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Driving commitment to sustainable food policies within the framework of American and European dietary guidelines

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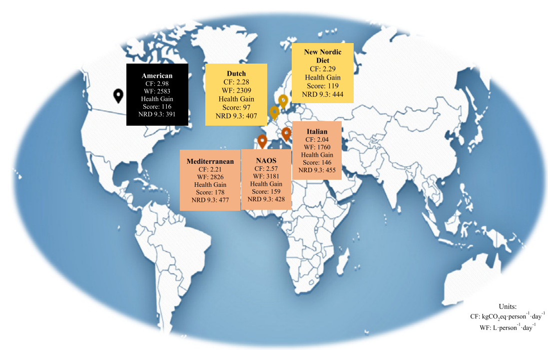
HIGHLIGHTS

- European and American dietary guidelines have been revised from a nutritional and environmental point of view.
- The most plant-rich dietary guidelines (Italian and Mediterranean) were the best in terms of carbon footprint.
- The water footprint showed variations associated with the climate and production systems of the reference countries.
- The Mediterranean Diet in the Spanish context was the best in terms of nutritional value.
- The lowest overall nutritional scores corresponded to the Dutch and American Dietary Guidelines.

GRAPHICAL ABSTRACT



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ABSTRACT

Diet and nutrition are essential factors in promoting good health throughout life. Their role as determinants of chronic non-communicable diseases is widely recognized. Additionally, the demand for food involves relevant environmental burdens that have to be taken into account on the way to achieving the Sustainable Development Goals. As an important part of nutrition policy, food-based dietary guidelines (FBDGs) have been revised. The key question is: Are environmental considerations being incorporated into them? To address this issue, we modeled and compared both the main environmental indicators in terms of carbon footprint (CF) and water footprint (WF), and nutritional quality (according to the Nutrient Rich Diet index, NRD9.3 and a health gain score) of dietary guidelines from Northern and Southern Europe and America. Particularly, the FBDGs compared were Dutch Dietary Guidelines (DDG), New Nordic Diet (NND), Spanish Strategy for Nutrition, Physical Activity and Obesity Prevention (NAOS), Mediterranean Diet (MD), Italian Dietary Guidelines (IDG) and American Dietary Guidelines (DGA).
The IDG and MD offered the best profiles from a climate change perspective (2.04 and 2.21 $kgCO_2eq \cdot day^{-1}$). Overall, DGA had the highest CF (2.98 $kgCO_2eq \cdot day^{-1}$). WF presented greater fluctuations, not only due to daily-recommended amounts, but also because of different climate conditions and production systems of the reference countries. Hence, WF ranged from 1760 $L \cdot person^{-1} \cdot day^{-1}$ in IDG to 3181 $L \cdot person^{-1} \cdot day^{-1}$ in NAOS. Finally, the nutritional value of MD, which had the highest NRD9.3 (477) and health gain score (178), has been demonstrated when the comparison was made with DDG, the one with the lowest health gain score (97) and DGA, the worst in terms of NRD9.3 (391).
To go ahead of the FBDGs that bet on all dimensions of sustainability, multi-criteria analysis is needed. Nutrition and environmental performance are not the only aspects of the problem; economy and sociocultural variables should be considered.
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1. Introduction

A strong scientific basis supports the fact that moving towards reciprocal dietary patterns that are not only healthy, but also sustainable, is affordable and wise (EAT-Lancet Commission, 2018). Governments can reinforce their commitment to a green and healthy future by striving to keep pace with the demand for dietary patterns in line with this integrated approach (Birt et al., 2017). Despite the growing evidence of data, only 83 out of 215 countries issued dietary recommendations, mainly focused on the health dimension (EAT-Lancet Commission, 2018). Therefore, research on the extent to which environmental issues are being incorporated into national food-based dietary guidelines (FBDGs) is a matter of major interest (Herforth et al., 2019; Springmann et al., 2020).

In the European Region, more than half of adults are affected by weight problems and obesity (European Commission, 2020a). Furthermore, non-communicable diseases - including cardiovascular diseases, cancer, diabetes and obesity - cause 70% of all deaths and 70–80% of healthcare costs in the European Union (European Commission, 2020a). Moreover, 20–30% of the total environmental impacts of household consumption is associated with food consumption (Tukker et al., 2006). Therefore, a change in food systems is needed. The FOOD 2030 initiative, in line with the European Green Deal, the Farm to Fork strategy and the bio-economy strategy, embraces this transformation with the ambition to achieve the following goals: promotion of sustainable healthy diets, circularity and resource efficiency, innovation and empowerment of communities (European Commission, 2018a, 2018b, 2019, 2020b).

FOOD 2030 highlights as an enabler of change the development of FBDGs for healthy, balanced and sustainable nutrition (European Commission, 2020a). These guidelines, such as the Linee guida per una sana alimentazione (CREA, 2019) in Italy, the Dutch dietary guidelines (Health Council, 2015) in the Netherlands or the Strategy for Nutrition, Physical Activity and the prevention of obesity - NAOS strategy in Spain (Neira and Onis, 2006), support consumers to make better food choices taking into account their cultural preferences, eating habits and food availability. In the United States, as in European countries, the Department of Health and Human Services (HHS) and the Department of Agriculture (USDA) jointly published the Dietary Guidelines for Americans, which have been updated every 5 years since they were first published in 1980. The latest edition, in addition to the goal of promoting health and preventing chronic diseases, marked for the first time the nutritional needs by all stages of life, from childhood to old age (USDA and HHS, 2020).

Therefore, FBDGs are an attempt to establish a framework for food and nutrition services, public health, agricultural policies and consumer education to promote healthy eating habits and control diet-related diseases (FAO, 2021; WHO, 2014). This analysis brings additional insight to the literature in three areas of this field of study. First, to date, few studies focus on quantifying the environmental burdens of different FBDGs worldwide, mainly in terms of GHG emissions. For instance, Kovacs et al. (2021) modeled the carbon footprint (CF) of the dietary guidelines from Germany, India, the Netherlands, Oman, Thailand, Uruguay and the United States. In another study, Behrens et al. (2017) provided a comparison between 37 dietary recommendations from middle- to high-income nations in terms of greenhouse gases (GHG) emissions, eutrophication and land use.

However, it is relevant to identify other environmental metrics, not as extensively studied for national-level FBDGs, such as water consumption. This paper incorporates the water footprint (WF) indicator by following the initial path marked by other authors who included the analysis of WF related to food consumption. In this line, Blas et al. (2016) assessed the WF of two one-week menus based on an earlier version of the American guidelines (USDA, 2016) and on the study by Haven et al. (2015). Vanham et al. (2018) found geographical differences between the water consumption values of the French, German and UK dietary recommendations and González-García et al. (2020) evaluated, among other metrics, the WF of the NAOS, Mediterranean Diet (MD) and the Atlantic diet.

Second, several studies have been undertaken on the CF assessment of previous versions of national dietary guidelines. Therefore, Van Dooren et al. (2014) examined the GHG and land use (LU) of the 2006 version of the recommended Dutch Dietary Guidelines (Health Council, 2006) or Pairotti et al. (2015) explored the energy consumption and GHG emission of the MD in the Italian scenario (Ministero della Salute, 2004). This study calculates the CF of the most updated versions of the dietary guidelines.

Third, we identify synergies between the nutritional, health and environmental outcomes of the European and American guidelines. Although the closely connection between these areas is central to the progress of the Millennium Development Goals, the Sustainable Development Goals and the Decade of Action on Nutrition (Willett et al., 2019), it has not yet been fully developed in the scientific literature. For the inclusion of nutritional and health information, stakeholders need appropriate metrics such as the Nutrient Rich Dietary score-NRD9.3 (Van Kernebeek et al., 2014) or the health gain scored (Van Dooren et al., 2014). Both are two nutrient-derived metrics, which can be used in a complementary way. They are based on different nutrients whose intake should be promoted (e.g., protein or fibre) and limited (e.g., saturated fatty acids or free sugars). The health gain score also considers food and energy intake (Van Dooren et al., 2014).

The aim of the present work is to analyse for the first time the CF and WF and the nutritional aspects (in terms of two nutritional indexes, NRD 9.3 and a health index) of the FBDGs of three representative regions: Northern Europe, Southern Europe and North America. For a broader perspective, several representative dietary guidelines from these geographical areas have been selected: the Dutch dietary guidelines 2015 (DDG), the Italian dietary guidelines 2016 revision (IDG), the dietary guidelines for Americans 2020-2025 (DGA), the NAOS strategy in Spain, the New Nordic Diet (NND) and the Mediterranean Diet (MD). This analysis can be considered a step forward on the road to the development of dietary guidelines that incorporate health and sustainability aspects and meet the nutritional needs of consumers.

2. Materials and methods

2.1. Scope of the food-based dietary guidelines

The scope of this research is focused on Western world, where the modern Western dietary pattern has gained much popularity recently, increasing the incidence of obesity, cardiovascular diseases, cancer or metabolic syndrome among the population, while threatening planetary health. America and Europe were the two geographical regions that were chosen as the study framework. For convenience, we classified the European dietary guidelines into two sub-regions: Northern Europe and Southern Europe. Countries classified as Western Europe according with the United Nations geoscheme classification, such as The Netherlands, were included in the Northern Europe region in this study.

2.1.1. America

2.1.1.1. Dietary Guidelines for Americans 2020-2025 - DGA. The National Nutrition and Related Research Surveillance Act 1190, the USDA and the HHS require the publication of the DGA at least every five years. The 2020–2025 edition was built upon the 2015 edition but incorporate new aspects in parallel with evolving scientific and medical knowledge. For instance, DGA address the general public, regardless of their health status; they emphasize the importance of following a healthy dietary pattern as a whole, rather than individual foods or nutrients; and finally, they also identify nutritional needs from a life-cycle approach. Therefore, the nutritional goals and amounts of each food group considered in this study are based on this latest version (USDA and HHS, 2020).

According to this version, a healthy dietary pattern is based on nutrient-rich foods and beverages from all food groups, including staple food such as vegetables of all types, fruits, grains, dairy, protein foods and oils. The United States was chosen as the reference country. Detailed information on the technical description of the dietary scenario designed is shown in the Supplementary Material 1 (Tables SM1.1-SM1.11).

2.1.2. Northern Europe

2.1.2.1. Dutch Dietary Guidelines 2015 - DDG. The Dutch Health Council periodically publishes the DDG, which are the product of the dietary research on the relationship between diet and its health gains. The first version of the guidelines was published in 1986 and provided advice only in terms of nutrients. Food recommendations were included in the second version in 2006. The third comprehensive assessment was released in 2015. This last report also reflects the scientific developments on the dietary patterns available to consumers (Health Council, 2015). These guidelines bet on: Eat more plant-based and less animal-based food; incorporate fruits, vegetables, wholemeal bread, nuts, few portions of dairy and three cups of tea to daily eating plan; consume legumes and fish weekly; promote whole-grain products, as well as, liquid cooking fats and vegetable oils; limit the consumption of red meat, sugary drinks, salt and alcohol.

However, the recommendations are rather broad and qualitative and, in many cases, do not prove to specify quantities ("eat legumes weekly", "limit consumption of red meat, in particular processed meat"). Therefore, to provide practical recommendations on daily intake per food groups for the consumer, further development of guidelines is needed. In this study, the development of the DDG by Brink et al. (2019) was considered as a reference. The detailed description of the methodology for the estimation of the recommended average daily intake per food group and foodstuff was displayed in Supplementary Material 1 (Tables SM1.1-SM1.11).

2.1.2.2. New Nordic Diet - NND. Inspired by the MD, NND emerged in 2004 within the Danish project OPUS (Optimal well-being, Development and Health for Danish children through a healthy New Nordic Diet) under the principles of health, gastronomic potential, Nordic identity and sustainability (Jensen and Poulsen, 2013; Meltzer et al., 2019; Mithril et al., 2012). The NND is a heuristic concept that combines the FBDGs of the five Nordic countries that collaborated on the long-term Nordic Nutrition Recommendations with typical products from the Nordic regions (Meltzer et al., 2019). Mithril et al. (2012) outlined their basic guidelines: i) more calories from plant foods and fewer from meat; ii) more food from the sea and lakes; iii) more food from the wild countryside. Supplementary Table SM1.12 shows the average-daily recommended intake and the carbon footprint per foodstuff for New Nordic Diet.

2.1.3. Southern Europe

2.1.3.1. Italian Dietary Guidelines 2018 (Linee guida per una sana alimentazione) - IDG. For more than three decades, guidelines for a healthy diet have been available to Italian consumers (the first edition was published in 1986). They summarize technical-scientific information focused on the food sector and practical recommendations for adults to organize their daily diet in the most balanced and varied way possible. The latest version of the Council for Agricultural Research and Economics (CREA) under the auspices of the Ministry of Agriculture, Food and Forestry was published in 2018 (CREA, 2019). Its principles are: i) stay active and maintain a healthy weight; ii) consume more fresh fruits and vegetables daily; iii) eat bread, pasta, rice and other grains (preferably whole grains) regularly; iv) drink plenty of water daily; v) moderate the amount of fats and oils for seasoning and cooking; and vi) limit the consumption of sugary foods, salt and alcoholic beverages. For details of the Italian case study design, see Supplementary Material 1 **(Tables SM1.1-SM1.11)**.

2.1.3.2. Strategy for nutrition, physical activity and the prevention of obesity - NAOS strategy in Spain. NAOS, in line with the policies of the World Health Organization (WHO) and the European Union, is a health strategy to reverse the trend in the prevalence of obesity. It was launched in 2005 and in 2011 it was consolidated by the Law 17/2011 on food safety and nutrition.[1] Its motto is based on the following statement: Eat healthy and move. In the latest update of the dietary recommendations for the Spanish population, the Spanish Agency of Food Security and Nutrition (AESAN) encompassed both human health and planetary sustainability (Neira and Onis, 2006). The detailed case study considered for NAOS regarding average daily-recommended country intake was taken from González-García et al. (2020).

2.1.3.3. Mediterranean diet - MD. The MD is a traditional plant-based diet typical of the olive-growing regions of the Mediterranean basin (Trichopoulou and Vasilopoulou, 2016), including France, Greece, Italy and Spain. It has been designed as an Intangible Cultural Heritage by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and as a healthy and nutritious diet by the Food and Agriculture Organization (FAO), for its proven health benefits (Azzini and Maiani, 2015). It was associated with the prevention of a wide variety of diseases such as cardiovascular (Martínez-González et al., 2019), neurodegenerative (Gardener and Caunca, 2018), inflammatory diseases (Casas et al., 2014), metabolic syndrome (Babio et al., 2009) and cancer (Mentella et al., 2019). The detailed scenario for MD was taken from González-García et al. (2020).

2.2. Assessment of environmental impacts, including quantification of water and carbon footprint

Food production is a major contributor to environmental change: more than one third of GHG emissions and two thirds of freshwater use come from the food sector (Grosso et al., 2020). Hence, there is a broad consensus that responses to these sustainability challenges should be addressed simultaneously (White et al., 2014). In this sense, addressing the dynamics of WF and CF from a joint approach for global dietary patterns has attracted global attention (Cambeses-Franco et al., 2021; Cao et al., 2020; Green et al., 2018; Pairotti et al., 2015).

For the estimation of the CF, a life cycle approach was considered. As the main objective of the study is to compare dietary patterns, it is convenient to consider only GHG emissions associated with the production of food ingredients. Actually, the production stage is by far the largest contributor to GHG emissions in FBDGs (Castañé and Antón, 2017; Esteve-Llorens et al., 2019a). CF scores for each foodstuff were taken from literature. Depending on the source, cradle-to-farm, cradle-to-factory gate or cradle-to-port gate were considered as system boundary.

Transport, household tasks and waste treatment were removed from the system boundaries due to fluctuations between data from different countries (Heller et al., 2013). The functional unit selected for this analysis was the average daily dietary reference intake per individual. Furthermore, despite variations across countries, the recommended average daily energy intake per day for a European citizen was about 2500 and 2000 kcal·person^{-1}·day^{-1} for men and women, respectively (European Commission, 2018c). Considering that environmental impact assessments of NAOS and MD were referred to a Spanish middle aged woman with a recommended energy intake of 2228 kcal·person^{-1}·day^{-1} (EFSA, 2017; González-García et al., 2020), the energy values of diets analysed in this study were adjusted to this value of reference for comparison purposes.

The WF was calculated following the first two steps (goal and scope and accounting) of the four-phase of the Water Footprint Assessment (WFA) methodology (WFN, 2020). The WF represents the amount of freshwater used to produce a product throughout the production cycle

[1] https://www.boe.es/boe/dias/2011/07/06/pdfs/BOE-A-2011-11604.pdf (accessed July 2021).

of the supply chain (Muthu, 2020) and is broken down into three components: green (rainwater), blue (surface and groundwater) and grey (freshwater required to assimilate the pollutant load) (Pal, 2017).

Mekonnen and Hoekstra (2011, 2012) explicitly estimated the three components of WF for farm animal products, crops and derived crops products by country. These two scientific papers were used as a reference database for the WF quantification of all foodstuffs included in the diets, excluding fish and seafood products. While for aquaculture products this metric was calculated according to the WF of their corresponding commercial aquafeed (Pahlow et al., 2015), for wild fishery products a WF of zero was considered (Blas et al., 2019; Harris et al., 2017). Climate, soils and production conditions make it necessary to consider the spatial variable for WF estimation (Mekonnen and Hoekstra, 2011, 2012). The methodology described by González-García et al. (2020) was followed in detail to calculate the average percentages of domestically produced and imported food. The open-access database Datacomex (Ministerio de Economia, 2019) and data from the USDA (2019) were used to find detailed information on import and export trade statistics for Europe and America, respectively. Detailed information on export volumes, import volumes, main importing countries and the percentage produced domestically and imported per foodstuff and country is collected in Supplementary Material 2.

2.3. Assessment of the nutritional quality of diets, including quantification of the nutrient rich diet (NRD9.3) and estimation of the health gain score

Poor diet quality is the leading cause of health problems worldwide (Miller et al., 2020). The United Nations Sustainable Development Goals outline a global commitment to achieve several nutrition goals by 2030, as well as, to tackle undernutrition and hunger (UNSD, 2017). In order to advance global progress on these goals, dietary quality metrics are needed to ensure dietary diversity and nutrient adequacy. Therefore, the nutritional quality of diets was analysed using the NRD9.3 (Van Kernebeek et al., 2014) and the health gain score (Van Dooren et al., 2014) in a complementary way.

The NRD9.3 is based on the principles of the Nutrient Rich Food 9.3 (NRF 9.3.) and reflects the nutritional quality of a diet. NRD 9.3 consists of a total of nine qualifying nutrients (protein, calcium, fibre, magnesium, potassium, iron, vitamin A, vitamin C, vitamin E) and three disqualifying nutrients (sodium, saturated fatty acids and added sugar) (Van Kernebeek et al., 2014). The NRD9.3 score of a diet was calculated with Eq. (1).

$$NRD9.3 = \left(\sum_{i=1}^{i=9} \frac{nutrient_{i,capped}}{RDV_i} - \sum_{k=1}^{k=3} \frac{nutrient_k}{RDV_k}\right) \cdot 100 \quad (1)$$

where $nutrient_i$ is the daily intake of the qualifying nutrient i in the diet, $nutrient_k$ the daily intake of the disqualifying nutrient k in the diet, and RDV_i, RDV_k the recommended daily values of nutrients i and k, respectively. It is worth mentioning that an average value was considered when the RDV fall between two values.

The recommended daily values of the nutrients were established according to the average requirements (AR), population reference intakes (PRI), reference intake ranges (RI) and tolerable upper intake levels (UL) established by EFSA (2021). The dietary reference intakes (DRI) issued by the Food and Nutrition Board of the Institute of Medicine (NIH, 2021) and the United States Department of Agricultures (USDA) were also used for cases where EFSA did not give quantitative recommendations (for details, see Supplementary Table SM1.13).

On the other hand, the health gain score developed by Van Dooren et al. (2014) is also a nutrient-derived metric, although it also includes three food groups (vegetables, fruits, and fish) and daily energy intake from free sugars, saturated and total fatty acids, and carbohydrates. Like NRD 9.3, it contains nutrients to score, such as fibre, and nutrients to limit, such as total fatty acids, free sugars or sodium (see Eq. (2)). For this metric, the nutrient goals reported by EFSA (2017), WCRF (2020) and WHO (2020) was taken into account, as can be seen in Supplementary Table SM1.13.

$$\{Health\ index = \left(\frac{g\ veg}{200} + \frac{g\ fruit}{200} + \frac{g\ fish}{37} + \frac{g\ fiber}{30} + \frac{6}{g\ sodium} + \frac{31.5}{E\%total\ fat} + \frac{10}{E\%free\ sugar} + \frac{9}{E\%sat.fat} + \frac{52}{E\%carbohydrates} + \frac{2228}{kcal\ energy}\right) \cdot \frac{100}{10} \quad (2)$$

3. Results and discussion

3.1. Composition of the food-based dietary guidelines

The daily recommended intake stood at 1.92, 1.58 and 1.96 kg·person^{-1}·day^{-1} for DGA, DDG and IDG, respectively. Their corresponding dietary energy supply was 2229, 2226 and 2226 kcal·person^{-1}·day^{-1}, respectively. Adjusting the caloric value of these three diets to 2228 kcal· person^{-1}·day^{-1}, allowed the comparison with the results of González-García et al. (2020) for NAOS and MD. Moreover, a normalization to the daily dietary intake established by Mithril et al. (2013) and used by Ulaszewska et al. (2017) in their assessment of diet-related GHG emissions for NND was made in order to include this diet in the benchmarking with other diets of 2228 kcal.

Differences in the contents of plant-based and animal source food can be found between the Northern European, Southern European and American guidelines. DGA are particularly rich in animal source foods (45% of the daily recommended intake) when the comparison was made with the Northern European dietary recommendations (36% and 34% of daily recommended intake for DDG and NND, respectively) and with Southern European Dietary Guidelines (31%, 19% and 28% for NAOS, MD and IDG, respectively). On the other hand, MD was the most predominantly plant-based diet (81% of the daily recommended intake). Plant based-foods sources (including fruits, vegetables, pulses, starch-based products, nuts and oils) were also the main focus of the other Southern European dietary guidelines, NAOS and IDG. The average contribution of each food category (%) to the average recommended daily intake for the diets is shown in Fig. 1 (for details, see Supplementary Table SM1.14).

3.2. Assessment of environmental impacts - quantification of carbon footprint

The GHG emissions of the DGA, DDG and IDG food guidelines were 2.98, 2.28 and 2.04 kg CO_2eq·person^{-1}·day^{-1}, respectively. Our results were in line with those reported for various recommended dietary patterns in Spain (NAOS), Mediterranean countries (MD) (González-García et al., 2020) and the Nordic Countries (NND) (Ulaszewska et al., 2017). The comparison between the dietary patterns was performed paying attention only to the production stage. Therefore, the additional stages of distribution to wholesalers and retailers, household consumption, and food losses and waste were eliminated from the results reported by González-García et al. (2020). On the other hand, the CF for NND was adapted to a cradle-to-gate approach considering the average intake reported by Mithril et al. (2013) standardized to 2228 kcal according to the methodology detailed in Ulaszewska et al. (2017). Beverages and daily allowance were discarded from the dietary composition of NND detailed by Mithril et al. (2013). To avoid inconsistencies in the comparison, the same data sources were used for the estimation of the GHG emissions of each foodstuff in all the diets analysed (see Supplementary Tables SM1.1-SM1.12). Despite the rigor of the study, and even taking into account this assumption is considered better for comparison purposes, it may mean a slight deviation of the results because the same LCA studies considered by González-García et al. (2020)

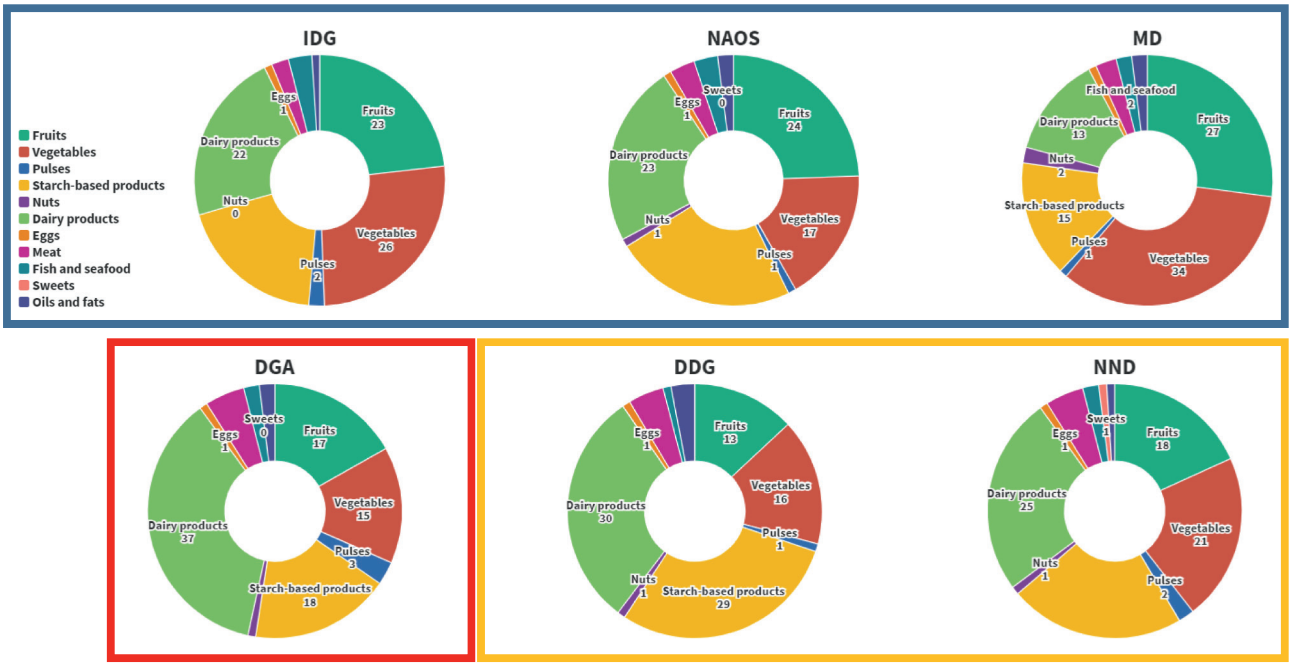

Fig. 1. Contribution of each food category (%) to the average daily recommended for Northern Europe (Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020–2025 - DGA.
Data for MD, NAOS and NND were taken from González-García et al. (2020), Ulaszewska et al. (2017) and Mithril et al. (2013).

were used and most of them take Spain as the reference location instead of considering a global perspective.

As can be seen in Fig. 2, DGA had the highest CF (2.98 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$) of the six dietary patterns. The CF of the DGA was about 1.5 times higher than that of the IDG, the country with the lowest GHG emissions (2.04 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$) and 1.3 times higher than that of MD (2.21 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$), the second lowest CF. The GHG emissions profiles of the Northern European dietary patterns were very similar.

Animal food sources accounted for 80% of CF for DGA, 69% and 61% for DDG and NND, 58% for IDG and MD, and 70% for NAOS. Dairy products were responsible for the highest emissions for the food-based dietary patterns in the three regions analysed, with the largest associated CF in DGA (1.19 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$) as can be seen in Supplementary Tables SM1.15. In general, meat was the second food category with the largest impact on global warming (between a range of 12% of GHG emissions for IDG and 34% of GHG emissions for DGA). Starch-based products also had a significantly impact in GHG emissions for all the nationally recommended diets, particularly for NND (0.45 kg $CO_2eq \cdot person^{-1} \cdot day{-1}$) and IDG (0.41 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$). For all the FBDGs the number of starch-based products consumed daily is high in comparison with other food categories. The inclusion of wholegrain cereals in the NND scenario and cereal breakfast in IDG explains the high CF results in this category for this two FBDGs. The highest fish and seafood intake in NAOS in comparison with the other FBDGs would result in a more significant CF in this food category (0.33 kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$). AECOSAN recommends the high intake of fish in NAOS due to its great protein richness and because it provides omega-3 fatty acids and other essential nutrients (Neira and Onis, 2006). Fig. 3 shows the breakdown of CF among food categories.

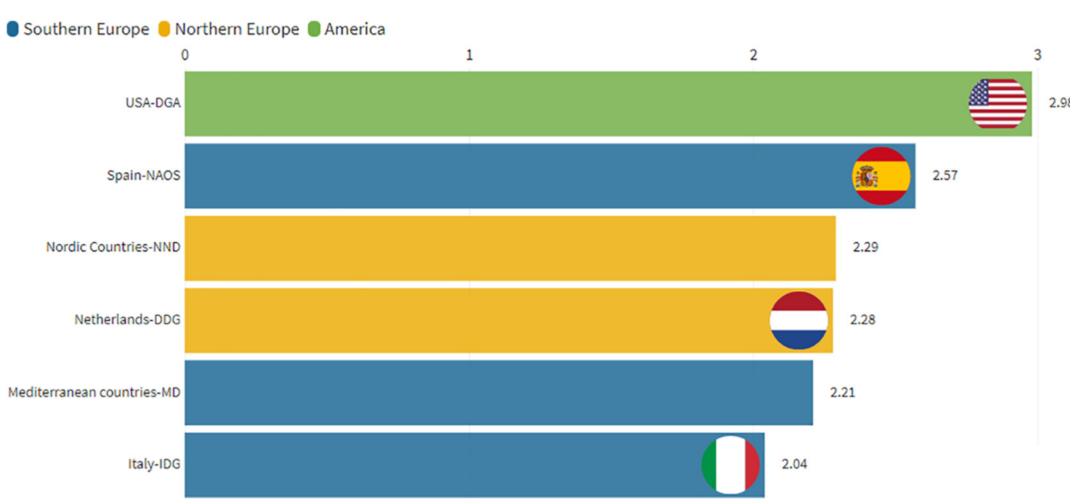

Fig. 2. Carbon footprint (kg $CO_2eq \cdot person^{-1} \cdot day^{-1}$) for Northern Europe (Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020–2025 - DGA. Data for MD, NAOS and NND were taken from González-García et al. (2020), Ulaszewska et al. (2017) and Mithril et al. (2013).

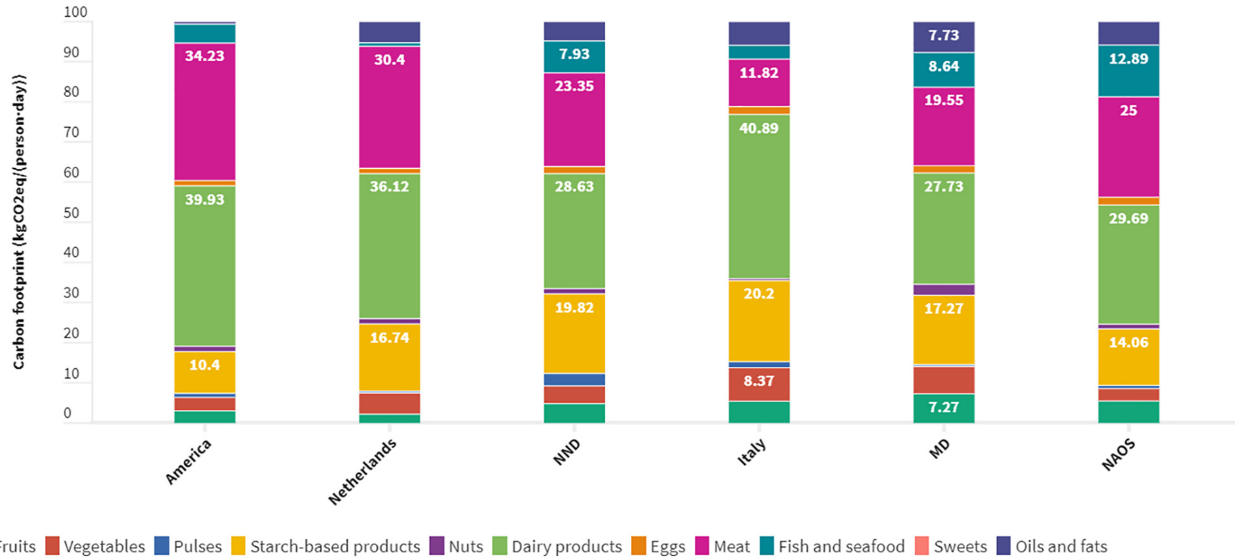

Fig. 3. Breakdown of carbon footprint (kg CO_2eq·person^{-1}·day^{-1}) between food categories for Northern Europe (Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020–2025 - DGA.
Data for MD, NAOS and NND were taken from González-García et al. (2020), Ulaszewska et al. (2017) and Mithril et al. (2013).

On the other hand, the GHG emissions derived from the fruit and vegetable categories that could be attributed to the country's dietary recommendations ranged from 7% of CF in DGA (0.19 kg CO_2eq·person^{-1}·day^{-1}) to 14% of CF in MD (0.32 kg CO_2eq·person^{-1}·day^{-1}). The great potential to drive up the GHG emissions attributed to dairy and meat products was not justified based on their recommended amounts in the nation-specific diets. Consumption of meat ranges from 2% of the total daily-recommended intake (g·person^{-1}·day^{-1}) in IDG to 5% in DGA. Moreover, even though dairy products were consumed in large proportions in the nationally recommended guidelines, their quantitative recommendations were still lower than those for fruits and vegetables together. These general trends can be explained with the fact that animal-based food production is more carbon intensive than plant-based food production, singularly for ruminants (Heller et al., 2018; Petrovic et al., 2015).

3.3. Assessment of environmental impacts- quantification of the water footprint

The WF varied depending on the country-specific recommended diet, although similar trends could be observed for all the countries analysed. Regarding the three nationally recommended diets analysed in this study, the dietary WF was 2583, 2309 and 1760 L·person^{-1}·day^{-1} for DGA, DDG and IDG, respectively. For comparison with NAOS and MD the WF related to food waste and losses was removed from the value provided by González-García et al. (2020). There were considerable differences in the WFs of food-based dietary patterns in the reference countries as can be seen in Fig. 4. NAOS and MD showed higher WFs (3181 and 2826 L per capita and day, respectively) than IDG, DDG and DGA (1760, 2309 and 2583 L·person^{-1}·day^{-1}, respectively). Then, to make the comparison of the WF of these three diets between

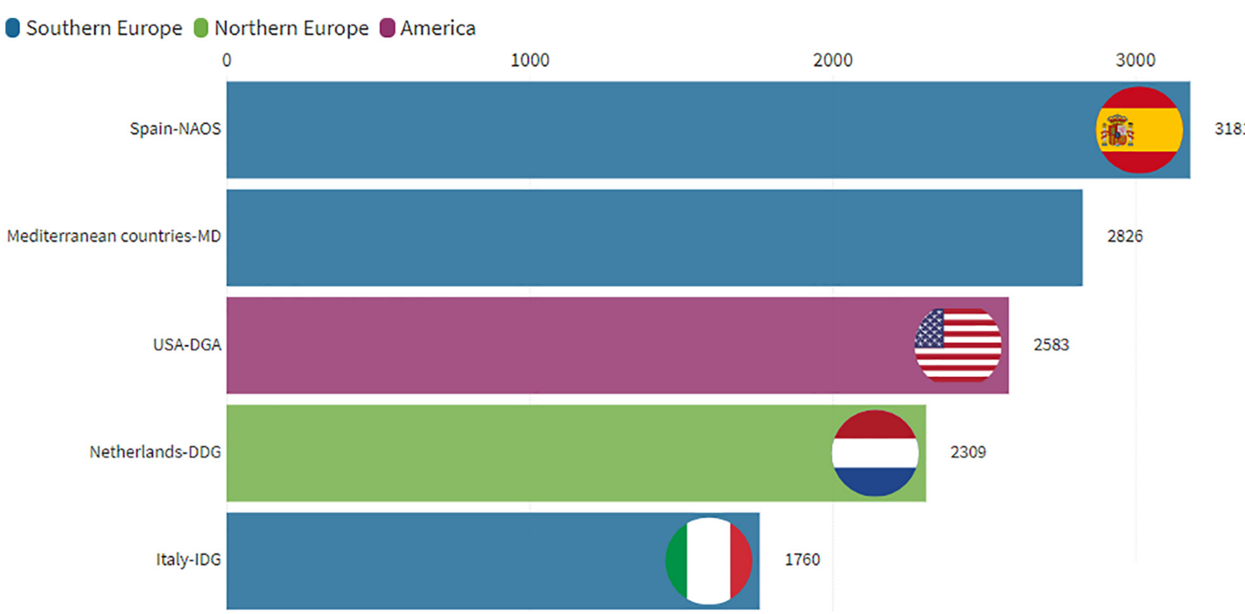

Fig. 4. Water footprint (L·person^{-1}·day^{-1}) for Northern Europe (Dutch Dietary Guidelines 2015 -DDG), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020–2025 - DGA.
Data for MD, NAOS were taken from González-García et al. (2020).

them and with NAOS and MD, it is interesting to check the breakdown of the WF between food categories shown in Fig. 5.

For the DDG, the WFs of fruits and vegetables were lower (103 L·person^{-1}·day^{-1}) than for the rest of FBDGs mainly due to their lower contribution to the recommended average daily intake. On the other hand, although dairy products contributed in a high proportion to daily intake in DDG compared to NAOS, MD and IDG, its associated WF (354 L·person^{-1}·day^{-}1) was also lower than that of them. Similarly, the comparative analysis of total meat intake could not account for the differences in meat-related WF for DDG (248 L·person^{-1}·day^{-1}), MD (311 L·person^{-1}·day^{-1}) and NAOS (422 L·person^{-1}·day^{-1}). The rationale behind these results is that marked differences were observed between the national WFs of the reference countries for milk (most representative item in the dairy food category) beef, pork and chicken. According with Mekonnen and Hoekstra (2010) local climate, soil conditions, data on irrigation and the relative occurrence of the different production systems (grazing, mixed and industrial) explains the differences regarding the corresponding WF of each reference country.

By far, in DGA the largest contribution to the total WF comes from dairy products (790 L·person^{-1}·day^{-1}). However, NAOS leads the ranking in terms of the WF associated with this food category. Although the contribution of milk to total dietary intake was much higher in the DGA than in NAOS, the Spanish WF for milk was a value 2.2 greater than that of America, according with the study of Mekonnen and Hoekstra (2010), who considered the different production systems and feed composition per animal type and country. On the other hand, DGA represented the country with the highest meat-related water impact (629 L·person^{-1}·day^{-1}). The high per capita beef consumption in the American guidelines and its associated water demand explain the high WF values for beef. On the other hand, oils and fats WF for DGA (118 L·person^{-1}·day^{-1}) was lower than for the other dietary patterns. The large variability was due to the fact that, in the DGA, olive oil was substituted by soybean oil, with a lower WF in USA than olive oil in Spain, The Netherlands or Italy (Mekonnen and Hoekstra, 2011).

Regarding the Italian case study, we found that the meat category had a relatively small WF (150 L·person^{-1}·day^{-1}). Based on the IDG, high levels of white meat consumption were observed with a lower WF than red meat (Mekonnen and Hoekstra, 2010). Finally, the low WFs for oils and fats in Italy (250 L·person^{-1}·day^{-1}) were indicative of lower olive oil consumption following Italian recommendations (23 g·person^{-1}·day^{-1}) compared to the FBDGs of the other olive-growing regions, MD (45 g·person^{-1}·day^{-1}) and NAOS (40 g·person^{-1}·day^{-1}). In addition, the national Italian WF for olive oil was less than that of the Netherlands and Spain (Mekonnen and Hoekstra, 2011).

Overall, meat, dairy products, oils and fats and starch-based products were the major contributing food groups to WF of the European and American dietary recommendations. Dairy products were the main components of total WFs of NAOS (964 L·person^{-1}·day^{-1}) (González-García et al., 2020), IDG (470 L·person^{-1}·day^{-1}) and DGA (790 L·person^{-1}·day^{-1}). However, oils and fats were dominant in the dietary WFs of DDG (883 L·person^{-1}·day^{-1}) and MD (776 L·person^{-1}·day^{-1}). Starch-based products were also major foods contributing to the WF of all the dietary guidelines (ranging from 11% of total WF in NAOS to 23% of total WF in IDG).

3.4. Assessment of nutritional quality of diets - nutrient rich diet (NRD9.3) and health gain score

Supplementary Table SM1.16 in the Supplementary Material 1 shows the nutrient intake for each FBDGs. These values were obtained considering the amount of each foodstuff and its nutritional information (see Supplementary Material 2). The analysis of nutritional quality focused on the analysis of qualifying nutrients, disqualifying nutrients, and food categories included in the health gain score. The results of

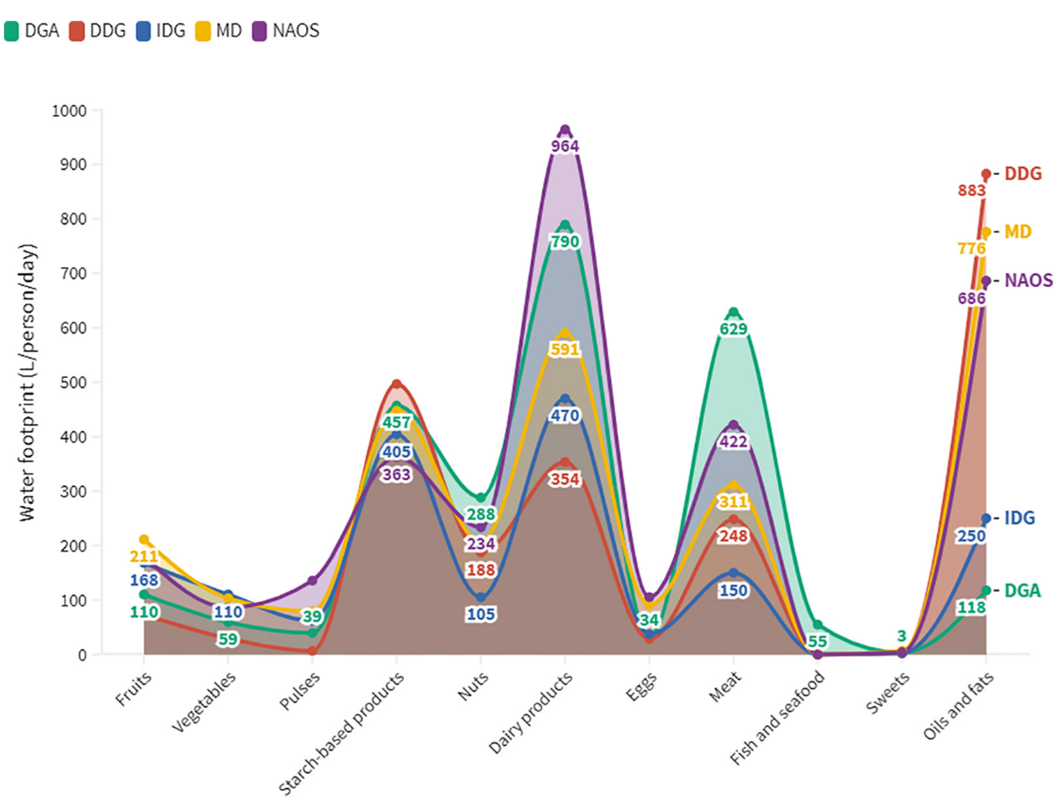

Fig. 5. Breakdown of water footprint (L·person^{-1}·day^{-1}) between food categories for Northern Europe (Dutch Dietary Guidelines 2015 -DDG), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020–2025 - DGA.
Data for MD and NAOS were taken from González-García et al. (2020).

this nutritional comparison were used for better interpretation of the NRD9.3 and the health gain score of the FBDGs.

Regarding the qualifying nutrients, all the diets reported an intake of protein, fibre, vitamin A, vitamin C, calcium, potassium and magnesium above the recommended daily values (RDV) (EFSA, 2021; NIH, 2021). Dairy products and starch-based products were the main source of protein in all of them. Protein intake came from dairy products in a range from 18 $g \cdot day^{-1}$ in MD to 40 $g \cdot day^{-1}$ in DGA and from starch-based products in a range from 20 $g \cdot day^{-1}$ in DGA to 34 $g \cdot day^{-1}$ in IDG. Meat was also a significant source of protein for DGA (25 $g \cdot day^{-1}$).

Fibre and potassium intakes came mainly from starch-based products (between 10 $g \cdot day^{-1}$ in DGA and 14 $g \cdot day^{-1}$ in IDG for fibre, and between 689 $mg \cdot day^{-1}$ in MD and 1391 $mg \cdot day^{-1}$ in NAOS for potassium). Fibre and potassium also came from fruits and vegetables for plant-rich diets such as the Southern European dietary recommendations and from pulses in the case of beans-rich diets, such as DGA. Dairy products were also identified as major contributors of dietary potassium.

As for the other elements, the main iron contributions came mainly from starch-based products in general (between 4 $mg \cdot day^{-1}$ in DGA to 14 $mg \cdot day^{-1}$ in DDG), and from cereal-based products (including cereal breakfast) in particular. In the case of the IDG, blue fish (striped Venus) and molluscs (clams) also affected the iron intake ratio (4 $mg \cdot day^{-1}$ of iron from fish and seafood in IDG). On the other hand, starch-based products were the major source of magnesium for all the diets (ranging from 75 $mg \cdot day^{-1}$ in DGA to 179 $mg \cdot day^{-1}$ in DDG), except for DGA, for which beans were the main dietary source rich in magnesium (101 $mg \cdot day^{-1}$).

As for vitamins, the amount of pepper in the diet can result in substantial values of vitamin C. Therefore, the highest intake levels of vitamin C were reported for Southern European dietary guidelines (266, 380 and 270 $mg \cdot day^{-1}$ for IDG, MD and NAOS, respectively). Otherwise, the attainment of adequate amounts of vitamin A in the diets analysed was strongly associated with beta-carotene, the main nutrient in carrots. The diet richest in vitamin A was the MD diet (1557 $\mu g \cdot day^{-1}$). Finally, calcium intake levels were also higher than calcium requirements. The highest intake levels corresponded to the DGA (1604 $mg \cdot day^{-1}$), and the lowest to the IDG (981 $mg \cdot day^{-1}$), which can be explained by comparing the recommended intake of dairy products in DGA and MD.

For the last qualifying nutrient (vitamin E) not all the dietary patterns reached the target levels. According to the DDG, IDG and NAOS guidelines, a citizen would not consume enough vitamin E on average to meet their needs (EFSA, 2021). Plant-based oils (ranging from 2 $mg \cdot day^{-1}$ in NND to 5 $mg \cdot day^{-1}$ in MD) and nuts (ranging from 1 $mg \cdot day^{-1}$ in IDG to 4 $mg \cdot day^{-1}$ NND) were the best dietary sources.

For nutrients associated with adverse health effects, added sugars met the limitations in all dietary patterns. However, saturated fats, obtained mainly from both animal fats (e.g., cheese, butter) and vegetable oils (e.g., olive oil), exceeded dietary requirements in DGA. NND, DDG and DGA also exceeded the recommended daily intake of sodium (EFSA, 2021).

For the three food groups included in the health gain score (vegetables, fruits and fish) (Van Dooren et al., 2014), vegetables and fruits consumed were higher than the baseline values (WHO, 2003) for all the dietary patterns. Even the quantity of fruits and vegetables exceeded the recommended amount for all of them, differences between diets could be observed. The vegetable and fruit supply for the Southern European recommendations were higher than for Northern European recommendations. The rationale behind this finding is that the Atlantic region is characterised by a wide availability and a culinary tradition of vegetables and fruits (Esteve-Llorens et al., 2019b). Regarding fish intake, Brink et al. (2019) set 100 g/week of fish as a minimum restriction and 125 g/week as a maximum in agreement with Kromhout et al. (2016). Therefore, DDG was the only one who did not meet the dietary recommendations for fish consumption (Van Dooren et al., 2014).

Finally, the assessment of nutritional quality was completed by comparing the NRD 9.3 and the health gain score of the different FBDGs. As can be seen in Fig. 6, MD clearly had the highest NRD 9.3 (477) and

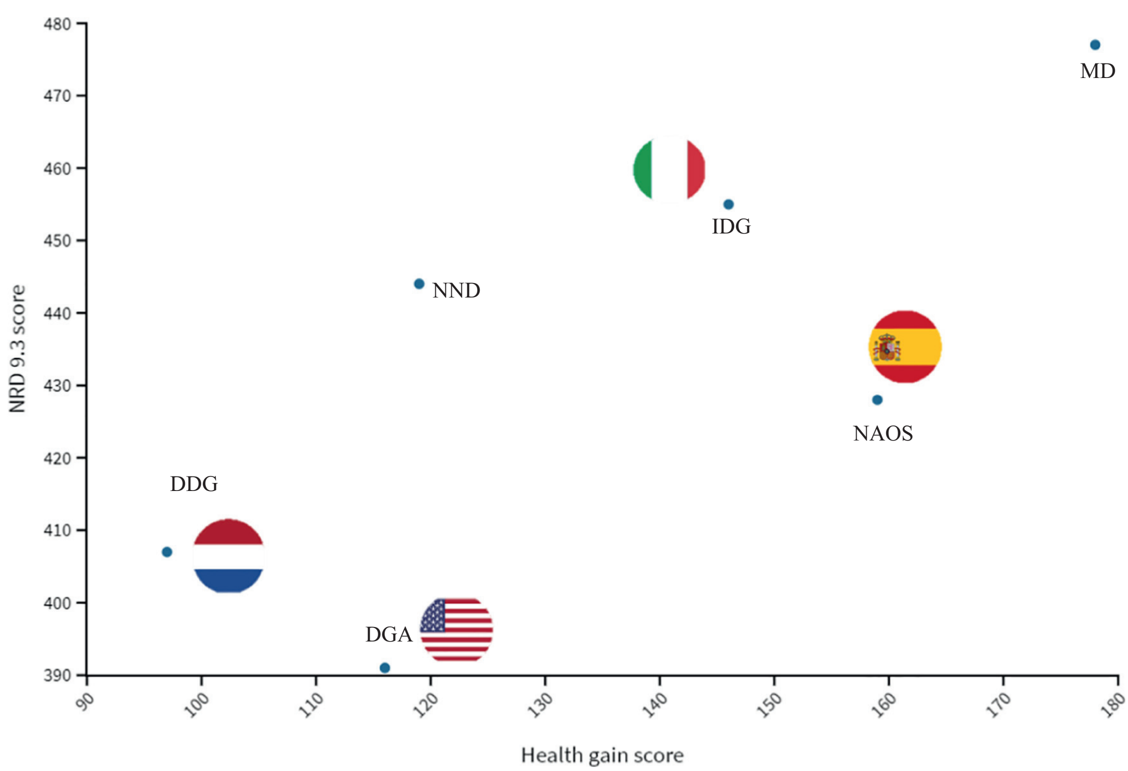

Fig. 6. Comparison between NRD9.3 and health gain score for Northern Europe (Dutch Dietary Guidelines 2015 -DDG, New Nordic Diet - NND), Southern Europe (Mediterranean Diet - MD, Spanish Strategy for Nutrition, Physical Activity and the Prevention of Obesity -NAOS and Italian Dietary Guidelines 2018 - IDG) and Dietary Guidelines for Americans 2020–2025 - DGA. Data for MD, NAOS and NND were taken from González-García et al. (2020) and Ulaszewska et al. (2017).

health gain score (178). IDG and NAOS also showed good results for NRD9.3 (455 and 428) and the health gain score (146 and 159). The NND guidelines had a similar value for NRD 9.3 (444) as the Southern European Dietary recommendations, but it did not show a clear correlation with the health gain score, which was lower compared to them (119), mainly due to the low amount of vegetables and fruits. The lowest overall health scores were for DGA (NRD9.3 - 391 and health gain score – 116) and DDG (NRD9.3 – 407 and health gain score – 97). These results can be explained considering the low content of vegetables, fruits, fibre intake and fish in DDG and the high content of saturated fatty acids and sodium in DGA, despite following sanitary recommendations. Both, DDG and DGA, should adopted the other FBDGs to improve their nutritional profile.

3.5. Comparison of the results with literature data

The findings of this study for CF of DDG, IDG and DGA are in agreement with others available in the literature. Considering the same system boundaries, our result of CF for DDG (2.28 kgCOeq·day^{-1}) and DGA (2.98 kgCO_2eq·day^{-1}) was considerably lower than that reported by Kovacs et al. (2021) (2.86 and 3.83 kgCO_2eq·day^{-1} for DDG and DGA respectively).

The difference is mainly related to the fact that the GHG emissions estimated by them not only focused on an earlier version of the DGA (USDA and HHS, 2015), but also includes GHG emissions from recommended daily discretionary calories (around 0.43 and 0.52 kgCO_2eq·day^{-1} for DDG and DGA, respectively, considering a caloric intake of 2000 kcal·person^{-1}·day^{-1}). Another reason behind these differences is that while Kovacs et al. (2021) used the database of Food Impacts of the Environment for Linking do diets (dataFIELD) (OECD-FAO, 2018) as a source for the environmental impact data, we used the same peer-reviewed journal articles as González-García et al. (2020) with the main objective of conducting comparative research.

On the other hand, the IDG for healthy eating is based on the well-known MD model. Therefore, their CF was in line with those found in the literature for MD. As an example, Castañé and Antón (2017) provided the total GHG emissions of the MD by designing weekly menus. They estimated a CF of 2.06 kgCO_2·person^{-1}·day^{-1} for the food production stage, excluding food waste from the system boundaries. This value was very similar to the one calculated for IDG (2.04 kgCO_2·person^{-1}·day^{-1}) and to the other MD value taken in this study as a basis for comparison (2.21 kgCO_2·person^{-1}·day^{-1}) (González-García et al., 2020).

The comparison in terms of WF showed the benefits of following the FBDGs for the transition to a fair and efficient use of freshwater resources. Our results regarding WFs for DGA (2583 L·person^{-1}·day^{-1}), DDG (2309 L·person^{-1}·day^{-1}) and IDG (1761 L·person^{-1}·day^{-1}) were considerably lower than those corresponding to the "average" patterns globally. According to the systematic review and meta-analysis by Harris et al. (2020), the available evidence suggested that total WF of the average dietary patterns was 3227 L·person^{-1}·day^{-1} for Europe and 2617 L·person^{-1}·day^{-1} for North America.

In terms of nutritional quality, the health gain score for DDG (97) and IDG (146) were consistent with the previous recommended DDG score (105) (Health Council, 2006) and with a basic MD (122) (Van Dooren et al., 2014). The American health gain score (116) was comparable to the total score of a vegan diet (118) (Van Dooren et al., 2014). The NRD9.3 was not directly compared to values reported in the literature due to variability between the recommended daily values set depending on the study and different decisions regarding the limitation of nutrients to reference intake levels. In order to make a useful comparison, NRD9.3 was calculated using the average daily nutrient intakes for the MD, vegan and the Atlantic diet established by Castañé and Antón (2017) and Esteve-Llorens et al. (2019a) with the considerations taken in this study. The NRD9.3 for IDG (455) was in line with the value for MD recalculated following the results of Castañé and Antón (2017) (477). However, it was lower than the scores for the vegan diet (584) and the Atlantic Diet (550). The NRD 9.3 scores for DGA (391) and DDG (407) were lower than the corresponding scores for these three diets.

3.6. Up-scalability of the outcomes

The need to deepen the integration of different sustainability domains in FBDGs is a recent issue that should be addressed by governments, international organizations and the food industry. The methodology proposed in this paper for five FBDGs in Northern and Southern Europe and America, can be scalable for the inclusion of sustainability concepts in FBDGs in other regions of the world with other cultural traditions and typical foods. Furthermore, the approach presented here can also be extended for the evaluation of other dietary trends that are not country-specific but widely spread, such as for example the popular Atkins diet or the South Beach diet.

A multilevel database with environmental indicators (such as carbon and water footprint), as well other metrics (nutritional, socioeconomic and health-related), based on a standardized methodology like the one described here for FBDGs of anywhere would be a good starting point to achieve the Sustainable Development Goals in the food sector. Sharing information through simple indicators would transfer the best features from one FBDGs to another, without forgetting the culture of each country or region."

3.7. Research limitations

Understanding the limits of this study is relevant for a correct interpretation of the results. The large variety and geography of the data from the peer-reviewed journal articles on food life cycle assessment consulted could affect the results. Besides the high variability, we have assigned a single carbon footprint to each food item. The diversity of food items involved in the FBDGs is too large and the uncertainty of the carbon footprint of each food is unknown to us. Therefore, we cannot provide a reliable and valuable uncertainty analysis on the dietary carbon footprint. Moreover, as the main objective of this study is the comparison between different dietary guidelines, priority has been given to the use of the same LCA for the same food in all the FBDGs, leaving geographical considerations and, consequently, local agricultural production methods in the background.

The scarce information for the estimation of WF of non-aquaculture fish species could also produce a slight deviation in the results. Moreover transport, food losses and food wastage along the food supply have not been taken into account, which may underestimate the results in absolute terms, but not for comparison purposes. Finally, the recommended minimum and maximum daily values in the nutrient profiles were mostly taken from European references (EFSA, 2021), without taking into account differences in the nutritional assessment of the DGA. This fluctuation may be the cause of a slight deviation in the NRD9.3 calculation of DGA.

4. Conclusions

The interrelationships between nutrition and environmental performance in FBDGs is central to the goal of achieving environmental sustainability objectives. Despite tremendous variation from country to country, as a general trend, high adherence to the recommended diets was associated with benefits on both nutritional and environmental indicators.

We found that the adherence to the DGA was associated with higher carbon emissions compared with recommendations from other high-income countries in Northern and Southern Europe. The CF for the DGA was more than 1.3 times higher when the comparison was made with the most plant-rich European diets analysed (e.g. IDG and MD). These findings were associated with the higher quantities of dairy products and meat in DGA.

In contrast, the DGA did not have the highest WF. The two diets recommended in Spain: NAOS and MD showed the highest values. To explain these results, special attention was paid not only to the recommended daily intakes of meat, dairy products, starch-based products and fats (main food categories contributing to WF), but also to the different climatic conditions of production, among other agricultural factors and different production systems (Mekonnen and Hoekstra, 2010, 2011) IDG was the best in terms of WF, due to its low red meat content and lower national WF for olive oil compared to the Netherlands and Spain.

Although the Italian case study showed the best environmental performance, MD in the Spanish context presented better nutritional quality, especially when it was compared with DDG and DGA, the worst according to the two nutritional indicators analysed (NRD9.3 and health gain score). Overall, considering the two nutritional indicators, the dietary patterns of Southern European countries showed better nutritional quality than those of Northern Europe and North America.

Future research on development of FBDG can benefit from the findings of this study. Increasing plant-based foods in a similar way of the IDG or MD may help regions with large dairy- and meat-derived impacts, such as North America, without compromising nutritional quality. The main dietary message of the study is that balancing nutrition and sustainability in the FBDGs, with a future incorporation of the sociocultural and economic dimension, is a key step in transforming dietary recommendations into practical consumption patterns. Governments should promote public awareness campaigns and educational programs with the aim of facilitating the adoption of these healthier and more sustainable dietary recommendations. In summary, governments should make available to the public affordable information on sustainable dietary choices that are in line with health guidelines.

CRediT authorship contribution statement

Conceived and designed the experiments: C·C.-F., S.G.-G., G.F., M.T.M.; Performed the experiments: C.C.-F.; Analysed the data: C.C.-F., S.G.-G., M.T.M; Contributed materials/analysis tools: G.F., M.T.M; Writing of the original draft: C.C.-F.; Review & Editing: C.C.-F., S. G.-G., G.F., M.T. M.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.150894.

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