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Encompassing health and nutrition with the adherence to the environmentally sustainable New Nordic Diet in Southern Europe

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A R T I C L E I N F O

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A B S T R A C T

The partnership for sustainable and healthy food is a challenge shared by governments, food industry, environmental science, and the health service. At the European level, the application of policies based on the Mediterranean-style eating pattern is recommended. In this regard, attention is being paid to the New Nordic Diet (NND), which shares many similarities with the Mediterranean one but comprises typical foods from Nordic countries. Therefore, it could be transferred to anywhere in the world, including Spain, where it would coexist with the recommendations of the Mediterranean Diet (MD) and the southern European Atlantic Diet (SEAD). The main objective of this study is to propose the modelling of the health, economic, environmental and nutritional indicators of the southern version of NND (SNND) and to compare, when possible, the results with those of the alternatives.

The environmental metrics for SNND, carbon footprint (CF) and water footprint (WF), were estimated at 3.58 kg CO_2·person^{-1}·day^{-1} and 3528 L·person^{-1}·day^{-1} respectively, a slightly worse environmental profile than for MD. In relation to economic metrics, the updated cost index to 2019 was 4.30 €·person^{-1}·day^{-1}, similar to MD and lower than for SEAD. The overall dietary quality score was 126, a higher result than the baseline (100), but worse than those identified for SEAD and MD. In terms of health outcomes, NND showed benefits that reduce non-communicable diseases such as the risks of type 2 diabetes mellitus (T2D) by 31%, colorectal cancer (CRCA) by 35% and cardiovascular disease (CVD) by 7%. Compliance with the NND was also associated with a weight loss of 1.83 kg per person following the diet. Epidemiological evidence supported greater weight loss when following the NND, but greater reductions in the CVD risk when adhering to MD.

The dissemination through educational campaigns of these recommended dietary patterns and the incorporation in the dietary guidelines of simple indicators of nutritional quality, environmental impacts and health, easily understood by a wide audience, is one of the most important challenges of public and environmental health.

1. Introduction

There is no doubt that food production must satisfy the global demand of a society on the premise of ensuring the use of resources and land that suffer increasing stress. In the context of food, a balance must be achieved between human health, the environmental sustainability of the planet, and economic decision-making factors. Humanity faces a double challenge: to reduce current rates of food loss with the aim of achieving a bio-circular economy and to provide healthy food from sustainable food systems (EAT-Lancet Commission, 2018; European Commission, 2020).

To take action for the Sustainable Development Goals, the transformation of global food systems must be accompanied by the integration of dietary guidelines that recommend increasing fruits and vegetables intake and reducing the consumption of red meat and sugar (Gonzalez Fischer and Garnett, 2016; Herforth et al., 2019). However, in recent decades, dietary changes are evolving toward diets rich in pre-packaged foods, refined sugars and greasy foods (Tilman and Clark, 2014).

Among European countries, special attention should be paid to Spain in terms of dietary trends. The actual consumption pattern in Spain is moving away from the recommendations towards a diet richer in meat,

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milk and sugar products and poorer in fruits and vegetables (Blas et al., 2019). Moreover, differences in food consumption patterns in terms of carbon footprint (CF) and nutritional requirements can be noticed between the different Spanish climatic zones (Esteve-Llorens et al., 2021). The dietary recommendations in Spain are guided by two well-established dietary patterns, the Mediterranean diet (MD) and the southern European Atlantic Diet (SEAD). A MD-style diet typically includes a high intake of olive oil, fruit, nuts, vegetables, legumes and a modest consumption of fish, meat, wine and dairy products (Preedy and Watson, 2020; Sánchez et al., 2020). SEAD is the common dietary pattern in the northwest of Spain and is characterized by the consumption of fresh and seasonal foodstuffs, freshly-prepared and low-processed foods (Esteve-Llorens et al., 2019a).

Following the philosophy of MD, Nordic nutritionists have developed a new dietary choice called the New Nordic Diet (NND) (Bere and Brug, 2009; Saxe et al., 2013). The NND is a daily reference diet developed within the framework of the project OPUS (Optimal well-being, Development and Health for Danish children through a healthy New Nordic Diet) (Jensen and Poulsen, 2013). The diet consists of locally grown, seasonal, nutritious and environmentally friendly foods, which are consumed mainly in Denmark, Finland, Iceland, Sweden and Norway (Meltzer et al., 2019). It is based upon three principles (Jensen et al., 2015; Mithril et al., 2012).

- Health: high intake of vegetables, fruits, potatoes, nuts, whole grains and fish and less consumption of meat compared to the current average Danish diet. This diet composition is crucial for a healthy lifestyle and has been linked to a lower relative risk for obesity, T2D, CVD and cancer.
- Gastronomic potential: Distinct regional culinary dishes based on foods from the countryside and from the fishing Area 27.
- Sustainability: selection of local products and organic production methods to minimize the use of pesticides.

Their principles can be transferred to any part of the world so that, within the specific context of a country, it is feasible to create for the first time the southern version of the NND (SNND), a new dietary design that could be incorporated into the dietary scenario in southern Europe, mainly in north-western Spain and northern Portugal. In the literature, Spanish dietary patterns and New Nordic Diet have been analysed from an environmental point of view, mainly in terms of CF. Thus, Castañé and Antón (2017) quantified GHG emissions for the MD, Esteve-Llorens et al. (2019a) analysed the link between the CF and the Nutrient Rich Diet 9.3 index for SEAD and Ulaszewska et al. (2017) used the environmental hourglass approach for the Mediterranean and new Nordic diets. González-García et al. (2020) incorporated another environmental metric not as widely explored in the assessment of SEAD and MD, the water footprint (WF) indicator. On the other hand, there is strong scientific evidence, which shows the close relationship between them and a lower risk of diseases such as T2D, obesity, CVD and different types of cancer (Ramezani-Jolfaie et al., 2020; Rosato et al., 2019; Schwingshackl et al., 2015). However, sustainability assessments are a further necessary step that has not yet been fully explored in the literature.

Therefore, this paper develops an integrated approach based on validated and standardised methods from different disciplines to solve the challenge of assessing the new version of NND designed for Southern Europe. First, epidemiological descriptors from cohort studies, such as the relative risk of a health event (diet-disease), are addressed. The usefulness of the cohort studies that have emerged so far is mainly based on individual foods or nutrients that influence disease risk. However, the adequacy of diets is not only based on the selection of individual foods, but on their nutritional balance in certain varied diets. Therefore, a more promising approach could focus on using a review of epidemiological studies to analyse which foods should be limited and promoted to improve health-related dietary quality. Secondly, both the life cycle assessment (LCA) approach followed to determine the CF associated with the dietary patterns analysed and the Water Footprint Assessment methodology (WFN, 2020) are incorporated to calculate the WF. Third, following Van Dooren et al. (2014) for national food-based dietary guidelines, this study complements the environmental assessment with a nutrient-derived metric: the health gain score. Fourth, it examines the economic barriers to healthy eating by estimating the total economic cost of the diet.

In this sense, this study aims to conduct a sustainability assessment integrating environmental, health, nutritional, and economic indicators of the SNND. The assessment includes the quantification of CF and WF, a nutritional quality index, daily cost and health outcomes (association with the prevalence of obesity, CVD, T2D and colorectal cancer (CRCA)). Special attention was given to the comparison with MD and SEAD based on this multi-perspective approach.

2. Materials and methods

2.1. Composition of the southern version of the New Nordic Diet

The average daily quantification of the most distinct Nordic identity dietary components detailed by Mithril et al. (2013) was consulted to establish the composition of the SNND. Although the advisable average quantity per food category for the most identifiable components of this diet was reported, no attention was paid to the specific amount of each food in mass units (usually grams) that constitutes each group. For example, they suggested a recommended fruit intake higher than 400 g·day^{-1} and a minimum average daily intake of berries of 50–100 g·day^{-1}, but did not develop a complete daily diet indicating the specific amount of different fruits (e.g., bananas, oranges or apples) that an average person should eat.

Thus, this gap in guidelines was used as a strategy to adapt the NND to the dietary scenarios in the southern Europe, particularly in Spain and Northern Portugal, regions where the SEAD is present. Galicia, an autonomous community in northwest Spain, is a reference in the Atlantic Diet pattern. Therefore, following the methodology proposed by González-García et al. (2020), data on current food consumption in Galician households for the year 2019 were managed in order to adapt the NND to the eating habits of this geographical area. The Consumption, Commercialization and Food Distribution: Household Consumption Database Program (MAPA, 2019) provided these updated data to identify the most popular foods by food category in the Galician shopping basket (see **Table SM1.1** in the **Supplementary material**). Consequently, Fig. 1 displays the recommended daily intake of the food items in the SNND.

As far as plant-based foods are concerned, the list initially includes different types of fruits: berries, which were selected because of their clear Nordic identity, and seven other fruits (oranges, bananas, apples, mandarins, melons, pears and watermelons), which represent 69% of the total fruits consumed on average in Galicia (MAPA, 2019). Secondly, the menus of the NND contain cruciferous vegetables (cabbage), root vegetables (carrots, onions), fresh herbs and mushrooms. As for the proposed adoption of the NND by the southern European citizens, other vegetables such as tomatoes, peppers, lettuce and courgette were included (MAPA, 2019).

Seaweed and pulses are also part of the composition of the NND diet. Seaweeds are a source of nutrition in NND because of their high content of essential minerals, dietary fibre, vitamins, and bioactive compounds (Cherry et al., 2019). The important role of pulses in the NND was also established in the guidelines, as well as the recommended amount per day (Mithril et al., 2012). Considering that chickpeas, beans and lentils represented more than 99% of the total legumes consumed in Galicia in 2019 (MAPA, 2019), they were selected as representative legumes in the designed daily diet.

It should also be noted that eating more nuts, whole grains, and potatoes is part of the NND principles (Mithril et al., 2012). Whole grains show an inverse relationship with the risk of suffering T2D, CVD and

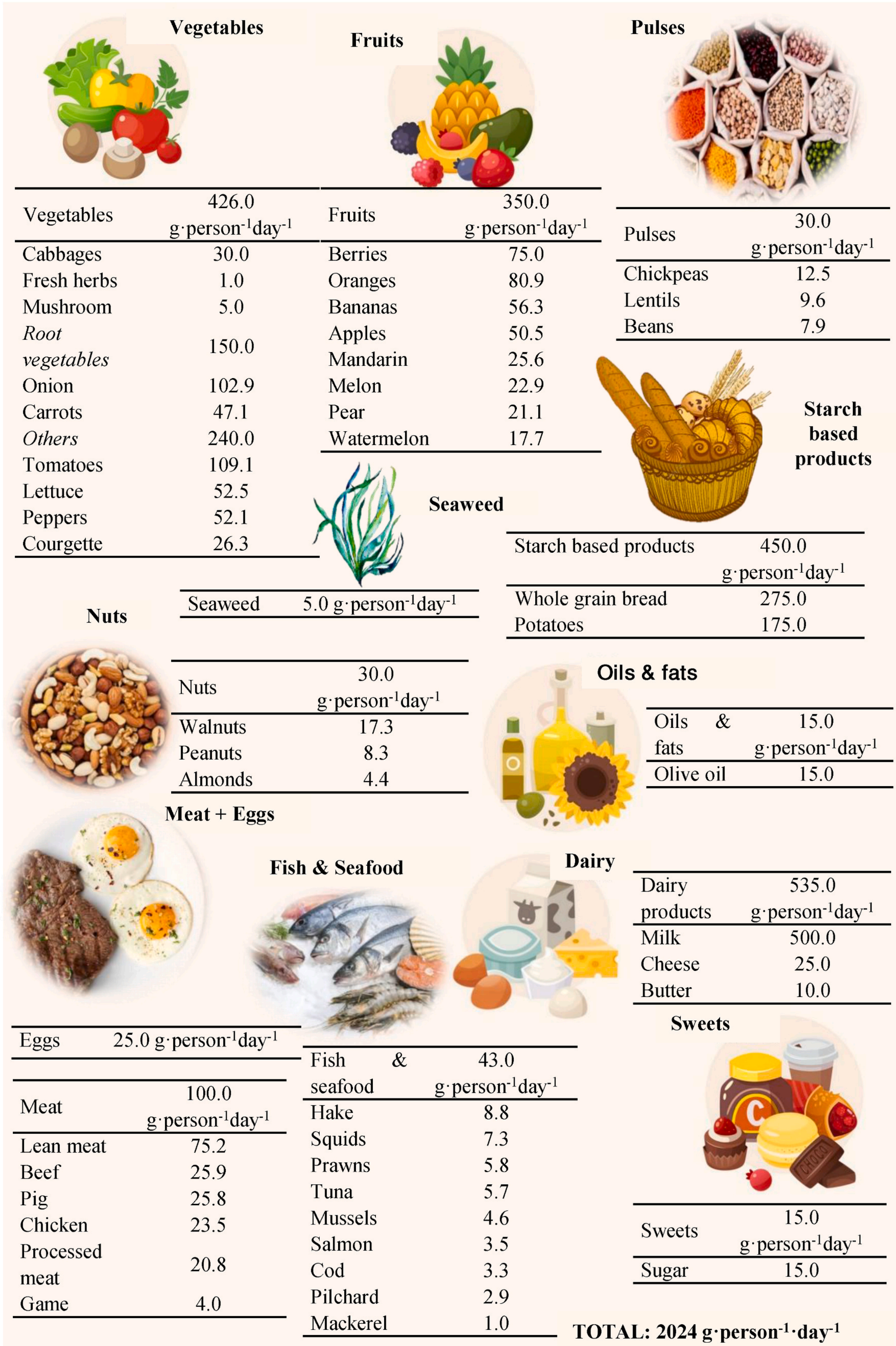

Fig. 1. Overview of the daily-recommended intake per food category ($g \cdot person^{-1} \cdot day^{-1}$) for the Southern version of the New Nordic Diet (SNND).

obesity (Ye et al., 2012). On the other hand, in addition to their potential health benefits, potatoes can be grown using sustainable organic cultivation methods. For non-seasoned nuts, NND detailed in its pyramid a recommended intake of 30 g·day^{-1}. The proportion was distributed among walnuts, peanuts and almonds, which represented 22%, 11% and 6% of the total nuts consumed in Galicia, respectively (MAPA, 2019).

As for food of animal origin, milk products were the food group with the highest intake. Three types of dairy products (milk, cheese and butter) were considered based on the Danish Food-Based Dietary Guidelines. Meat was the second highest intake category. The significance of meat as a source of protein can certainly be achieved with an average meat intake of 85–100 g·day^{-1}. The NND typically includes meat from free-range livestock and game due to their nutritional and sustainability advantages (Costa et al., 2016; Elgersma, 2015; Mithril et al., 2013). In addition, beef contributes with a significant percentage (19%) to the total meat consumption in Galicia (MAPA, 2019). Therefore, it was also included in this food category. Finally, eggs were managed separately from meat.

The other foods of animal origin are fish and seafood. The NND recommends regular consumption of fish with an average content in the diet higher than 43 g·day^{-1}. In order to adapt the NND to the southern regions, it recommends an amount distributed between the most consumed fish (hake, tuna, salmon, cod, sardine and mackerel) and shellfish (squids, prawns and mussels) in Galicia (MAPA, 2019).

Other considerations in the composition of the SNND diet were the type of oil used and the possibility of incorporating sweets. In Galicia, olive oil is the main oil consumed with a representation of 59%. Thus, it was considered the only source of fat. Regarding the latter, the amount of refined sugar in the NND was restricted to 4% as a percentage of total energy intake (Mithril et al., 2013).

2.2. Functional unit

With the aim of establishing a joint comparison between the SNND and the other two well-known dietary scenarios recommended in Spain, based on the suggested economic, nutritional quality, environmental and health indicators, the definition of a functional unit was required. Taking into account that energy intake (kcal), food consumed (kg) and nutrient intake per person and day were estimated in relation with the guidelines for the NND, the functional unit selected was the individual recommended daily dietary intake. Moreover, for the SNND the recommended daily energy intake regardless of drinks was of 2304 kcal·person^{-1}·day^{-1}, a value very close to 2228 kcal·person^{-1}·day^{-1}, the recommended value for a Spanish citizen by the Panel on Dietetic Products, Nutrition and Allergies (EFSA, 2017).

2.3. Environmental outcomes

2.3.1. Carbon footprint

CF was used as a well-known indicator of climate change to quantify GHG emissions emitted in terms of carbon dioxide equivalent (CO_2eq) associated with each dietary pattern (Silalertruksa and Gheewala, 2018). CF was carried out from a "cradle-to-consumer" approach, i.e., contemplating the whole food supply chain until the foodstuffs were distributed for household consumption. The system boundaries include food loss and food waste. The cooking stage (e.g., boiling or frying) was not included with the aim to facilitate the comparison with the results obtained by González-García et al. (2020) for MD and SEAD. The exclusion of the consumption stage from the scope of the study was also considered in other similar studies available in the literature (Esteve-Llorens et al., 2019b; Van Dooren et al., 2014). Therefore, the system was divided into the following three stages (see Fig. 2):

Food production stage (S1): This stage comprises the production of the

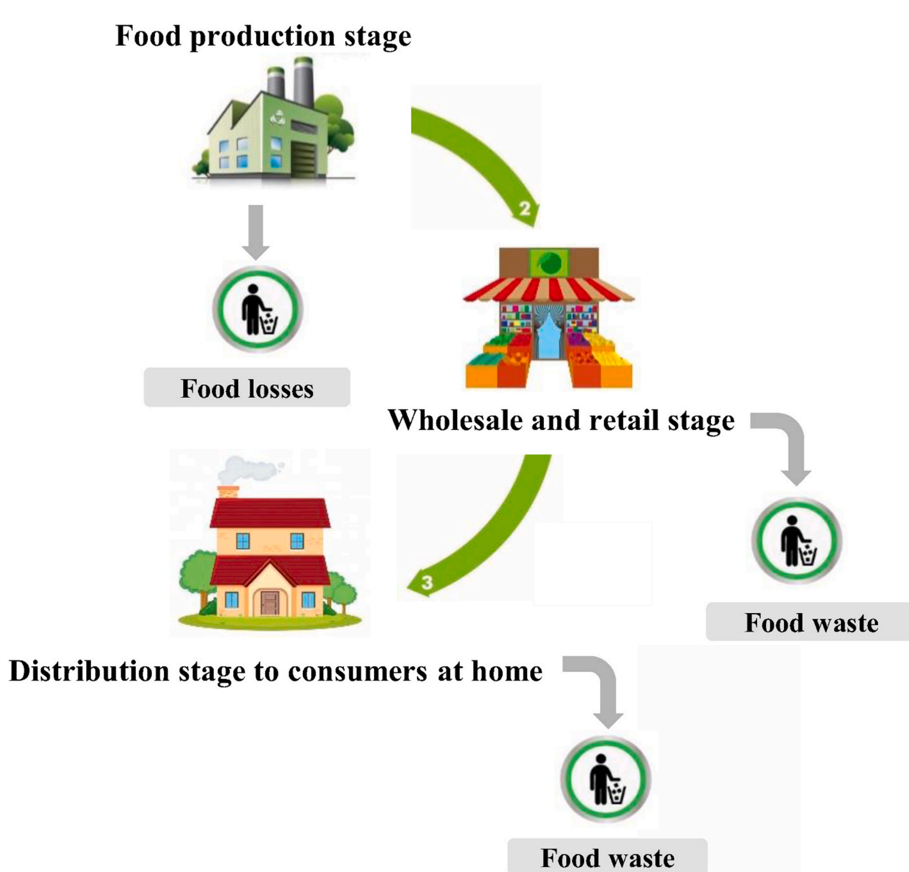

Fig. 2. System boundaries considered in the carbon footprint (CF) assessment of the Southern Version of New Nordic Diet (SNND).

dietary components that make up the complete daily diet. Regarding data collection, 27 LCA scientific articles were consulted to estimate the corresponding embodied GHG emissions per each foodstuff. All these LCA studies were managed from a "cradle to gate" approach taking into account that these were the boundaries set for S1. Therefore, when the life cycle studies analysed covered the "cradle-to-grave", "cradle-to-retailer" or "cradle-to-consumer" perspectives, the GHG emissions corresponding to these additional stages were discarded. A detailed summary of the sample of 45 food items grouped into 12 categories and their GHG emissions associated were reported in **Table SM1.2.** in the **Supplementary Material**. Due to the lack of information available in the literature, some assumptions were considered. Thus, cabbage was assimilated to cauliflower and broccoli. As for fresh herbs, they were excluded from the analysis because they only represent 0.5% of the total recommended daily intake. In addition, in accordance with the NND guidelines, the CF values for organic food production were considered when data was available in the literature.

Wholesale and retail stage (S2): This stage comprises the transportation from the factory or farm gate to wholesaler and retailer. The estimation of CF corresponding to this stage was made considering the amount of food produced in Spain and imported, according to the methodology proposed by González-García et al. (2020). The corresponding volumes of food imported to Spain were considered following the information of the multidimensional database DATACOMEX, provided by the Spanish Ministry of Economy and Competitiveness (Ministerio de Economia, 2019). Regarding imports, at least the group of countries representing 80% of the total volume of imports was considered. All the data used correspond to the reference year 2019. Transoceanic vessels and lorry were considered in transport activities from the production site to the retailer. An average import distance per food product was also estimated, as detailed in González-García et al. (2020). For the foodstuffs produced at national level, an average delivery distance of 400 km by Euro 5 diesel freight lorries (>32 tons) was considered (Castañé and Antón, 2017). The GHG emissions factors, which were calculated using the Ecoinvent ® v3.2 database and the characterization factors of the Intergovernmental Panel on Climate Change (IPCC), were 92.10 mg $CO_2eq{\cdot}kg^{-1}{\cdot}km^{-1}$ and 18.60 mg $CO_2eq{\cdot}kg^{-1}{\cdot}km^{-1}$ for lorry and transoceanic transport, respectively.

This procedure was used to estimate the CF associated with the distribution of all the food products with the exception of fish and shellfish. It was assumed that the production of these seafood involves their landing into a Galician port according to the LCA studies reviewed (González-García et al., 2015; Hospido and Tyedmers, 2005; Iribarren et al., 2010a, 2010b; Vázquez-Rowe et al., 2010). Consequently, the average distance per food product was calculated considering that all the production is carried out at national level. The necessary background information for the estimation of GHG emissions associated with the distribution stage by food, except for fish and shellfish, was summarized in **Table SM1.3** in the **Supplementary material.** Food waste in the wholesale and retail distribution stage were taken from Gustavsson et al. (2013), who estimated waste percentages for each food category in each step of the food supply chain for Europe (see **Table SM1.4** in the **Supplementary material**).

Distribution stage to consumers at home (S3). This phase considers the logistics from supermarkets to households. As in the previous stages, the methodology proposed by González-García et al. (2020) was followed in detail. Household consumption involves the production of food waste. This issue was included in the analysis, although the cooking stage itself was not considered. Regarding logistic activities, the distribution of the total amount of food that makes up the shopping bag from the market to the household was considered. Consequently, one purchase every six days was assumed, which includes all the products that constitute the diet. Thus, they were purchased simultaneously and transported every six days (one purchase a week) from the grocery store in a diesel vehicle for 3.3 km with an emission rate of 106 g $CO_2eq{\bullet}km^{-1}$ (Batlle-Bayer et al., 2019). Average ratios of food waste per food item in households were taken from Garcia-Herrero et al. (2018). A detailed description of the food waste ratios in the household stage can be found in **Table SM1.4** in the **Supplementary material.**

2.3.2. Water footprint

The WF is a metric that quantifies the amount of direct and indirect water use of a process, product or sector (Vanham and Bidoglio, 2013). The green and blue WF refers to both consumptive use of rainwater, surface and groundwater, respectively. The grey WF indicates the freshwater needed to dilute pollutants ensuring that the quality of the water remains above existing quality standards (Pal, 2017; Pfister et al., 2017).

Mekonnen and Hoekstra (2011, 2012) provided a comprehensive study of the global green, blue and grey WF of crops and derived crops products, farm animals and animal products between 1996 and 2005 for different countries. Therefore, the three components of WF for each ingredient (with the exception of fish and seafood) were estimated following the procedure indicated by González-García et al. (2020), which considers the origin of food (domestic or imported production), the food production stage (S1) and the values reported by Mekonnen and Hoekstra (2011, 2012). The detailed WF for the foodstuffs that constitute the NND dietary pattern were reported in **Table SM1.5** in the **Supplementary Material**.

Regarding fish and seafood, Pahlow et al. (2015) determined the WF for the major farmed species cultivated under an aquaculture production regime (e.g. prawns and salmon). For the other non-aquaculture species, which grown with natural food from aquatic environment (e.g. hake and sardine), it was assumed a WF of zero for each marine species.

2.4. Nutritional quality index

A Dietary Quality Index developed by Van Dooren et al. (2014) was proposed for estimation to consider the potential health benefits of a balanced diet. For the dietary quality rating, different health organizations around the world, such as World Health Organization (WHO), World Cancer Research Fund (WCRF) or Dutch Health Council (DHC) include up to ten different nutritional indicators. In this study, the Dietary Quality Index was developed considering the ten nutritional parameters detailed in Equation (1) and having in mind the nutrient intake targets reported by WHO, Food and Agricultural Organization (FAO) and the European Food Safety Authority (EFSA) for the prevention of diet-related chronic diseases. Consequently, the parameters selected were the amount of vegetables (g), fruit (g), fish (g), fiber (g) and sodium (g) ingested; the share of total energy consumption from total fats, free sugar, carbohydrates and saturated fatty acids and the total energy intake in kcal.

$$Healthindex=\left(\frac{gveg}{200}+\frac{gfruit}{200}+\frac{gfish}{37}+\frac{gfiber}{30}+\frac{6}{gsodium}+\frac{31.5}{E\%\ totalfat}+\frac{10}{E\%\ freesugar}+\frac{9}{E\%\ sat.fat}+\frac{52}{E\%\ carbohydrates}+\frac{2228}{kcalenergy}\right)\cdot\frac{100}{10} \quad (1)$$

The reference energy was set at 2228 $kcal{\cdot}person^{-1}{\cdot}day^{-1}$ taking into account the health recommendations established for an average Spanish adult according to EFSA (2017). As for the amount of vegetables and fruits, the WHO (2003) reports a goal of more than 400 g per day. Thus, it was assumed in the index 200 g per each one. The category of tubers (e.g., potatoes) was not included in fruits and vegetables according to WHO (2003). In the case of fish, an intake of approximately 37 g per day was recommended (Van Dooren et al., 2014).

On the other hand, 25 g of fiber was considered adequate for normal laxation in adults (EFSA, 2010) and 6 g of sodium was proposed, which is consistent with dietary advice for the general population (Turck et al., 2019). The WHO and EFSA reported recommendations that a maximum of 31.5% of total energy consumption should come from total fatty acids and limited the intake of free sugars (or added sugars) to 10% of total energy consumed. Moreover, EFSA recommends 260 g per day of carbohydrates corresponding to 52% of the total energy demand (for a 2000 kcal diet) and a reference intake of 20 g of saturated fatty acids corresponding to 9% of total energy consumption. In order to complete the nutritional composition of the raw foodstuffs that constitute the diet, the Spanish Food Composition Database (BEDCA, 2017) was consulted. A detailed description of the nutritional values per foodstuff was displayed in **Table SM1.6** in the **Supplementary Material**.

2.5. Health outcomes

The relationship between dietary patterns and different food categories with the main diseases associated with malnutrition in the societies of advanced countries was evaluated. In particular, four health outcomes were included in this analysis: T2D, obesity, CVD and CRCA. To conduct the health evaluation, prospective cohort studies were taken from the literature. Note that cohort studies are observational epidemiological studies that follow the population over time as a way to examine how certain diseases depend on changes in risk factors, such as food consumption or dietary patterns (Clark et al., 2019). The statistical models used in these studies are flexible to control for or eliminate the effects of possible confounders such as gender, age, or smoking habits (Pourhoseingholi et al., 2012).

First, the percentage of disease reduction dependent on eating habits was examined. Specifically, the influence of MD and the SNND on the risks of T2D, obesity, CVD and CRCA was analysed (see **Table SM1.7** in the **Supplementary Material** for the cohort studies included in this analysis). SEAD was not included in the health assessment due to the lack of valuable information in the literature in terms of cohort studies.

Secondly, the connection between food consumption present in Spanish dietary patterns and the risk of disease was examined through a dose-response meta-analysis. A dose-response meta-analysis of prospective cohort studies is a useful tool to investigate the possible dose-response relationship between a certain food category and a health outcome (Springmann et al., 2018).

The health impact is the relative risk (RR) of suffering an illness because of consuming an extra plate of food per day in relation to the mean intake reported in an observational study (Clark et al., 2019). If the RR is greater than 1, the health outcome is more likely to occur if an extra serving is consumed. If the RR is less than 1, the health outcome is less likely to occur if an additional serving is consumed. The RR of one implies that there is no difference in the health outcome if an additional consumption of a food has occurred or not (Steven Tenny, 2020). Further description of the dose-response meta-analysis considered with their corresponding serving sizes was reported in **Tables SM1.8-SM1.11** in the **Supplementary Material**.

2.6. Cost index

Price is one of the main pillars of food safety and a key determinant in the selection of a daily diet (FAO, 2019). Thus, it is of great interest to estimate the theoretical cost (€•person^{-1}•day^{-1}) of the SNND. For this, the average prices (€•kg^{-1}) per foodstuff were collected from the national database Spanish Ministry of Agriculture, Food and Environment (MAPA, 2019). A detailed description of the costs per foodstuff were gathered in **Table SM1.12** in the **Supplementary Material.**

2.7. Combining health, environmental, nutritional quality and economic outcomes

Radar charts were used to visualize the multivariate outcomes analysed. Therefore, the two environmental parameters calculated (CF and WF), the four health outcomes (T2D, obesity, CVD and CRCA) and the cost index were combined into a radar plot for each food category in the SNND.

3. Results

3.1. Carbon footprint assessment

The SNND CF was estimated at 3.58 kg CO_2eq·person^{-1}day^{-1}. The food production stage (S1) was by far the main responsible for GHG emissions (i.e. 3.41 kg CO_2eq· person^{-1}day^{-1}) covering 95% of the total CF. The other two main stages, wholesale and retail distribution (S2) and distribution to consumer's households (S3) were responsible for around 3% and 2% of total GHG emissions, respectively (see Fig. 3a). Fig. 3b shows the distribution of the CF between the twelve food categories for the food production stage (S1).

Animal-based products were behind 75% of the contributions to the CF in S1. Meat and dairy consumption reported two remarkable shares, approximately 35% for both food categories in S1. Focusing on meat products, although the amount of this food category ingested in terms of the recommended daily intake is low (100 g·person^{-1}·day^{-1}), it is well-known that meat is associated with higher GHG emissions rates (Clune et al., 2017). Beef alone accounted for about 0.67 kgCO_2eq·person^{-1}·day^{-1} due to background issues related to its production, mainly enteric fermentation and manure management, among other factors (Petrovic et al., 2015). Dairy products were the other main contributors to CF, not only because they represented the first pillar in terms of recommended food intake in SNND, but also because they are a major source of major GHG emissions (e.g., CF of cheese was 10.44 kg CO_2eq·kg^{-1}). Other important food categories for CF were starch-based products with an associated CF of 0.51 kg CO_2eq·person^{-1}·day^{-1} and the group of fish and seafood with an associated CF of 0.23 kg CO_2eq·person^{-1}·day^{-1}. In terms of daily consumption, starch-based products contributed 22% to the recommended daily intake and fish and seafood 2%. In contrast, fruits and vegetables, which were considered staple foods in the diet with a total daily dietary intake of 350 and 426 g·person^{-1}·day^{-1} respectively, together represented 7% of the total CF.

As for the other stages included in the supply chain, S2 contributed 0.21 kgCO_2eq·person^{-1}day^{-1} to the total CF, being 49% of the GHG emissions derived from national and international transport and 51% derived from food losses produced at wholesale and retailer levels. On the other hand, S3 accounted for 0.15 kgCO_2eq·person^{-1}day^{-1} including the transport of foodstuffs from retail to household (responsible for40% of GHG emissions) along with the generation of food waste at household (60%). In terms of quantitative waste production ratios, food waste at wholesale and retail distribution (S2) and waste production at household (S3) were around 84.0 and 125.4 g·person^{-1}day^{-1}, respectively.

3.2. Water footprint assessment

The global average WF related to the SNND was 3528 L per capita and day. Fig. 4a shows the distribution of WF considering colour (green, blue or grey). WF green contributed to the total WF by more than 74%. In terms of the global average WF by food group, animal-based products make up 59% of the total score (see Fig. 4b). Dairy products had a WF of 1146 L·person^{-1}·day^{-1}, the highest proportion among food categories, closely followed by meat with a WF of 812 L·person^{-1}·day^{-1}. Considering the global WF of food categories, olive oil and nuts showed a remarkable effect with a WF associated of 17 L·g^{-1}·day^{-1} and 10 L·g^{-1}·day^{-1}, respectively. Finally, each foodstuff was analysed separately in terms of WF. The highest WF corresponded to almonds (24 L·g^{-1}·day^{-1}), game (18 L·g^{-1}·day^{-1}), olive oil (17 L·g^{-1}·day^{-1}), beef (13 L·g^{-1}·day^{-1}) and walnut (10 L·g^{-1}·day^{-1}).

3.3. Nutritional quality index

Diets link environment and human health through the nutritional quality of food. It is therefore important to pay attention to dietary

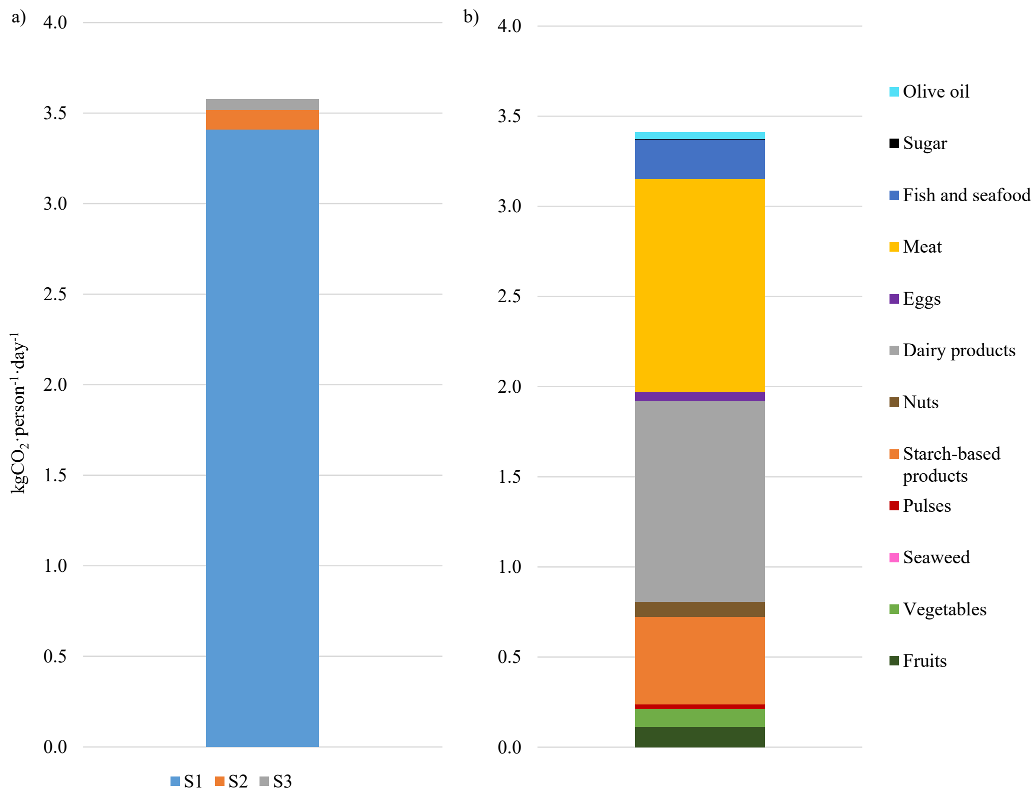

Fig. 3. Carbon footprint (CF) estimation (kgCO_2eq·person^{-1}day^{-1}) of the Southern version of New Nordic Diet (SNND) a) distribution per life cycle stages b) distribution per food categories for the food production stage (S1).

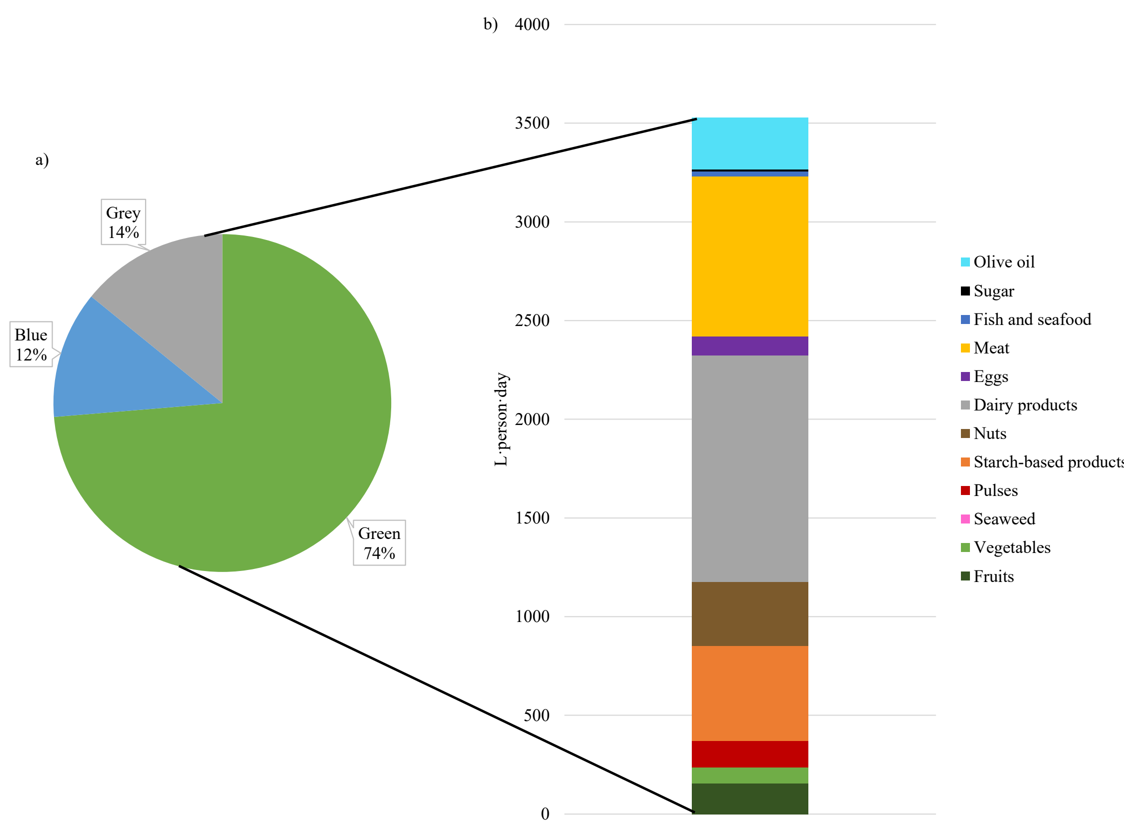

Fig. 4. Water footprint (WF) estimation (L·person^{-1}·day^{-1}) for the Southern version of New Nordic Diet (SNND) a) distribution per WF colour (WFgreen, WFblue and WFgrey) b) distribution per food categories.

transitions. In this regard, the NND under assessment in this study is among the most recommended in the Nordic countries (Iriti et al., 2020). Accordingly, a dietary quality index of 126 was calculated for the SNND, as detailed in Section 2.4.

3.4. Health outcomes

The NND has benefits in reducing non-communicable diseases (Iriti et al., 2020). Adherence to the NND was related to a weight loss of 1.83 kg per person following the diet (Ramezani-Jolfaie et al., 2020). In addition, it was associated with a significantly lower risk of T2D by 25% in women (Hazard ratio (HR): 0.75, 95% CI: 0.61–0.92) and 38% in men (HR: 0.62; 95% CI: 0.53–0.71) (Lacoppidan et al., 2015) and also reduced the risk of CRCA by 35% (IRR = 0.65, 95% CI 0.46, 0.94) in women and to a similar extent, in men (Kyro et al., 2013). In terms of CVD risk, the NND pattern improved cardiovascular risk factors by decreasing CVD risk (RR: 0.93, 95% CI, 0.88, 0.99) (Kahleova et al., 2019; Massara et al., 2020).

Having analysed how dietary choices determine human health, efforts focused on studying the impact of different food categories on health outcomes. Fig. 5 shows how the consumption of one extra serving per day of these food groups is linked with the risk of T2D, CVD, CRCA, and obesity. If RR > 1, it indicates a positive correlation between a food category and a disease, i.e., the existence of the risk factor is correlated with an increased prevalence of the event. For example, as can be seen in Fig. 5a, the consumption of processed meat presents a RR > 1 (RR = 1.46), indicating that processed meat is linked with an elevated risk of T2D. On the other hand, RR < 1 indicates a negative association. This is the case of fish in Fig. 5c (RR = 0.89), which implies that fish consumption is associated with decreased CRCA risk.

3.5. Cost index

This score pays attention to the cost that a consumer should have in his daily diet following the dietary recommendations of SNND. The estimated cost for the SNND was 4.30 €·person^{-1}day^{-1}. As can be seen in Fig. 6 starch-based products were the largest contribution to the daily food expenses (20%), followed closely by meat (16%), vegetables (17%), dairy products (14%) and fruits (14%).

3.6. Combining health, environmental and economic outcomes

Fig. 7 plots the two environmental impacts analysed (WF and CF), the cost, the health outcomes (T2D, CVD, obesity and CRCA) for the main plant-based food categories (Fig. 7a) and the main animal-source food categories (Fig. 7b) of SNND in axes classified quantitatively. Note that meat was classified into three subgroups (red meat, poultry

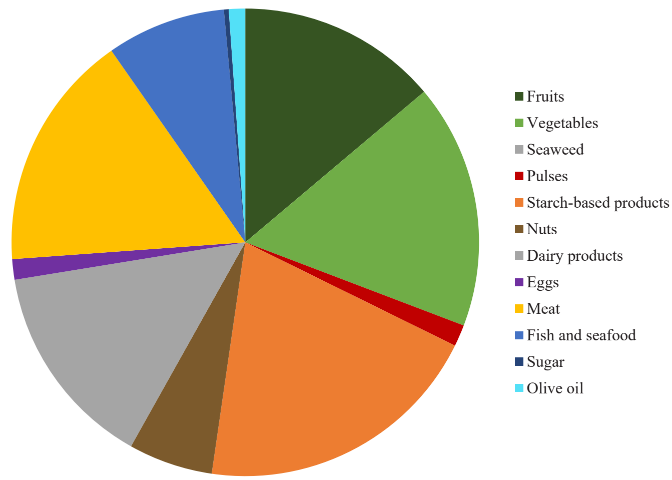

Fig. 6. Daily food expenses per food categories (€•person-1•day-1) for Southern version of New Nordic Diet (SNND).

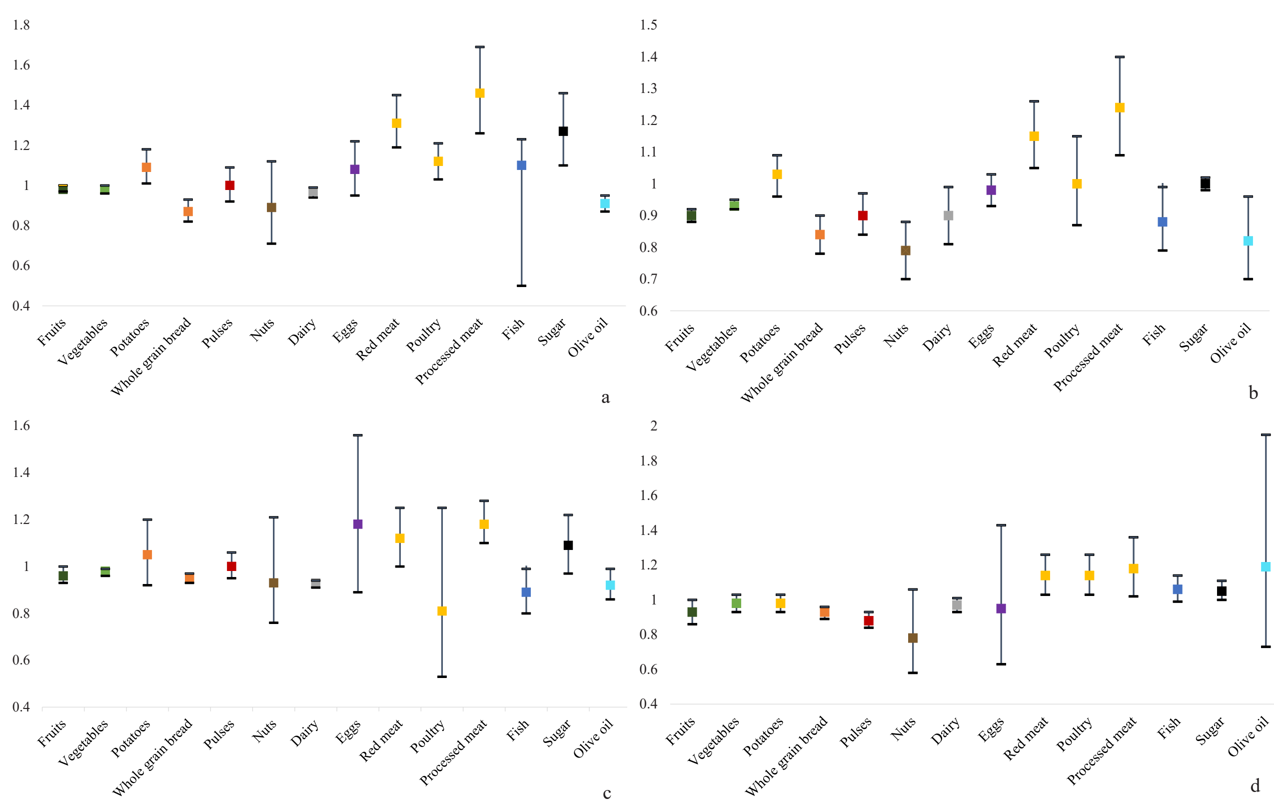

Fig. 5. Relative risk per serving of foodstuff consumed of a) Type 2 Diabetes b) Cardiovascular disease c) Colorectal cancer d) Obesity.

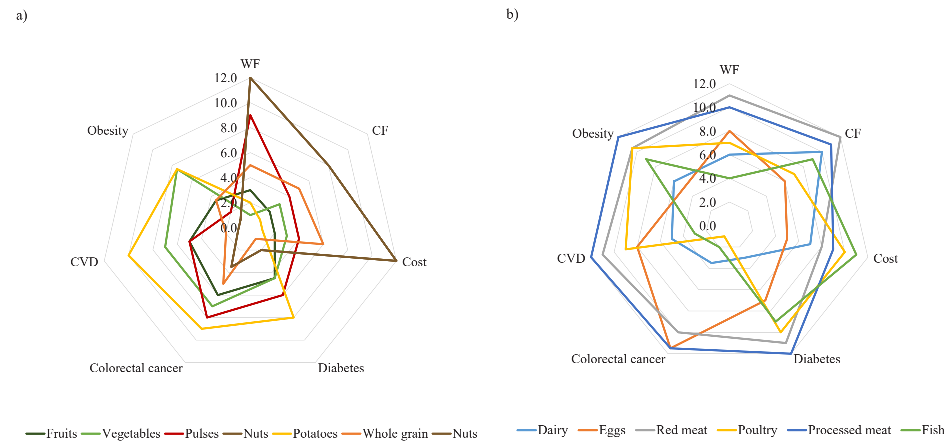

Fig. 7. Radar plot of rank-ordered environmental, health and cost metrics for Southern version of New Nordic Diet (SNND) a) per plant-based food category b) per animal source food category.

and processed meat) with the aim of adapting to the division made in the epidemiological studies analysed. Food categories were ranked from 1 to 12 for each of the environmental, health and economic indicators analysed. The value 1 indicates the best food category for a given indicator and the value 12 the worst food category. In general, food categories with low environmental impacts had good health indicators, and food categories with high environmental impacts were associated with higher RRs of disease.

Consequently, per unit of food category produced, fruits, vegetables and whole grains had lower impacts on the environmental metrics, low costs and they were not associated with a significant RR of suffering non-communicable diseases. Pulses also presented good health, environmental and economic indicators, although they had a relatively high WF. On the other hand, per unit of food category produced, red meat and processed meat were associated with the largest increases in RR of diseases and the greatest environmental impacts and economic costs. White meat, eggs and fish did not have environmental indicators as bad as red meat. Moreover, poultry contributed to reduce the risk of CRCA, eggs reported a lower RR of CVD and obesity than one, and fish was associated with greater decreases in CRCA and CVD.

Other food categories did not follow this regular trend. Potatoes were associated with increased risk of T2D, CRCA and CVD, although they were low cost and tend to have lower environmental impacts because they do not contain animal sources. The opposite happened with nuts and dairy. Although nuts and dairy produced a higher WF, had an average CF per unit of food category of 2.5 kg CO_2eq·person^{-1}·day^{-1} and 6.7 kg CO_2eq· person^{-1}·day^{-1} and were high cost (8.3 €·kg^{-1} and 5.2 €·kg^{-1}), they were not associated with an increasing risk of T2D, CRCA, CVD and obesity.

The data extracted from the SNND multidisciplinary radar diagram can be extrapolated to improve any dietary pattern. Fruits, vegetables, pulses and whole grains are key foods because they benefit planetary and human health without compromising food security. Governments should therefore highlight the importance of consuming more of these healthy and climate-friendly foods in their awareness and education campaigns. Dietary guidelines should also emphasize the importance of eating less meat, especially processed meat and beef, which are drivers of climate change and nutritional diseases. These findings are in line with the philosophy of the EAT-Lancet diet, the global reference diet for people and the planet (Kesse-Guyot et al., 2021).

4. Discussion

Bearing in mind the results obtained for the SNND, it is possible to point out the similarities and differences with the traditional dietary patterns in Spain, MD and SEAD. The comparison in terms of CF and WF was made taking into account the results obtained from González-García et al. (2020). In addition, the cost index reported in this article for MD and SEAD was updated to 2019. On the other hand, no health or nutritional quality parameters for MD and SEAD were analysed by them. Therefore, the nutritional quality index and health outcomes were estimated here in the same way as for the SNND. In the Supplementary Figures SM1.1 and SM1.2. can be seen the coexistence points and differences regarding the contribution of each food category and the mean scores (CF, WF, dietary quality and cost index) for these three omnivorous diets.

Regarding environmental metrics, the GHG emissions for SNND were 3.58 kg CO_2eq·person^{-1}·day^{-1}, in comparison with the CF values reported by González-García et al. (2020) for MD (2.79 kg CO_2eq·person^{-1}·day^{-1}) and SEAD (3.62 kg CO_2eq·person^{-1}·day^{-1}). This comparison may be perfectly acceptable considering that the same approach was considered (cradle to consumer) and that the cooking stage was excluded from the analysis in both studies. The rationale behind these results is that MD is a more plant-based dietary pattern than the other two. The recommended daily intake of animal products per day per person was higher for SNND (703 g·person^{-1}·day^{-1}) and SEAD (677 g·person^{-1}·day^{-1}) than for MD (390 g·person^{-1}·day^{-1}). Concerning food waste produced throughout the supply chain, 261, 278 and 209 g·person^{-1}·day^{-1} were produced in SEAD, MD and SNND scenarios. The fact that MD emphasizes plant-based products and their perishability explains the higher waste production for this diet (Batlle-Bayer et al., 2019).

The results for SNND were also broadly consistent with the GHG emissions calculated for other recommended diets at global level. For example, according with Kovacs et al. (2021), the total GHG emissions that could be attributed to consumption of the recommended diet in the United States are 3.83 kg CO_2eq·person^{-1}·day^{-1}. The CF of the Germany guideline is about 2.2 kg CO_2eq·person^{-1}·day^{-1} and the GHG emissions from the EAT-Lancet diet are 1.36 kg CO_2eq·person^{-1}·day^{-1}. For the purpose of comparison with the SNND, differences in boundary conditions have to be taken into account, as Kovacs et al. (2021) focused only on food production without taking into account emissions at household and delivery level. Considering the same system boundaries as they do, the SNND would report 3.24 kg CO_2eq·person^{-1}·day^{-1}, which is higher than the EAT-Lancet diet but lower than the Dietary Guidelines for Americans. On the other hand, the SNND scores better than other dietary trends associated with a European lifestyle, such as the Caveman Diet (Paleo), whose CF was assessed under the same system boundaries (5.44 kg CO_2·person^{-1}·day-1) (Cambeses-Franco et al., 2021).

SNND achieved a score of 3528 L·person^{-1}·day^{-1} for WF in comparison with MD (3044 L·person^{-1}·day^{-1}) and SEAD (3754 L·person^{-1}·day^{-1}). The largest differences between WF for the three dietary options were found in WFgreen. Considering that animal-based eating patterns involve a higher WFgreen (Mekonnen and Hoekstra, 2010), the WFgreen is expected to be higher for SNND and SEAD than for MD, with values of 2599 L, 2753 L and 2193 L per capita and day, respectively. Moreover, according with the systematic review on global water use of human diets by Harris et al. (2020), the total and green WF values for SNND are in agreement with those for an average dietary pattern in Europe (3227 L·person^{-1}·day^{-1}).

Regarding economic metrics, the cost index updated to 2019 was 4.86 €•person^{-1}•day^{-1} for SEAD and 4.18 €•person^{-1}•day^{-1} for MD. **Table SM1.13** in the **Supplementary material** gathered the average market prices per food item necessary to calculate the cost index of MD and SEAD. Therefore, the cost was 1.13 times higher if the consumer follows the SEAD recommendations instead of following the SNND guidelines (4.30 €•person^{-1}•day^{-1}). On the other hand, the daily cost of SNND per person and day was 1.03 times higher than the cost of MD. Animal-based products accounted for 42% of food expenses in the SEAD and SNND dietary patterns respectively, and 30% in MD. In SEAD and SNND, starch-based products represented the highest contribution to the cost index (23% and 20% respectively), followed by dairy products (19%) in SEAD and vegetables (17%) and fish and seafood (17%) in SNND. In MD, vegetables and fruit expenses represented the greatest contribution to the cost index (18% and 28% of food expenses, respectively).

The quality index calculation for MD and SEAD was made based on the average daily recommended intake per foodstuff established by González-García et al. (2020). These calculations were made due to the absence of these values in the literature and with the aim of subsequently comparing from a multidisciplinary perspective the recommended dietary patterns in Spain with the SNND proposed here (see **Table SM1.14.** in the **Supplementary material**). According to the results, all the evaluated dietary patterns had higher scores of overall dietary quality than those corresponding to the recommended intake level that has the reference value of 100. The best score was achieved by MD (178), followed by SEAD (150) and the SNND (126). The nutritional quality index was 0.79 times lower for the SNND than for the MD and 0.71 times lower than for the SEAD. Although the SNND reported higher vegetables and fruits intake (425 g and 350 g per day respectively) as well as fibre (35 g) and fish (43 g) than the WHO and EFSA recommendations, intakes of these elements were generally (except for fish in MD) lower than those of MD and SEAD, as shown in **Supplementary Table SM1.15.**

On the other hand, the benchmarking between SNND and other dietary patterns at global level, shows the nutritional value of this dietary design approach. The health gain score for the SNND is above other common diets analysed such as vegetarian (100), vegan (118) or the official recommended Dutch (105) (Van Dooren et al., 2014). However, its health index is far behind other diets rich in fat, protein and polyunsaturated fatty acids and restricted in carbohydrates such as the Paleo Diet, with a diet quality score of 260 (Cambeses-Franco et al., 2021).

For the comparison of health among the recommended dietary guidelines in Spain, health outcomes data related to MD were also taken from the bibliography. MD has a beneficial effect on the risk of CVD (RR = 0.70, 95% CI: 0.62–0.80) (Rosato et al., 2019), T2D (RR = 0.81, 95% CI: 0.73–0.90) (Schwingshackl et al., 2015) and CRCA (RR = 0.82, 95% CI, 0.75–0.88) (Schwingshackl et al., 2017). Similar to the NND, the epidemiological findings support that MD has also an important repercussion on weight loss (−1.75 kg, 95% CI: −2.86,-0.64 kg) (Esposito et al., 2011). No comparison was made with SEAD, as no cohort studies are available in the literature. Furthermore, only one comparison was made between NND and MD in terms of weight loss and CVD. It was not compared the diet-dependent RR of T2D and CRCA for both diets due to the variability of clinical statistical measures in the cohort studies analysed. While RRs were used in the MD cohort studies, risk ratios were used in the NND clinical research. To summarize, the cardiovascular risk profile for an individual that follows the Mediterranean-style eating pattern is better than for another who follows the NND one. However, a higher adherence to NND allows a greater weight loss than a higher adherence to MD.

4.1. Limitations and data quality

Limitations are important for a correct interpretation of the validity of this scientific work. The CF estimation is sensitive to the wide variety of LCA peer-reviewed scientific articles consulted for the estimation of the CF of each food item. In order to determine the reliability and validity of the research, the uncertainty in the dietary CF was quantified using the general equation for error propagation. For the estimation of the uncertainty of the CF of each food, the maximum and minimum values reported by Barilla Center for Food Nutrition (2016) and Clune et al. (2017) were considered (for details, see Supplementary Table SM1.16).

From the uncertainty analysis it is concluded that the CF of SNND is 3.58 ± 1,14 kgCO_2eq·person^{-1}·day^{-1}. The uncertainty range is too large mainly due to the large variety of CF values collected in meta-analyses and LCA reviews available in the literature for major climate hotspots, such as beef (Barilla Center for Food Nutrition, 2016; Clune et al., 2017). Despite the uncertainty, the CF result provides valuable knowledge if trying to inform the public about good dietary choices for environmental purposes.

Regarding the calculation of WF, an important limitation is the absence of data for non-aquaculture fish species. A limitation that also needs to be taken into account in relation to the health conclusions is that the health data come from cohort studies, which evaluate the original version of the NND and not the SNND proposed in this article.

5. Conclusions

On the way to changing diets towards healthier and more sustainable directions, the concept of NND emerged in the Nordic countries. Its principles can be transferred anywhere, including southern European countries like Spain, where two recommended omnivorous diets (MD and SEAD) are widely recognized. The present study evaluates the SNND from a multidisciplinary approach, considering economic (cost index), nutritional, environmental (CF and WF) and health indicators (RR).

First, the results of our study support the close relationship between food consumption patterns and environmental impacts. From an environmental point of view, SNND can be considered a good alternative dietary choice to SEAD and MD, although it presented highest scores in CF and WF than MD, the most plant rich diet (González-García et al., 2020).

In terms of dietary quality, the nutritional quality index of the SNND, as well as the MD and SEAD, was higher than the recommended intake level. MD scored was the best with a value of 178. SEAD had the second-best score with a value of 150. Finally, the overall quality score for SNND was 126. Concerning economic assessment, the expense was similar for MD and SNND and higher for SEAD. The epidemiologic evidence showed the protective effects of SNND and MD against CVD, T2D, and CRCA, as well as their potential effect on weight loss.

To sum up, SNND as well as SEAD and MD, is also a win-to-win diet. The three are well ranked under economic, health and environmental criteria, and should be part of dietary guidelines fostered by government and public campaigns to avoid the current shifting to a Westernized unhealthy diet.

CRediT authorship contribution statement

Cristina Cambeses-Franco: Conceived and designed the experiments, Performed the experiments, Formal analysis, Writing – original draft, Review & Editing. **Sara González-García:** Conceived and designed the experiments, Formal analysis, Review & Editing. **Gumersindo Feijoo:** Conceived and designed the experiments, Contributed materials/analysis tools, Review & Editing. **María Teresa Moreira:** Conceived and designed the experiments, Formal analysis, Contributed materials/analysis tools, Review & Editing.

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.jclepro.2021.129470.

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