-intensive.

Jungbluth et al. (2000) proposed a simplified LCA approach to assess consumption patterns in Switzerland with the aim of identifying environmental-friendly decisions. The authors propose different actions to reduce environmental impacts. Therefore, it was proposed to reduce meat consumption and demand for airborne products as well as to promote the consumption of organic products.

The effect of Dutch consumption patterns on agricultural land needs was also assessed in detail (Gerbens-Leenes et al., 2002; Gerbens-Leenes and Nonhebel, 2002). According to these studies, large differences in land requirements for food production were identified not only in the Netherlands, but also for other European countries. A hypothetical analysis of a wheat-based diet would require up to six times less soil compared to a meat-rich diet.

Finally, Van Kernebeek et al. (2014) addressed the question of whether plant-based diets have lower environmental impact than those with a significant contribution of food with animal origin, but taking into consideration nutritional quality. To this end, a review of more than fifty peer-reviewed studies was conducted. The results showed that diets with higher percentages of food products of animal origin could be associated with higher GHG emissions and land use requirements, but these results were variable depending on the functional unit considered. Special mention was made of the need to assess the overall nutritional quality of a diet and the recommended levels of protein intake as particularly relevant elements to be taken into account when comparing dietary patterns.

The most recent literature contains numerous references on the selection of the most appropriate functional units for the calculation of the environmental impacts of food consumption patterns. The energy content (daily calories), protein or fat content of diets are some of the most common examples (Pimentel and Pimentel, 2003; Heller et al., 2013). Moreover, profiles per serving or per potential economic value are also available (Heller et al., 2013; Van Der Werf and

Salou, 2015). However, nutritional value must be the crucial element of reference for the definition of a healthy diet. Nutrient-based recommendations should be specifically considered in the search for and promotion of a sustainable dietary pattern that meets these values (Smedman et al., 2010; Heller et al., 2013).

The high consumption of fruits, vegetables and whole grains in the diet is closely related to the reduction of the risk of developing chronic diseases such as cancer and cardiovascular diseases, which are the main causes of death in industrialized countries (Cencic and Chingwaru, 2010). Based on this type of food, healthier and more fruit and vegetable-rich diets have been identified in southern countries. In contrast, northern countries have diets rich in animal fats and food products of animal origin. It is interesting to identify different social contexts and cultural values in relation to food (Nordström et al., 2013). While food is an individual issue in northern countries, society in central and southern Europe associates food with the social dimension of sharing a meal (Cencic and Chingwaru, 2010).

Spain is one of the European countries with the lowest mortality rates for ischaemic heart disease. Within the country, regional differences have been identified in this regard. In fact, variations have been reported to be up to 40% lower than the average in northern cities (Medrano et al., 2012). The traditional Atlantic diet is a common dietary pattern in northern Portugal and Galicia (northwest Spain), culturally and climatically similar areas and has been associated with a lower likelihood of myocardial infarction and good metabolic health (Calvo-Malvar et al., 2016; Atlantic Diet Foundation[1]). The Atlantic diet is characterised by an abundant consumption of plant-based products, as well as local and fresh products (seasonal food) with reduced cooking time. The consumption of meat (mainly beef and pork) and eggs is reasonable and olive oil is considered as the main source of fat for cooking and seasoning (Calvo-Malvar et al., 2016; Charro et al., 2006). Recently, it has been rated as a world reference for a healthy diet (Vaz Velho et al., 2016). The Atlantic diet differs from the Mediterranean - the most popular in southern Spain, in terms of increased consumption of fish, red meat, pork, milk, potatoes, fruit, vegetables and olive oil (Guallar-Castillón et al., 2013), which implies significant changes in nutrients and functional components. However, both of them can be taken as examples of healthy diet (Tojo and Leis, 2009; Sáez-Almendros et al., 2013).

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[1] https://www.fundaciondietatlantica.com/eng/index.php (accessed July, 2018)

This study has a twofold objective: to quantify the carbon footprint of the Atlantic diet through a LCA approach associated with the production of the different foods that make up this diet, while identifying its nutritional quality. The recommended Galician dietary pattern and the corresponding intake data have been taken into account. The main causes of GHG emissions will be highlighted to identify options for improvement.

2. Materials and methods

2.1. Weekly menu based on the Atlantic diet

The concept of the Atlantic diet dates back to the traditional menus of Galician gastronomy. With the social awareness of a healthy diet, the benefits of this dietary pattern are reflected in a recent study (Vaz Velho et al., 2016) (see Figure 1). It is characterised by i) a high intake of seasonal foods, vegetables, fruits, potatoes, bread and cereals, chestnut, whole nuts, legumes and honey, fish, molluscs and crustaceans; ii) a moderate consumption of milk, cheese, meat (beef and pork), eggs and iii) cooking methods based on boiling, stewing, grilling and roasting. An abundant intake of complex sugars, fibre, polyunsaturated fatty acids, vitamins, minerals and functional components is therefore guaranteed (Tojo and Leis, 2009; Vaz Velho et al., 2016).

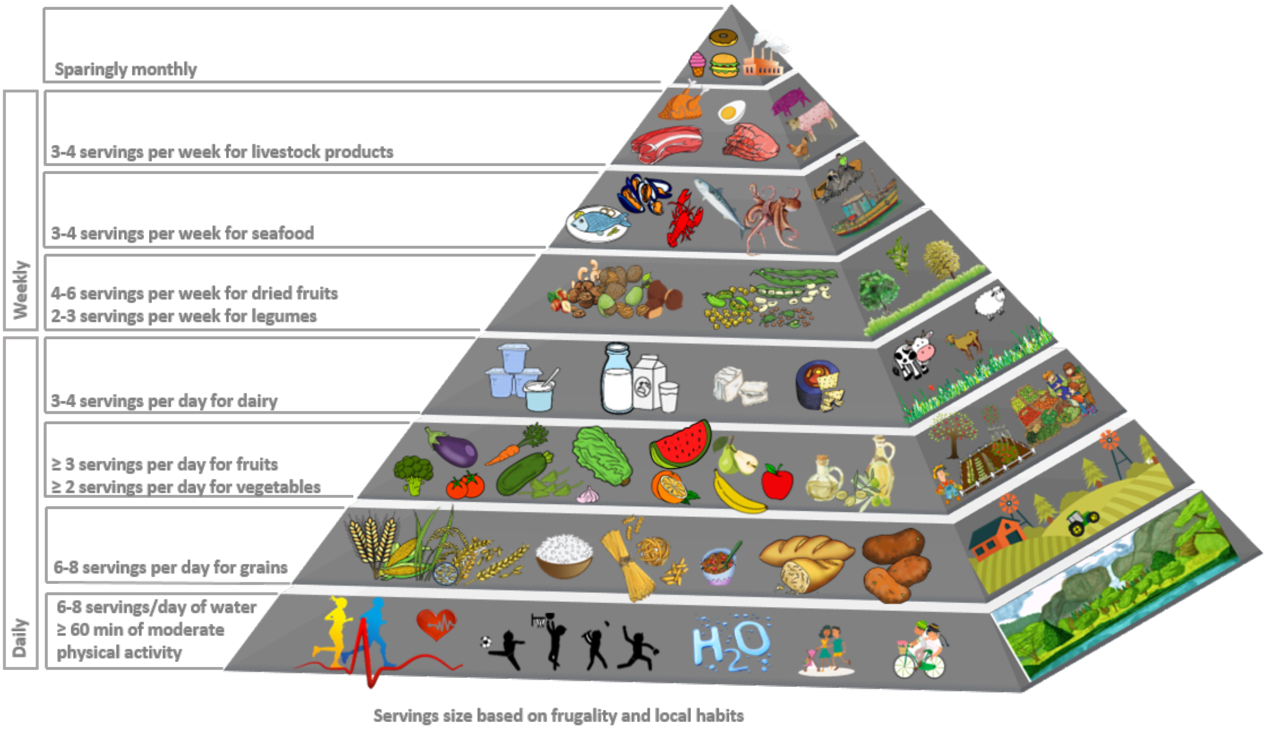

Figure 1. Atlantic diet pyramid. The base and the top of the pyramid include the foodstuffs that must be daily consumed or occasionally consumed, respectively.

Although studies can be found in the literature that consider individual meals, daily or annual diets (Van Kernebeek et al., 2014), a weekly diet has been considered for analysis, as it may facilitate comparison with other types of dietary patterns. Following the recommendation of Tojo and Leis (2009), a weekly diet has been designed– displayed in Table 1 – consisting of seven daily menus (daily diets) divided in five meals (breakfast, mid-morning snack, lunch, afternoon snack and dinner) has been designed, as similar as possible to the recommended Galician eating habits (Xunta de Galicia, 2013). This weekly diet is based on 2,100 kcal and corresponds to the energy needs of an active Spanish adult woman (regular physical activity) according to FAO (2014).

Table 1. Atlantic diet based weekly menus designed for this study taking into account the recommended servings of the different food groups. The daily diets have been adjusted to a recommended energy intake of 2,100 kcal.

	Daily diet						
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Breakfast	Glass of milk and bread with tomato	Glass of milk. cereals. nectarine	Glass of milk. Wholemeal bread. orange	Glass of milk. wholemeal cereals. nectarine	Glass of milk. wholemeal bread. orange	Curd with honey. wholemeal bread	Glass of milk. bread. peach
Mid-morning Snack	Orange	Yogurt	Yogurt	Infusion	Apple	Kiwi	Pear
Lunch	Steamed cockles. vegetable cannelloni. nectarine. bread	Vegetables and fruits salad. black rice with cuttlefish. bread	Carrot salad. Galician style conger. two figs. bread	Mackerel with potatoes and roasted peppers. watermelon. bread	Octopus with potatoes. salad. curd with honey. bread	Cod croquettes. vegetable stew. tangerine. bread	Padron peppers. roast beef with potatoes
Afternoon snack	Banana	Melon	Banana	Peach	Banana	Yogurt	Nectarine
Dinner	Grilled beef steak with rice. bread	Grilled pork steak. steamed Brussels sprouts. pear. bread	Pumpkin cream. pear. bread	Pasta salad. fresh cheese. bread	Grilled beef steak with rice and steamed vegetables	Chicken steak with pasta and mushrooms. grapes. bread	Scrambled eggs with mushrooms and pasta
Total energy intake	2,124 kcal	2,101 kcal	2,295 kcal	2,140 kcal	2,051 kcal	2,189 kcal	2,097 kcal

Recommended servings of different food groups have been considered for evaluation. Table 2 shows the frequency servings for the Atlantic dietary pattern. Although the specific composition of the diet changes with age and sex, this level of uncertainty can be assumed for the estimation of the carbon footprint.

Table 2. Main recommendations of servings (s) frequency for each food group for the Atlantic Diet adapted from Velho et al. (2016).

Food group	**Servings frequency**
Cereals/Grains	6-8 s·day^{-1}
Fruits	3s or more·day^{-1}
Vegetables	2s or more·day^{-1}
Olive oil	3-4s·day^{-1}
Dairy products	3-4s·day^{-1}
Dried fruits	4-6s·week^{-1}
Legumes	2-3s·week^{-1}
Seafood	3-4s·week^{-1}
Meat	3-4s·week^{-1}
Eggs	3-4s·week^{-1}
Sweets	Sparingly monthly

2.2. Estimation of the Atlantic diet nutrient composite score

One of the main objectives of this study is to analyse the nutritional quality of the Atlantic diet to identify whether this dietary pattern meets healthy parameters. It is well known that consumers are advised to look for nutrient-rich foods rather than discretionary calories. Taking into account the main recommendations from Van Kernebeek et al. (2014), the nutrient intake associated with one single meal cannot be used to assess the nutritional quality of a daily diet. Therefore, the nutritional quality has been analysed through daily menus. This perspective will facilitate comparison with alternative dietary patterns. The Nutrient Rich Food (NRF9.3) score (Drewnowski, 2009; Fulgoni et al., 2009) is considered the cornerstone of a dietary guidance approach to healthy eating. However, the Nutrient Rich Diet (NRD9.3) score was considered in this study to estimate the nutritional quality of the Atlantic diet. This method has been proposed by Van Kernebeek et al. (2014) as a modification of the NRF9.3 index as it is not scaled to energy intake (the former refers to 100 kcal of a given food).

A total of nine nutrients to encourage (protein, fibre, calcium, iron, magnesium, potassium, vitamin A, vitamin C, vitamin E) and three nutrients to limit (sodium, saturated fat and added sugar) have been considered for the estimation of the score (see Equation 1). In this sense, the greater the amount of nutrients ingested to encourage and the smaller the amount of nutrients to limit, the higher the NRD 9.3 index is. Nevertheless, when the 9 nutrients to encourage exceed the Recommended Daily Value (RDV), they are capped to this previous value, in order to avoid overestimation caused by overconsumption.

$$NRD9.3 = \left(\sum_{i=1}^{i=9} \frac{nutrient_{\ i\,capped}}{RDV_i} - \sum_{k=1}^{k=3} \frac{nutrient_{\ k}}{RDV_k}\right) * 100 \qquad \text{Equation 1}$$

Table 3 shows the average daily nutrient intake corresponding to a typical Atlantic diet (Fundación Española de la Nutrición, 2004), as well as those recommended for each nutrient to be promoted and the maximum for each nutrient to be limited, taking into account health recommendations (Castañé and Antón, 2017).

Table 3. Recommended nutrients daily intake (RDV) and daily average nutrients composition for the Atlantic Diet (AD).

	Boosting nutrients									Limiting nutrients		
	Protein	**Fiber**	**Vit A**	**Vit C**	**Vit E**	**Ca**	**Fe**	**K**	**Mg**	**Saturated fat**	**Added sugar°**	**Na**
	g	g	µg	mg	mg	g	mg	g	mg	g	g	g
RDV[1]	50	25	700-3000	60-2000	20-1000	1.0-2.5	18-45	3.5	400	20	50	1.5-2.4
AD[2]	91	21	1404	179	13	1.01	13.8	3.5	237	28	2.0	1.9

The NRD9.3 score has been estimated for each daily diet previously designed and reported in Table 1. In addition, an average score has been calculated with these specific indexes with the aim of obtaining a final dietary quality score for the Atlantic diet. This average score has been benchmarked with others available in the literature (Van Kernebeek et al., 2014) to identify how it is ranked in terms of nutritional quality. Finally, the nutritional quality score has been supplemented with the assessment of individual nutrient scores, taking into account the 12 nutrients mentioned above. For this purpose, the Nutrient Rich (NR) index for each nutrient is calculated according to the method proposed by Van Kernebeek et al. (2014). This index reports the nutrient intake in relation to the RDV.

2.3. Estimating the Carbon Footprint of the Atlantic diet

The relevance of food products to the environmental pressure of society-related activities is truly outstanding (Garnett, 2011; Sonesson et al., 2005; Irz et al., 2016). Within environmental pressures, GHG emissions receive special attention (Garnett, 2011). There are multiple studies focused on the environmental profiles of individual food products such as onion (Aguilera et al., 2015), yogurt (González-García et al., 2013a), cheese (Berlin, 2002; González-García et al., 2013b), canned tuna (Hospido and Tyedmers, 2005), bread (Andersson and Ohlsson, 1999), cod fillets (Ziegler et al., 2003), pork (Noya et al., 2017) or tomato ketchup (Andersson et al., 1998). However, studies that focus on environmental profiles related to dietary patterns have started to attract interest in recent years (Van Kernebeek et al., 2014; Coelho et al., 2016; Pernollet et al., 2016). According to the literature (Carlsson-Kanyama and González, 2009; Committee on Climate Change, 2010; Scarborough et al., 2014), GHG emissions vary considerably between food products and also depends on the efficiency of the production chain.

For the estimation of the carbon footprint of each daily diet that constitutes the weekly menu of the recommended Atlantic diet, the Life Cycle Analysis (LCA) approach, a standardized methodology for the systematic assessment of the environmental burdens of a product or service system at all stages of its life cycle, has been taken into account (ISO 14040, 2006). LCA has increased its application in food analysis in recent years and has been considered as a potential assessment method for environmental profiles of food products and dietary patterns (Goldstein et al., 2016). In line with other authors (Carlsson-Kanyama and Faist, 2000; Duchin, 2005; Jungbluth et al., 2000), a simplified LCA has been carried out considering only the most important stages in terms of resource consumption (from food production to consumption) and avoiding other relevant minor stages such as the production of packaging materials or waste management, mostly due to the lack of detailed data for some foodstuffs.

Therefore, this study addresses the estimation of GHG emissions in the Atlantic diet considering the recommended dietary patterns with the aim of answering the question “*Is the Atlantic diet a healthy and environmentally sustainable diet?*”.

2.4. Functional unit

LCA attempts to quantify the material and energy flows throughout the life cycle of the system under analysis, in this case, daily menus of the Atlantic diet. Thus, a functional unit is required to provide a common basis for comparison and to report the corresponding carbon footprint. Although different functional units have been considered in related studies the recommended 2,100 kcal per day supply of food, excluding non-dairy beverages, has been considered (FAO, 2014), which is in line with the one selected in other relevant studies available in the literature (Sáez-Almendros et al., 2013; Scarborough et al., 2014) and allows comparison between the results achieved. In this functional unit, the primary function of the daily diet, i.e. the supply of energy and nutrients for an adult woman, is fulfilled. However, it is important to note that consuming 2,100 kcal per day does not imply a nutritionally adequate diet. For this reason, the assessment of the nutritional score (NRF9.3) is selected to complete this study and give an answer to the former question.

2.5. Scope of the Atlantic diet analysis

The carbon footprint for each daily diet reported in Table 1 will be estimated according to a cradle-to-mouth perspective (see Figure 2). The system analysed has therefore been divided into three stages:

- Food production stage, i.e. production of the different food ingredients that make up each daily menu (breakfast, mid-morning snack, lunch, afternoon snack and dinner). At this stage, a "cradle-to-farm or industry" approach was considered, depending on the food product. A detailed description by food product is given in the Supplementary material (SM Table 1).
- Household stage, i.e., preparation of the different menus at households and refrigeration (if necessary).

- Transport stage, i.e., the distribution of the different food products from the factory or farm gate to the retailer, as well as from the retailer to households.

The carbon footprint of the household stage has been calculated taking into account three main cooking processes, such as boiling, frying, and baking as well as home storage in refrigerators. The abundance of fresh products in the Atlantic Diet makes large cooking processes unnecessary (Tojo and Leis, 2009; Vaz Velho et al., 2016). For this reason, it has been assumed that only one of the three cooking methods is used for each serving when necessary, in line with Castañé and Antón (2017). According to Sonesson and colleagues (Sonesson et al., 2003), the carbon footprint associated with the cooking process is expected to derive mainly from the energy consumption of household appliances. Regarding home storage, it has been computed the average electricity consumption reported by Muñoz et al. (2010) associated with the use of a combined refrigerator and a freezer. According to that study, electricity requirements correspond with 0.52 kWh per person and day.

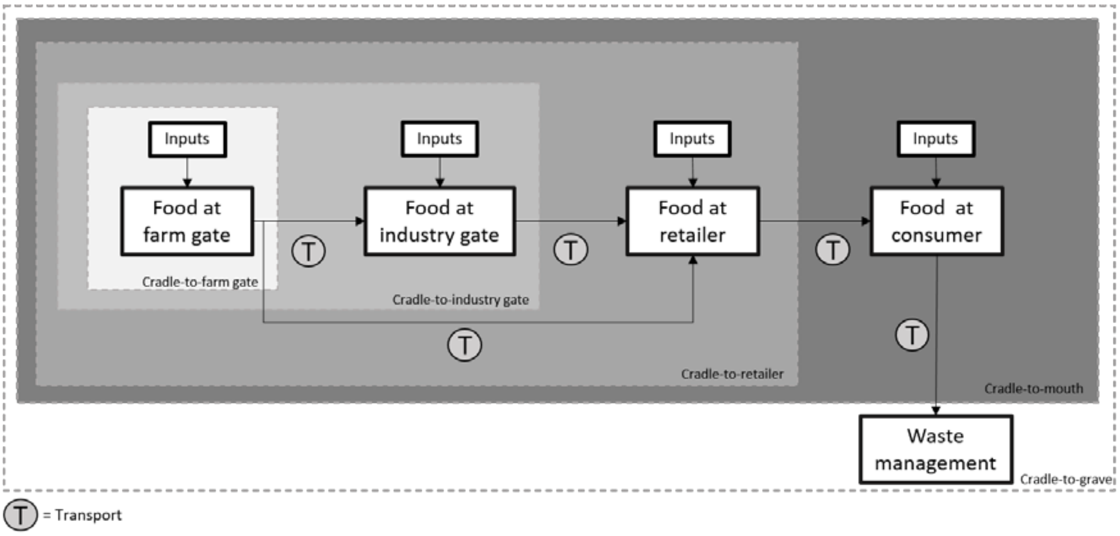

Figure 2. System boundaries considered in the analysis of the carbon footprint associated to the recommended Atlantic dietary pattern (cradle-to-mouth) as well as alternative limits available in the literature.

As far as transport activities are concerned, Euro 5 diesel freight lorries (>32 tons) have been considered for transport from the factory/farm gate to retailers for the food produced in Spain. Thus, average distribution distances of 400 km and 60 km (on average) have been estimated for distribution from outside and within Galicia respectively. For products manufactured outside Spain, an average distance by ship and lorry from their country of origin to Galicia has been considered. In all the situations, refrigerated transport has been considered when necessary.

Moreover, the transport from retailers to households has also been taken into account despite their negligible contribution reported in other works (Castañé and Antón, 2017). According to Sonesson et al. (2005), consumers go shopping once a week, mainly on foot (70%) rather than by car or public transport (30%). In line with González-García et al. (2013), an average distance of about 10 km has been established between the retail trade and households. In our study, we have excluded from the analysis those inputs that can be assumed to change to a lesser extent between diets such as cleaning products, kitchen utensils, cutlery and dishes, following the recommendations of Pernollet et al (2016).

Data quality for the estimation of carbon footprint of food products

A sample of 67 food items in the shopping basket have been grouped into 9 different categories, as shown in the Supplementary material (SM Table1) (fruits, vegetables, legumes, grains, dairy, meat, fish/crustaceans, eggs, olive oil and sweets). The origin of products has been selected on the basis of their most common origin, data availability and, when possible, the consumption of local and seasonal products.

With regard to the data sources considered for the estimation of the GHG emissions associated with each food product, 32 LCA studies focused on the production stage have been considered. The system boundaries in most foods range from cradle-to-farm gate, as shown in the Supplementary material (SM Table 1). However, in certain products the system boundaries cover the perspectives of cradle-to-retailer or even cradle-to-grave, as in the case of mushrooms (Leiva et al., 2015) and yoghurt (González-García et al., 2013a), respectively. Therefore, in these cases the corresponding GHG emissions have been discarded to be consistent with the system boundaries established in our analysis at the production stage. In other cases, some food products have been assimilated to others because of the lack of information on their production stages and the similarity between production chains. These hypotheses have been taken into account in the case of nectarine (peach), pumpkin (melon) as well as leek (onion). Food products excluded from the analysis include spices and condiments such as salt. Alcoholic beverages, soft drinks, coffee and infusions have also been excluded from the analysis in line with related studies (Castañé and Antón, 2017; Van Kernebeek et al., 2014).

The Ecoinvent ® v3.2 database has been considered for the estimation of GHG emissions (carbon footprint) linked to background processes (e.g., production of electricity requirements) and for transport activities considering the characterisation factors from Intergovernmental Panel on Climate Change (IPCC).

3. Results and discussion

3.1. Nutritional quality of Atlantic daily diets

Table 4 shows the nutrient intake for each dietary daily scenario, as well as the average value of the Atlantic dietary pattern. In accordance with the considerations assumed, all diets have been developed to cover all nutritional needs These values are the result of considering the complete menus together with the corresponding amount of each food ingredient and its nutritional composition as can be seen in Tables 2 to 8 of the SM. A detailed description of the daily diet and the food included is given in Table A1 of the Appendix.

Table 4. Daily average boosting/limiting nutrients intake for the Atlantic diet based weekly menus designed for assessment in this study.

	Boosting nutrients									**Limiting nutrients**		
	Protein	**Fiber**	**VitA**	**VitC**	**VitE**	**Ca**	**Fe**	**K**	**Mg**	**Saturated fat**	**Added sugar**	**Na**
	g	g	µg	mg	mg	mg	mg	mg	mg	g	g	g
Monday	120.4	35.5	1692	339	11	1436	73	4578	487	24.2	1.9	1.51
Tuesday	85.5	43.9	635	203	11.9	848	21	5234	483	14.3	2.3	1.50
Wednesday	123.0	36.8	734	250	10	1105	21	4948	407	23.6	1.8	1.33
Thursday	91.0	41.0	1609	463	13	1152	66	4948	505	19.9	2.3	1.50
Friday	88.7	46.6	2108	391	12	1114	19	5071	425	16.5	1.8	1.31

Saturday	88.7	39.2	1680	309	11	1009	17	4479	345	18.1	2.3	1.56
Sunday	111.0	36.3	1680	289	92	921	18	5308	393	18.8	1.9	1.46
Daily average	101.2	39.9	1448	321	23.	1084	33	4938	435	19.3	2.0	1.45

As shown in Table 4, the average daily diet reports an intake of numerous nutrients to be encouraged (i.e., protein, fibre, potassium and magnesium) higher than the values recommended in Table 3, as well as the average values corresponding to the Atlantic diet reported in the literature (Fundación Española de la Nutrición, 2004).

The high protein intake observed is related to the outstanding consumption of fish and moderate consumption of meat (mainly beef and pork). All designed daily diets exceed the recommended daily protein intake value of 50 g (up to 2.5 times).

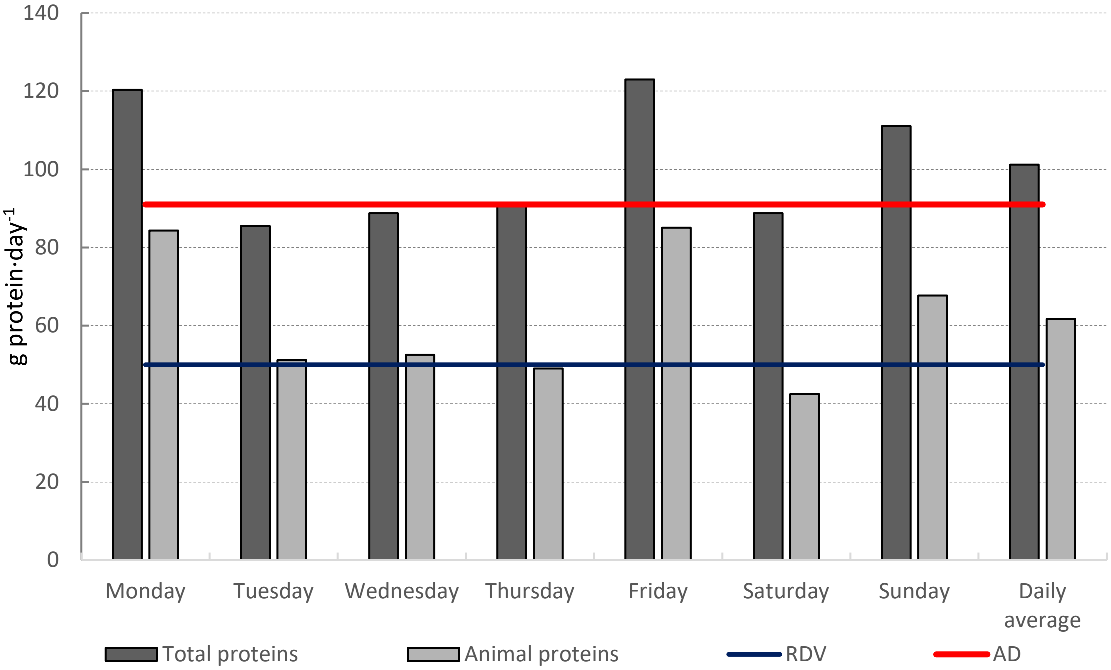

Figure 3. Total protein and animal based protein ingestion per daily diet designed under the Atlantic dietary patterns (g·day^{-1}). RDV – Recommended Daily Value (g·day^{-1}). AD – Established average daily protein intake under Atlantic dietary pattern (g·day^{-1}).

Figure 3 represents the daily protein intake for each designed daily diet, together the average dietary value and the recommended daily value suggested by Fundación Española de la Nutrición (2004). Protein intake per person ranges from 85.5 to 123 g·day^{-1}, with the percentage of animal protein in relation to total dietary protein varying between 48% and 70%.

In line with Van Kernebeek et al. (2014), protein intake is positively associated with AP%. According to the intrinsic characteristics of the Atlantic diet, protein intake comes mainly from seafood and meat, as well as 26% (on average) from dairy products such as milk, yoghurt and cheese.

Fibre intake can be almost double the recommended value, mainly due to the high intake of fruits, vegetables (e.g., potatoes) and cereals (bread). This high intake of seasonable products also leads to a high dose of potassium. As for magnesium, the remarkable consumption of blue fish (e.g., mackerel) and molluscs (e.g., cockles) along with cereals affects the intake ratio.

With regard to other nutrients to encourage, such as vitamins A, C and E, as well as calcium and iron, the amount consumed is within the recommended range. It can be associated with the consumption of a nutrient-enriched product, such as carrots (common as side dish) for vitamin A, pepper (the food product with the highest vitamin C content and a common spice ingredient) and vitamin E, molluscs and dairy products for calcium and fish and molluscs for iron.

For nutrients to limit (saturated fat, added sugar and sodium), their intake is below the recommended limits. The consumption of olive oil and dairy products such as cheese is associated with consumption of saturated fats (both food groups present a serving frequency of 3-4 $s \cdot day^{-1}$). For added sugar, the intake is around 4% of the maximum recommended value. In designed daily diets, it is associated with the consumption of bread and whole grain cereals. The consumption of bread is a characteristic of the Atlantic diet, being greater than in other types of diets such as the Mediterranean. The outstanding presence of fish (mackerel, cuttlefish,…), bread and meat is mainly responsible for sodium in the diet. Moreover, the Atlantic diet is characterised by a high intake of unsaturated fatty acids, which makes it one of the highest in the world (Fundación Española de la Nutrición, 2004).

Just as a remark, potatoes are a basic food ingredient in the Atlantic diet, unlike other dietary patterns such as Mediterranean or even vegan diets. It is considered an important source of complex carbohydrates, fibre, minerals, vitamins and water.

Another point to take into account is the notable difference between the intake of nutrients (mainly fibre, vitamin C, vitamin E, iron, potassium, magnesium and added sugar) estimated for the daily diets designed and those reported in the literature for the Atlantic diet (Fundación

Española de la Nutrición, 2004). Dietary scenarios depend on individual meals, which are affected by factors such as local conditions, seasonal food, gender and even the economic profile of the family. The relationship between these factors and the nutrients intake could be further explored, but it is beyond the scope of this study.

With regard to the NRD9.3 scores for each diet designed (Table 1), scores range from 418 (corresponding to the diet proposed for Tuesday) to 525 (corresponding to the diet proposed for Thursday), as shown in Figure 4. These values are in line with others reported in the literature ranging from 260 to 666, corresponding to other different types of dietary patterns (Nordic, Finish, Indian, English, Mediterranean, vegan…) (Collins and Fairchild, 2007; Risku-Norja et al., 2008; Pathak et al., 2010; Saxe et al., 2012).

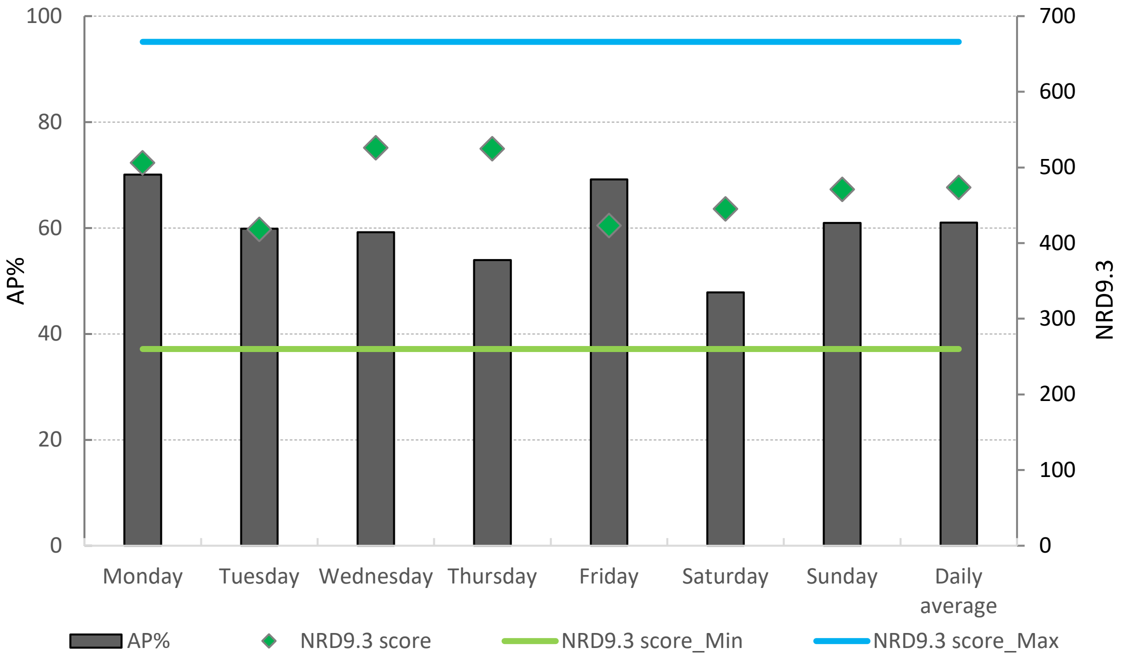

Figure 4. NRD9.3 scores and AP% (ratio of animal based protein and total dietary protein) for each diet that constitutes the designed weekly menu. Minimum (Min) and maximum (Max) NRD9.3 score values found in the literature are also displayed. Numbers on the left-y-axis represent the AP% (in %). Numbers on the right-y-axis represent the NRD9.3 scores.

The specific characteristics of each particular type of diet are responsible for the wide range of values in the NRD9.3 index. Moreover, this index is also affected by the above-mentioned parameters (nutrients to encourage/limit as well as RDV) since its estimation is directly dependent on nutrient intake. According to the literature (Van Kernebeek et al., 2014), the relationship between the NRD9.3 score and the percentage of animal protein can vary considerably between studies and there is no a general trend. Risku-Norja et al. (2009) and Gerbens-Leenes and Nonhebel (2002) identified a reduction in the NRD9.3 score with an increase in the ratio of animal protein to total protein consumed. In contrast, other authors (Collins and Fairchild, 2007; Saxe et al., 2012) identified the opposite trend. Thus, this effect has been also analysed in this study considering the different daily diets proposed for analysis along with the average. The results in Figure 4 do not show a clear correlation. Some daily diet scenarios have a downward trend, while others have an upward trend in the NRD9.3 score, with an increase in the ratio of animal protein to total daily protein consumed (AP%).

Van Kernebeek et al. (2014) proposed an association between both parameters (NRD9.3 and AP%) considering the results reported in the literature and concluded that the NRD9.3 score is negatively associated with the protein ratio. With this consideration in mind, Figure 5 shows the association between the NRD9.3 score and the AP% for the weekly diet proposed here. In addition, the NRD9.3 scores corresponding to these AP% values have also been estimated considering the correlation proposed by Van Kernebeek et al. (2014). The estimated values are 1.1-1.3 times higher than those calculated for our weekly menu. Variations in nutrient composition and dietary characteristics are responsible for these differences. However, in line with Van Kernebeek et al. (2014), the same behaviour can be observed and the score is negatively associated with the AP%. In this sense, these results can be useful and provide information to both consumers and policy-makers to achieve healthier food choices in the supermarket or advise on the need to prioritise the intake of plant rather animal protein to reduce the intake of products of animal origin, respectively.

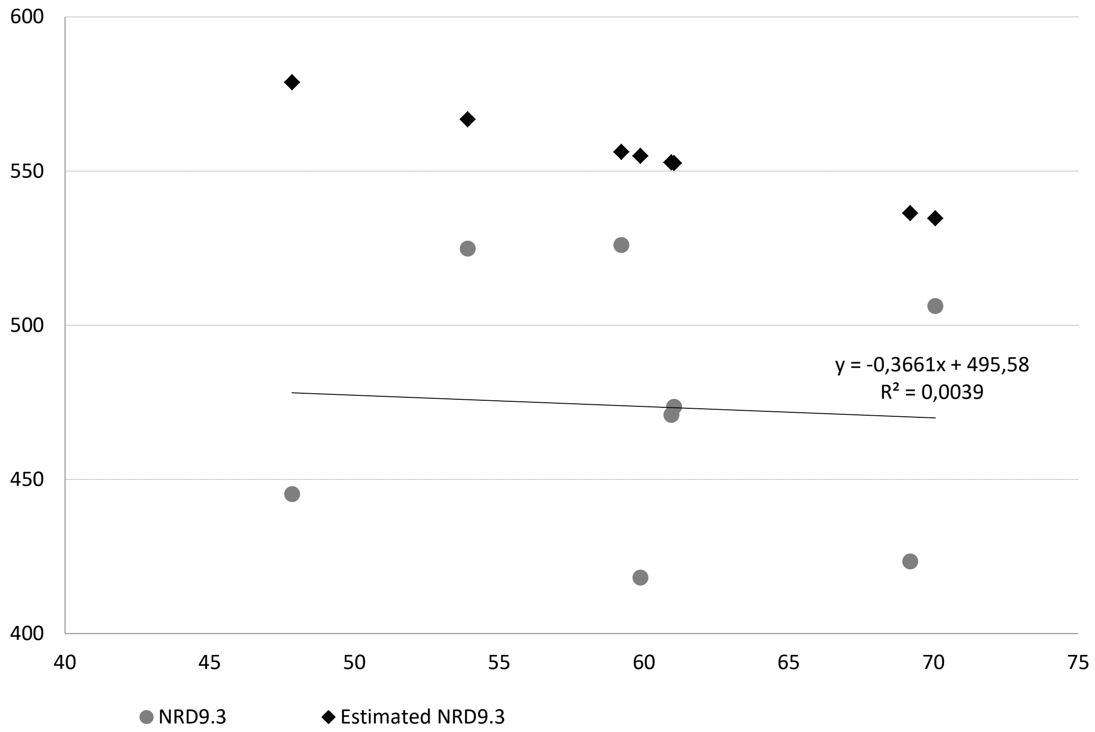

Figure 5. Correlation (grey marks) between NRD9.3 scores (y-axis) and AP% (x-axis) for the weekly Atlantic diet designed for analysis. Marks in black have been estimated considering the correlation established by Van Kernebeek et al. (2014) and the AP% values of our daily diets.

Finally, the nutritional quality of the diets has been completed with the estimation of individual nutrient-rich indexes to report dietary intake in relation to recommended daily values. Table 5 summarizes the corresponding NR scores per daily diet. NR corresponding to protein, fibre and potassium present a value of 100% since their intake exceeds the recommended values. Magnesium intake also implies outstanding NR indexes, equal or very close to 100%. In accordance with the methodology and in order to avoid credits for the overconsumption of nutrients to encourage, nutrient intake is assumed to be equal or greater than the RDV. Conversely, values are not rounded to 100% for nutrients to limit if the recommended daily value is exceeded. Nutrients to limit such as sodium and saturated fats generally present high NR indexes (above 56 and 76% respectively). In contrast, the intake of added sugar reports NR indexes below 5% regardless of the designed diet. These values are much lower than those of other diets such as Mediterranean one (Castañé and Antón, 2017), where NR indexes of between 80% and 136% can be expected. These high values are mainly related to the consumption of products such as yoghurt and jam.

According to Table 5, the Atlantic diet should report really low NR indexes of Vitamin E and C (for Vitamin E below 3% in most proposed daily menus). Improvements in this diet should focus on promoting the intake of ingredients rich on both components, as they are nutrients to encourage. Consumption of citrus products (e.g., orange, mandarin) and nuts (e.g. almonds, hazelnuts) may contribute to increasing the NR-values for Vitamin C and Vitamin E, respectively.

Table 5. Nutrient Rich (NR) score for each analysed nutrient. Scores have been calculated with regard to the recommended daily value of each nutrient.

	Boosting nutrients									Limiting nutrients		
	Protein	**Fiber**	**VitA**	**VitC**	**VitE**	**Ca**	**Fe**	**K**	**Mg**	**Saturated fat**	**Added sugar**	**Na**
Monday	100	100	91.5	32.9	2.1	82.1	100	100	100	121	3.8	77.5
Tuesday	100	100	34.3	19.7	2.3	48.5	65.9	100	100	71.7	4.6	76.3
Wednesday	100	100	39.7	24.3	1.9	63.1	65.5	100	100	99.4	3.6	68.1
Thursday	100	100	87.0	44.9	2.6	65.8	100	100	100	94.1	4.6	76.8
Friday	100	100	100	38.0	2.3	63.6	61.0	100	100	75.9	2.9	56.3
Saturday	100	100	90.8	3º0.0	2.2	57.7	53.2	100	86.3	90.5	4.6	80.0
Sunday	100	100	90.8	28.0	18.1	52.7	55.6	100	98.2	94.0	3.8	74.7
Daily average	100	100	76.3	31.1	4.5	61.9	71.6	100	97.8	93.3	4.1	74.3

3.2. Carbon footprint of the Atlantic diet

3.2.1. Detailed analysis of carbon footprint for the designed menus

The estimation of GHG emissions (i.e., carbon footprint) corresponding to the menus designed following the recommendations of the Atlantic diet represents an absolute value of 21.04 kg CO_2eq per person and week, i.e., an average of 3.01 kg CO_2eq·person^{-1}·day^{-1}. This value is slightly higher (~5%) than that reported in the literature focusing on the assessment of the Mediterranean dietary pattern, the most widespread diet in Spain (Castañé and Antón, 2017; Muñoz et al., 2010) and with characteristics similar to those of the Atlantic. The rationale behind that difference is mostly associated with differences on the dietary patterns as well as with the consideration of refrigeration process at households within the system boundaries, which was excluded from analysis by Castañé and Antón (2017) and which adds to 0.23 kg

CO_2eq·person^{-1}·day^{-1}. Considering the same system boundaries, the AD presents a carbon footprint around 8% lower than the corresponding to the Mediterranean one (2.86 kg CO_2eq·person^{-1}·day^{-1}). The shift towards consumption of fish and fresh products (seasonal food) with limited cooking is behind this difference.

Through a more detailed assessment of the factors responsible for the carbon footprint of the AD, the production of the different food products is identified as a hot spot followed by household (cooking and refrigeration) and transport activities. Contributions from the production stage account for approximately 78% of total GHG emissions, with the remaining 22% is split between the household stage (92%) and transport activities (8%). Figure 6 displays the carbon footprint per day, as well as the distribution between the stages included in the analysis (food production, household and transport).

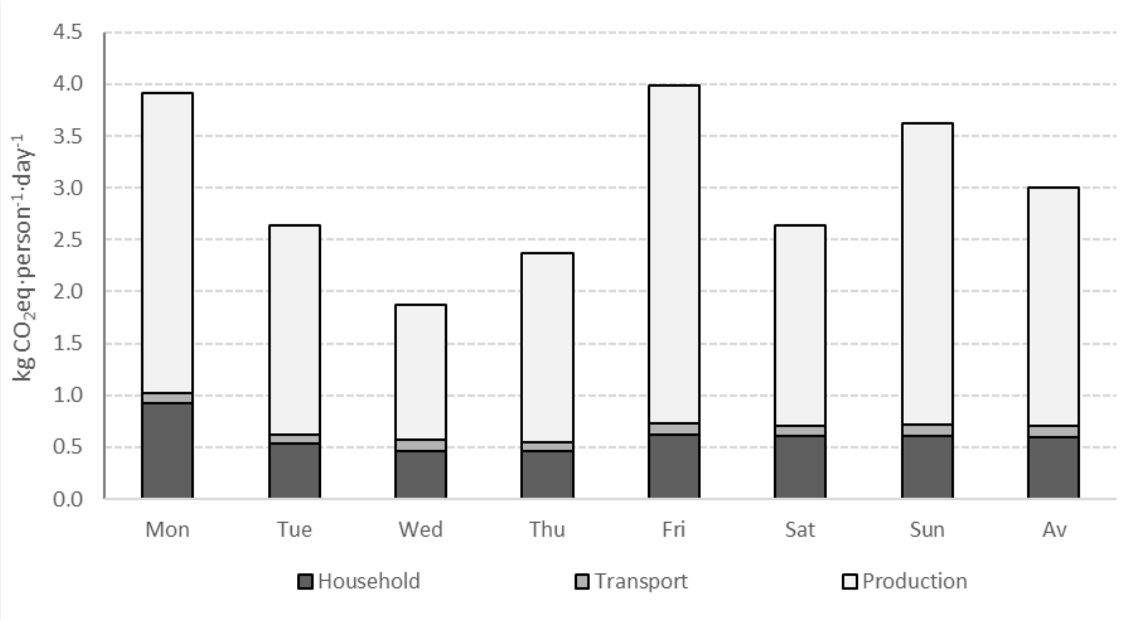

Figure 6. Daily carbon footprint (in kg CO_2eq·person^{-1}·day^{-1}) taking into account the distribution between food production, transport and household stages.

Regarding the stage of food production (with an average of 2.31 kg CO_2eq·person^{-1}·day^{-1}), it includes all the background activities carried out in the field and on the farm as well as the corresponding industrial processing, if necessary. According to Figure 7, meat and dairy production (livestock-based items) is primarily responsible for GHG emissions at this stage (26% and 30%, respectively). Moreover, both food categories are primarily responsible for variations in the carbon footprint between different daily diets. Looking more closely at the contribution of meat production, red meat accounts for 23%, followed by white meat (1.6% pork and 1.4% chicken, respectively).

In contrast, vegetables and fruits are low-carbon food categories (see Table 1 of SM) but consumed in major shares in the Atlantic diet. Therefore, both categories report contributions of 8% of total GHG emissions from the food production stage.

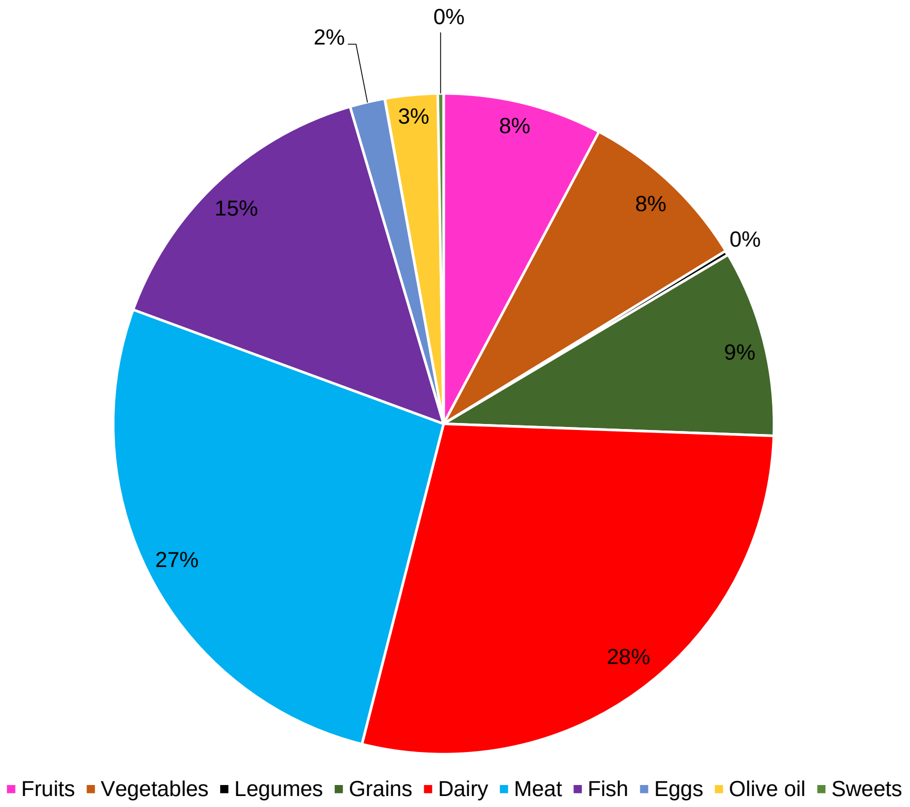

Figure 7. Relative distribution of GHGs emission from food production stage between the food groups involved in the designed 7-day menu.

The remarkable effect on the carbon footprint of livestock products has been highlighted by numerous studies, including those focusing on very different dietary patterns such as Spanish, Peruvian, Western European, American, British and French (Castañé and Antón, 2017; Coelho et al., 2016; Muñoz et al., 2010; Pimentel and Pimentel, 2003; Sáez-Almendros et al., 2013; Scarborough et al., 2014; Vázquez-Rowe et al., 2017). Both products are an important source of protein and energy, and their production involves resource-intensive activities (e.g., fodder production and agricultural activities), as well as methane emissions from rumiant enteric fermentation.

The seafood category has an outstanding contribution (15% of the total). This contribution is directly related to the remarkable consumption of fish in the Atlantic diet (Vaz Velho et al., 2016) despite reporting moderate rate of GHG emissions per kg of product (see Table 1 of SM). Grain products such as cereals and bread are basic products of the Atlantic food pyramid and their contributing ratio rises to 9%.

In terms of GHG emissions from household activities, the total energy required for the 7-day menu is about 33 MJ per week and person split between cooking (60%) and refrigeration (40%). Energy consumption in cooking activities is slightly lower than that of Castañé and Antón (2017), i.e., 30 MJ for the Mediterranean diet. In this sense, the abundance of fresh food products in the Atlantic diet makes complex cooking processes unnecessary, and therefore, implies low energy requirements for cooking. Taking into account the distribution of the carbon footprint among the contributing stages (see Figure 6), there are no significant differences in the average energy consumption for household activities regardless of the designed daily diet, as shown in Figure 6. The consideration of only boiling, frying and baking as the main cooking processes in the analysis -as recommended by the Atlantic diet- is also responsible for these negligible differences between the daily menus with regard to the household stage. Boiling and frying (the most common daily cooking methods) report similar energy requirements (~0.75 MJ per meal and person, on average). For baking, it is considerably higher, about 4.1 MJ per meal and person.

Finally, the contribution of the transport stage to the global carbon footprint can be considered negligible since it represents less than 2% of the total (on average) with 0.70 kg $CO_2eq \cdot week^{-1} \cdot person^{-1}$. As far as the origin of food is concerned, Galician products have the lowest GHG emissions due to the shorter distribution distances by lorry. Products of foreign origin are distributed by sea freighter and/or lorry. Maritime transportation does not report outstanding contributions to the carbon footprint despite long distances. Once again, road transport is the main contributing factor to the carbon footprint (five times more than maritime transport).

3.2.2. Comparison with results from literature

Numerous studies available in the literature were developed with regard to the environmental assessment of human diets where special attention was paid to the estimation of the carbon footprint (Castañé and Antón, 2017; Coelho et al., 2016; Notarnicola et al., 2017; Pairotti et al., 2015; Pernollet et al., 2017; Röös et al., 2015; Saxe et al., 2012; Scarborough et al., 2014; Vázquez-Rowe et al., 2017). All these studies highlight the limitations of the analysis in the absence of an established methodology and data. The focus on the carbon footprint is based on the availability of data and the awareness of society to avoid anthropogenic GHG emissions to prevent climate change (Rockström et al., 2009). The comparison between our results for the Atlantic diet and those available in the literature for other types of dietary patterns (e.g., Mediterranean, average European, average Spanish, German, Swedish, French, vegan, vegetarian, Nordic, among others) is complex because the results depend on a wide variety of factors and hypotheses.

The number of calories that an average person needs on a daily basis depends on several factors, such as minimum and average dietary energy requirements (Vázquez-Rowe et al., 2017), level of activity, gender, age, weight, geographical location and cultural aspects (EFSA, 2009). Therefore, the range of energy requirements per capita identified in the literature varies from 1,702 kcal·person^{-1}·day^{-1} in Indian diets (Pathak et al., 2010) to 3,596 kcal·person^{-1}·day^{-1} in Western European countries (Tukker et al., 2011). The daily energy intake recommended by the Panel on Dietetic Products, Nutrition and Allergies (EFSA, 2009) is 2,000 kcal·person^{-1}·day^{-1} in European countries. It falls in half the range for a moderately active woman (1,625-2,400 kcal·person^{-1}·day^{-1}), which is consistent with the values recommended in other countries such as the United States, Australia and New Zealand, as well as by the European food industry (EFSA, 2009). According to experts, this value (2,000 kcal·person^{-1}·day^{-1}) is more consistent with dietary advice for the general population compared to men (2,200-2,300 kcal·person^{-1}·day^{-1}). Therefore, the value set in our study (2,100 kcal·person^{-1}·day^{-1}) could be considered representative for the assessment and coincides with other relevant studies available in the literature (Castañé and Antón, 2017; Collins and Fairchild, 2007; Peters et al., 2007; Sáez-Almendros et al., 2013; Scarborough et al., 2014).

Therefore, in order to compare the carbon footprints of different dietary scenarios or patterns, the results should be expressed on the basis of the so-called functional unit, in this case, the average energy requirement per person and day. Thus, only the isocaloric diets available in the literature in the range of 2,000-2,100 kcal·person^{-1}·day^{-1} have been considered for comparative analysis of the carbon footprint. This range can be assumed since diets use realistic amounts of food (see Table 1) and it is complex to fix the energy to an identical number.

Consideration of that unit can be used to estimate the change in GHG emissions that would result from changing dietary patterns without modifying the dietary energy intake, which should be more relevant when considering the potential impact of dietary change diets on GHG emissions. According to the CF values depicted in Figure 8, the results obtained for the Atlantic diet (Scenarios A and A1-A7) of 3.01 kg CO_2eq·person^{-1}·day^{-1} (on average) are comparable to the values found in other studies focusing on the estimation of this environmental impact for Spanish diets such as Castañé and Antón (2017) (Scenarios B and C) and Sáez-Almendros et al. (2013), who reported about 2.86 and 2.19 kg CO_2eq·person^{-1}·day^{-1}, respectively, for the Mediterranean dietary pattern. Both types of diets are conceived as healthy and are essentially very similar. However, there are two remarkable differences between them, namely: i) the promotion of fish as the main foodstuff[2] and ii) the high intake of red meat and pork in the Atlantic one. However, attention must be paid to the system boundaries. Sáez-Almendros et al. (2013) considered the same system boundaries as in our study but excluding only refrigeration at households. However, Castañé and Antón (2017) excluded not only home storage but also retailing from the analysis as they considered it irrelevant to global GHGs emissions.

The results of the Atlantic diet are not similar to those reported by Sáez-Almendros et al. (2013) for the current Spanish diets, based on food balances and consumption surveys (Scenarios E and F, 7.76 and 4.39 kg CO_2 eq·person^{-1}·day^{-1} respectively). These remarkable results are directly related to the source of information considered for the estimation of the carbon footprint. In both cases, diets were based on food consumption/purchase data and not on recommended intake values. Regarding the scenario considering the typical Western dietary pattern (Scenario G), the worst environmental outcomes were reported. Consideration and

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[2] http://www.fundaciondiabetes.org/

promotion of the Atlantic diet would substantially reduce GHG emissions by up to 4.5 times. Excessive consumption of animal products, such as meat and dairy products, is primarily responsible for contributions to GHG emissions due to the high impact of livestock production. The Western dietary pattern is characterised by the outstanding presence of meat and dairy products, up to 8 and 4 times –respectively, higher than in other dietary patterns such as the Mediterranean one (Sáez-Almendros et al., 2013).

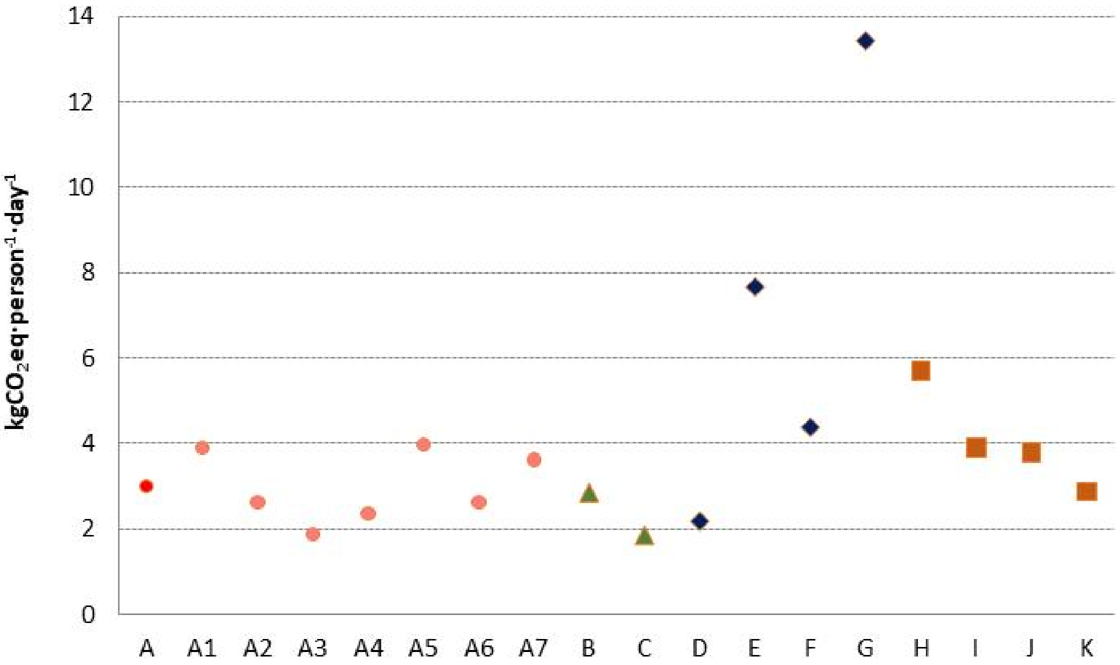

Figure 8. Carbon footprint scores for the different diet scenarios considered for comparison. Acronyms: A – average Atlantic diet; A1-A7 – designed daily Atlantic diets; B and C from Castañé and Antón (2017); D, E, F and G from Sáez-Almendros et al. (2013); H, I, J and K from Scarborough et al. (2014).

For the values proposed by Scarborough et al. (2014), the meat-rich diet reported the worst carbon footprint score. Fish-rich and vegetarian diets reported similar scores (3.90 and 3.80 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$). The vegan diet score is closing similar to those for the Atlantic and Mediterranean diets. Therefore, according to scientific literature, the presence of food products of animal origin in the dietary pattern contributes significantly to increasing GHG emissions, which demonstrates the positive relationship between dietary CF and the ratio of animal based products.

Moreover, attention must be paid to the quality of data sources and system boundaries definition. In our estimation, household stage includes not only cooking but also refrigeration. Several studies available in the literature remark the outstanding contribution from energy use in household storage to the global carbon footprint of a dietary choice (Berlin and Sund, 2010; Heller et al., 2013; Muñoz et al., 2010; Sáez-Almendros et al., 2013). However, other authors (Castañé and Antón, 2017), excluded this cold storage from analysis. According to our results, refrigeration at household is close to 10% (in average), being an important hot spot in the carbon footprint. The exclusion of this factor from the system boundaries should derive into an average carbon footprint of 2.78 $kgCO_2eq \cdot person^{-1} \cdot day^{-1}$ for the Atlantic diet being this value under the one estimated for the Mediterranean diet by Castañé and Antón (2017). Regarding data quality, the way in which foodstuffs are produced, cultivated or farmed potentially affects GHG emission (González-García et al., 2018). Thus, the definition of both system boundaries and food production strategies are issue which require special attention mostly if the carbon footprint profiles are going to be compared between dietary choices as well as in decision making strategies

As final recommendations to moving dietary patterns towards more environmentally sustainable ones, the following actions should be taken into consideration:

- Promote the reduction of meat and dairy products by increasing consumption of plant based products
- Promote the consumption of local and seasonal products, which should lead to a reduction in transport activities and management, respectively
- Reduction of red meat intake by consuming white meat such as chicken and pork
- Social campaign (cultural training, special taxes for ecologic products, …) to promote the benefits of environmental sustainable diets.

4. Conclusions

According to the main findings reported in this study, the Atlantic diet can be considered beneficial not only from a health, but also from an environmental perspective due to the significant consumption of fish and plant based products compared to other dietary patterns richer on livestock products. Moreover, the characteristics of the Atlantic diet, based on promoting the consumption of seasonal, fresh and local products, home-made cooking and low-processed foods also contribute to its low carbon footprint. In this sense, it can be considered as a sustainable diet as defined by FAO, since it has a low environmental impact and contributes to food safety and quality (FAO, 2010).

In terms of contributions to the carbon footprint, the food production stage is primarily responsible for GHG emissions, followed by the cooking stage and transport activities. Meat, dairy and fish products have the highest individual footprint, especially cheese and beef, although their quantities consumed are not as important as other foods such as vegetables or fruits, which are considered basic foods in the recommended Atlantic diet. With regard to the nutritional quality, daily diets with higher NRD9.3 scores should be promoted since they are linked to lower intake of total protein and animal based products. According to our results, daily diets with higher values of AP are associated with higher GHGs emissions. In this way, the possibility of a change in the direction of a lower consumption of animal protein is related with more sustainable diets, as mentioned in several studies in many countries (Perignon et al., 2016).

The total carbon footprint of the diet could be reduced by minimizing the intake of livestock products in agreement with other studies. Thus, even though the ingested quantities of meat and dairy products are not very high in the Atlantic pattern, they could still be reduced, being compensated for by the intake of plant origin protein. The increase in the nutritional quality together with the improvement of the carbon footprint associated to the shift of protein intake from animal to vegetable origin needs to be analysed in more detail.

Although this study focuses on outlining a designed Atlantic diet, following recommendations, future researches should take into account the current consumption trends of the region, with the same purpose of linking the environmental and nutritional quality, but under real consumption conditions, which could be compared with the results from this study. In addition, it would be interesting to include socioeconomic variables, relating them to those mentioned above.

Further research should pay attention to how to communicate environmental and nutritional dietary information that is attractive and valuable to consumers. The design of labels or logos could be considered as a strategic solution to promote sustainable food consumption, but comprehensive educational programs must be developed.

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