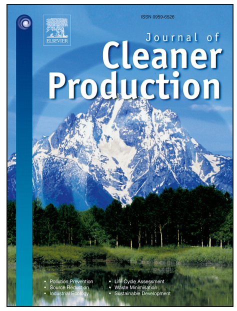
Journal Pre-proof




Efficiency assessment of diets in the Spanish regions: A multi-criteria cross-cutting approach

Xavier Esteve-Llorens, Mario Martín-Gamboa, Diego Iribarren, Maria Teresa Moreira, Gumersindo Feijoo, Sara González-García

PII: S0959-6526(19)33361-X

DOI: https://doi.org/10.1016/j.jclepro.2019.118491

Reference: JCLP 118491

To appear in: *Journal of Cleaner Production*

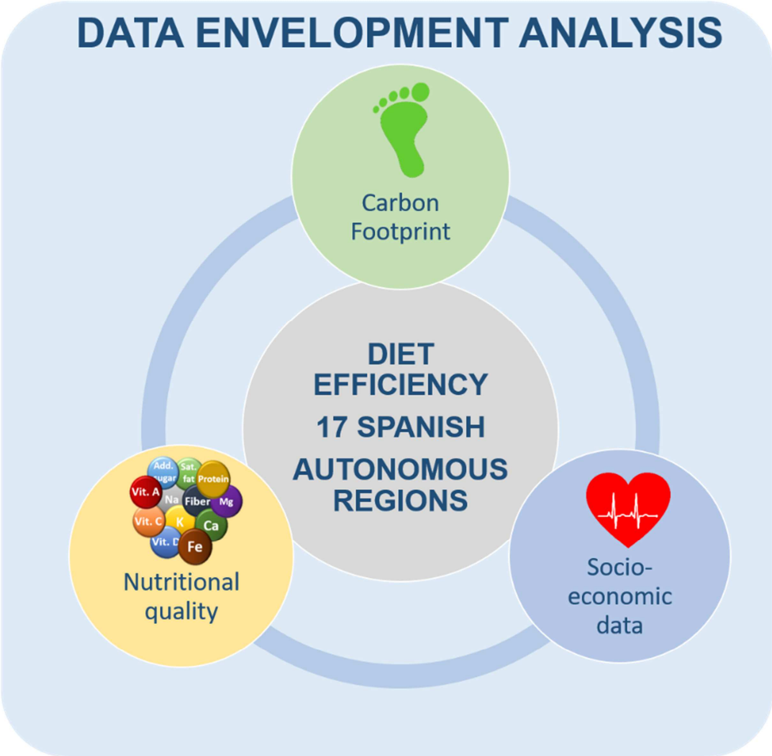
Received Date: 16 April 2019

Revised Date: 23 July 2019

Accepted Date: 18 September 2019

Please cite this article as: Esteve-Llorens X, Martín-Gamboa M, Iribarren D, Moreira MT, Feijoo G, González-García S, Efficiency assessment of diets in the Spanish regions: A multi-criteria cross-cutting approach, *Journal of Cleaner Production* (2019), doi: https://doi.org/10.1016/j.jclepro.2019.118491.

**Graphical Abstract**



*7,489 words*

**Efficiency assessment of diets in the Spanish regions: a multi-criteria cross-cutting approach**

Xavier Esteve-Llorens[1]*, Mario Martín-Gamboa[2], Diego Iribarren[3], Maria Teresa Moreira[1], Gumersindo Feijoo[1], Sara González-García[1].

[1]Department of Chemical Engineering, Institute of Technology, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Galicia, Spain

[2]Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

[3]Systems Analysis Unit, IMDEA Energy. 28935 – Móstoles, Spain.

*Corresponding author: Xavier Esteve-Llorens. E-mail: Xavier.esteve.llorens@usc.es

**Abstract**

Food systems are one of the main drivers of the global greenhouse gases emissions from anthropogenic sources, which could be aggravated by the projected increase in world population. Hence, the adoption of sustainable diets that guarantee good and accessible nutrition and a low environmental impact is an increasingly important need. This goal is, by nature, a multi-dimensional and multi-criteria challenge that should take into account nutritional, environmental and socio-economic aspects. In this sense, this work proposes a novel methodological framework that involves the use of Data Envelopment Analysis for the efficiency assessment of dietary patterns integrating nutritional (Nutrient Rich Diet 9.3 index), environmental (carbon footprint) and socio-economic criteria (number of deaths due to tumours of the digestive system, obesity-related health expenditure, and number of persons with food shortages). The applicability of this methodology is proven through the case study of the dietary patterns of the 17 Spanish autonomous regions. The analysis reveals the existence of seven autonomous regions with sustainable dietary patterns. Furthermore, most regions have multi-criteria efficiency scores above 0.60, which suggests the presence of relatively good dietary habits in Spain. Overall, it is concluded that the proposed methodology is a viable and valuable tool for benchmarking dietary patterns under multiple cross-cutting criteria.

**Keywords**: carbon footprint; data envelopment analysis; dietary habits; efficiency; food; nutritional quality

**Nomenclature**

| | |
|---|---|
| CF | Carbon Footprint |
| DEA | Data Envelopment Analysis |
| DMUs | Decision Making Units |
| FAO | Food and Agriculture Organization of the United Nations |
| FU | Functional Unit |
| GHG | Greenhouse Gas |
| LCA | Life Cycle Assessment |
| LCI | Life Cycle Inventory |
| MDV | Maximum Daily Value |
| NRD | Nutrient Rich Diet |
| RDV | Recommended Daily Value |

## 1. Introduction

Food systems encompass a wide range of processes and activities focused on feeding the population, such as the production, processing, packaging, transporting, marketing and consumption of food (Duchin, 2005; Vermeulen et al., 2012). In this sense, they are one of the main drivers of global greenhouse gas (GHG) emissions from anthropogenic sources (≈ 25%) (Niles et al., 2017; Payne et al., 2016; Springmann et al., 2016). Furthermore, it is expected that by 2050 the world population will have increased to nearly ten billion people (United Nations, 2017) and thus the environmental pressure caused by the food system will also be much greater (Springmann et al., 2018; Steffen et al., 2015). Hence, a set of actions is required to adequately mitigate the effect of the expected environmental pressure. These actions could be focused, for example, on improvements in technology and management practices, reducing food loss and waste production, and changing dietary habits of population. For instance, the latter could involve promoting the consumption of plant-based products since about 80% of GHG emissions derived from the food system come from animal-based products (Springmann et al., 2016, 2018). In this regard, many recent studies highlight the environmental benefits associated with dietary patterns that are less dependent on animal-origin products (Esteve-Llorens et al., 2019; Hallström et al., 2015; Meybeck and Gitz, 2017).

In addition to a low environmental impact, nutritional quality is also necessary to achieve a sustainable diet. According to the definition from the Food and Agriculture Organization of the United Nations (FAO), a sustainable diet should have a low environmental impact, while ensuring food safety and security and, therefore being protective and respectful of biodiversity and ecosystems, accessible and economically fair and affordable (FAO, 2010). In this way, a high intake of vegetables, fruits and whole grains is related to suitable nutritional quality and also to the prevention of chronic diseases such as cancer or cardiovascular diseases (Cencic and Chingwaru, 2010). Conversely, excessive consumption of red meats such as beef, processed and ultra-processed foods with high caloric and fat contents is not recommended (Friel et al., 2009), although meat supplies nutrients that plant-origin products cannot provide (Van Dooren et al., 2014).

Bearing in mind the concept of sustainable diet (FAO, 2010), the Mediterranean diet is widely recognised as an example, as it is a plant-based diet with a moderate intake of animal-based products (Castañé and Antón, 2017). It is the most widespread traditional consumption pattern in Spain, along with other suitable variations such as the Atlantic diet, located mainly in the northwest of the Iberian Peninsula (Esteve-Llorens et al., 2019; Vaz Velho et al., 2016). However, it is important to note that current consumption patterns deviate from the traditional Mediterranean recommendations (Sáez-Almendros et al., 2013), including some types of foodstuffs that are not advisable, such as industrially processed food (AECOSAN, 2018; MAPA, 2018a).

Moreover, socio-economic factors, such as lifestyle, along with marketing and economic factors, are also important when talking about access to safe and secure food consumption patterns (Appelhans et al., 2012; Pechey et al., 2013). Consumption habits differ regionally depending on cultural preferences and levels of development (De Ruiter et al., 2014). Food cost is a relevant contributor to socio-economic patterns of diets, since foods rich in energy and of lower nutritional quality tend to be cheaper (Drewnowski, 2010). Moreover, higher quality diets are often associated with higher food expenditures(Lee et al., 2011; Pechey et al., 2015). In addition, more educated consumers usually make healthier food purchase (Handbury et al., 2015).

Therefore, the achievement of sustainable diets is, by nature, a multi-dimensional and multi-criteria challenge. The measurement of sustainability should take into consideration nutritional, environmental and socio-economic aspects in order to ensure well-being and quality of life without increasing impacts on the environment. Furthermore, this measurement is particularly relevant when a high variability of dietary patterns is observed, even between regions within the same country. However, a lack of comprehensive but practical metrics to measure the multiple aspects of sustainable diets has hampered progress towards analysing the influence of new guidelines and implementing relevant policies (Jones et al., 2016). Along with the development of well-defined and interdisciplinary criteria and metrics on the sustainability of diets, the need for tools that collectively accounts for this set of criteria is increasingly evident. Among the tools available to achieve this goal, Data Envelopment Analysis (DEA) is a linear programming tool to evaluate the relative efficiency of a number of homogenous entities (Cooper et al., 2007). Within the context of this study, this efficiency could be understood as a composite index that jointly interprets the sustainability of dietary patterns under multiple criteria. This study aims to enrich the current literature on sustainability assessment of diets by developing and applying a methodological framework for the efficiency assessment of dietary patterns under multiple cross-cutting criteria. In particular, the Spanish dietary patterns are considered as the case study to test the feasibility of the methodology. To this end, the Spanish regions (17 autonomous regions) are analysed and benchmarked taking into account nutritional, environmental and socio-economic criteria. Beyond this specific case study, the proposed methodological approach is generally relevant to the multiple-criteria assessment of the efficiency of dietary patterns regardless of the geographical scope (regional/national/international).

## 2. Materials and methods

Differences in diets available worldwide are associated with variations in the aspects surrounding them, such as economic, social and environmental factors (Van Kernebeek et al., 2014). Moreover, within the same country there may also be variations between regions, taking into account different cultural, lifestyle and climatic features, as is the case of Spain (MAPAMA, 2017). In these circumstances, a methodological framework is developed herein to evaluate the multi-criteria efficiency of diets, including the factors mentioned above. Its feasibility is proven by applying it to the 17 Spanish autonomous regions.

### *2.1. Spanish dietary habits across regions*

It is well-known that the Mediterranean diet is traditionally the one with the highest percentage of adherence in Spain (Bach-Faig et al., 2011). Additionally, it coexists with other lesser-known dietary patterns such as the Atlantic diet, located in north-western Spain (Vaz Velho et al., 2016). However, adherence to these traditional diets is shifting towards the so-called western diet, with higher consumption of animal products, processed food, and lower intake of plant-based foods than recommended (Sáez-Almendros et al., 2013; Varela-Moreiras et al., 2010). Furthermore, the great differences that exist at both climatic and cultural levels in Spain also cause a variation between regional patterns of food consumption. In this sense, the type and amount of food differs among the 17 autonomous regions (Carbajal, 2013).

### *2.2. Methodological framework for the efficiency assessment of diets*

The methodological approach proposed for the multi-criteria efficiency assessment of diets is summarised in Figure 1. The methodological structure presented herein is a variant of the three-stage Life Cycle Assessment (LCA) + DEA method proposed by Lozano et al. (2010). In particular, the list of criteria included in the analysis is extended beyond the implementation of life-cycle indicators (Martín-Gamboa et al., 2017). In this regard, a nutritional quality index and socio-economic criteria are also taken into consideration to offer a holistic vision in terms of sustainability. As shown in Figure 1, the first step of the methodological framework refers to data acquisition for socio-economic indicators, as well as for the compilation of inventories needed to assess the carbon footprint (CF) and the nutritional quality index of the annual dietary patterns of the 17 average citizens (i.e., one average citizen per autonomous region). The socio-economic indicators chosen in this study are the following: number of deaths from tumours of the digestive system, obesity-related health expenditure and number of people with food shortages. The selection of these indicators is based on their ability to represent health, economic and social aspects closely related to dietary habits in Spain. A more explanation of these indicators is provided later in Section 2.3.4. The second step of the proposed methodology focuses on the calculation of the CF and the nutritional quality index, as detailed in Sections 2.2.1 and 2.2.2, respectively.

The final stage involves the use of DEA as a tool for the multi-criteria efficiency evaluation of the dietary habits of the 17 autonomous regions in Spain. The usefulness of this approach for reporting a sustainability index has already been tested in the energy sector (Martín-Gamboa et al., 2019). For the present case study, the dietary habits of the average citizen of each Spanish autonomous region constitute the set of homogenous entities under assessment, also called decision making units (DMUs). In the DEA step, a data matrix (see Section 3.3) is processed to compute the efficiency scores of the dietary patterns of the Spanish regions. These multi-criteria efficiency scores can be understood as a composite index that jointly accounts the sustainability of Spanish dietary patterns under multiple cross-cutting aspects.

[Figure 1 around here]

*2.2.1. Carbon footprint of diets*

According to FAO (2010), one of the requirements for classifying a diet as sustainable is its low environmental impact. In this sense, the consumer is increasingly aware of the impact of certain type of foodstuffs on the environment, such as the amount of GHG emissions derived from a diet depending on the included foodstuffs (Annunziata et al., 2019; Thøgersen, 2017). In this study, the CF is selected as a key environmental indicator in all studies available in the literature regarding diets (Batlle-Bayer et al., 2019; Ritchie et al., 2018). Accordingly, an LCA approach is used to estimate the GHG emissions throughout the life cycle of the foodstuffs consumed (ISO 14040, 2006). Bearing in mind that the main objective is to evaluate the efficacy of diets taking into account the multiple criteria associated with the dietary patterns of the Spanish autonomous regions, in this LCA study only the production phase of food products is considered. In fact, this stage is the main source of GHG emissions in dietary patterns according to the literature, generating around 70% of them (Castañé and Antón, 2017; Esteve-Llorens et al., 2019; Muñoz et al., 2010), and where the greatest variations may exist between the different regions analysed and the food consumed. Other stages such as transport, household activities and waste disposal, are omitted because minor fluctuations are expected between the autonomous regions within a country (Heller et al., 2013). Therefore, the LCA approach follows a cradle-to-gate perspective.

The functional unit (FU) selected for this study refers to the foodstuffs purchased by the average citizen of each Spanish region for household consumption on an annual basis. Therefore, it is a caloric-independent FU that only takes into account the annual consumption per person of food in the different Spanish regions to compare the impacts between different dietary habits. This amount is extracted directly from the household consumption survey carried out by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA, 2018a) as explained later in Section 2.3. Thus, besides being a FU commonly used in related LCA studies (Arrieta and González, 2018; González-García et al., 2018; Martin and Brandão, 2017), its versatility allows the comparison of Spanish consumption patterns with other diets, whether referred to caloric intake or not.

*2.2.2. Nutrient Rich Diet 9.3*

The widely recognized Nutrient Rich Diet 9.3 (NRD9.3) index, proposed by Van Kernebeek et al. (2014), is selected to estimate nutritional quality. This index is based on the difference between nine nutrients to encourage (protein, fibre, calcium, iron, magnesium, potassium, vitamin A, vitamin E, and vitamin C) and three nutrients to limit (saturated fats, free sugars, and sodium), and their link to daily reference values (see Equation 1):

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

where nutrient *i* is the nutrient to encourage and nutrient *k* is this to limit; and Recommended Daily Values (*RDV*) and Maximum Daily Values (*MDV*) are taken from Codex Alimentarius (FAO/WHO, 2017). In addition, to avoid overestimating the nutritional quality due to excessive consumption of the nutrients to encourage, the amount ingested of each of them is capped to the RDV when it is exceeded.

The selection of the NRD9.3 allows the comparison of the nutritional quality results with other relevant studies available in the literature (González-García et al., 2018). In this way, it is important that the index is not scaled to energy intake, also allowing the comparison between diets with different caloric content.

*2.2.3. DEA for multi-criteria efficiency assessment*

The slacks-based DEA model proposed by Tone et al. (2001) is used herein to calculate the multi-criteria efficiency of dietary patterns. The analysis includes 17 DMUs corresponding to the 17 average citizens of the Spanish autonomous regions, taking 2016 as the reference year. Every DMU is characterised by four inputs (i.e., deaths from tumours of the digestive system, obesity related health expenditure, number of people with food shortages, and CF) and one output (the NRD9.3 index). The selection of the DEA elements takes into account not only the goal of the study (sustainability assessment of diets in terms of multi-criteria efficiency), but also the recommendations available for the combined LCA + DEA studies (Iribarren et al., 2016), which refer to features such as quantifiability, specificity, availability and quality.

DEA is a linear programming methodology that non-parametrically calculates the comparative efficiency of multiple similar entities (DMUs), and projects the inefficient DMUs at the efficient frontier, thereby providing target values for the inefficient entities into efficient ones

(Cooper et al., 2007). This is done through the formulation of a model with specific features in terms of metrics (radial or non-radial model), orientation (e.g., input- or output-oriented model), and display of the set of production possibilities (e.g., constant or variable returns to scale). In this study, the specific non-radial DEA model used is an input-oriented slacks-based measure of efficiency model with variable returns to scale (SBM-I-VRS model), formulated herein according to Tone et al. (2001) and Iribarren et al. (2013):

$$\Phi_0 = \mathrm{Min}\left(1 - \frac{1}{\mathrm{M}}\sum_{\mathrm{k}=1}^{\mathrm{M}} \frac{\sigma_{\mathrm{k0}}}{x_{\mathrm{k0}}}\right) \quad (2)$$

subject to

$$\sum_{\mathrm{j}=1}^{\mathrm{N}} \lambda_{\mathrm{j0}} x_{\mathrm{kj}} = x_{\mathrm{k0}} - \sigma_{\mathrm{k0}} \quad \forall\, \mathrm{k} \quad (3)$$

$$\sum_{\mathrm{j}=1}^{\mathrm{N}} \lambda_{\mathrm{j0}} y_{\mathrm{j}} = y_0 \quad (4)$$

$$\lambda_{\mathrm{j0}} \geq 0\ \forall\, \mathrm{j}, \sigma_{\mathrm{k0}} \geq 0\ \forall\, \mathrm{k} \quad (5)$$

Where *N*: number of DMUs; *j*: index on the DMU; *M*: number of inputs; *k*: index on inputs; $x_{kj}$: amount of input *k* demanded by DMU *j*; $y_j$: amount of output generated by DMU *j*; *0*: index of the DMU under assessment; $(\lambda_{10}, \lambda_{20}, \ldots, \lambda_{N0})$: coefficients of linear combination for assessing DMU *0*; $\sigma_{k0}$: slack (i.e., potential reduction) in the demand of input *k* by DMU *0*; and $\Phi_0$: efficiency score of DMU *0*.

The choice of an input-oriented model aims to reduce inputs and ensure at least the same output (i.e., the same nutritional quality). Solving the optimisation problem results in the efficiency score (Φ) of each dietary pattern linked to the average citizen of each Spanish autonomous region. Efficiency scores lead to discriminate between efficient (Φ = 1) and inefficient (Φ < 1) dietary habits. It should be noted that these efficiency scores act as an index that brings together the different selected criteria to provide a single measure of sustainability of the dietary habits currently present in Spain. In this sense, reporting one single measurement rather than multiple criteria may facilitate the formulation of guidelines and policies based on the best-performing dietary habits identified within the set of entities under assessment.

### ***2.3. Data acquisition***

#### *2.3.1. Dietary patterns in the Spanish autonomous regions*

The information on the current consumption habits in the 17 autonomous regions that constitute the Spanish territory comes from the survey of household food demand, performed by the Spanish Ministry of Agriculture, Fishery and Food (MAPA, 2018a). The methodology followed in these surveys is based on daily data collected at the household level through a scan of their food purchases, with a total sample of 12,000 households distributed across the regions. Thus, in the selected households, foodstuffs purchases were recorded daily through a code reader and collected in a monthly sample, covering all possible seasonal variations in consumption; as a result, the average amount of food consumed per person and year was directly obtained (kg food·person$^{-1}$·year$^{-1}$). This quantity, without modification, is directly used for the estimation of both the CF and the nutritional quality of Spanish dietary patterns. It should be borne in mind that in the aforementioned database a large amount of information on the food consumed is provided. In summary, a total of 101 foods considered as the most representative (see Table 1) are grouped into 15 different food categories (i.e., fruits, vegetables, grains, legumes, nuts, dairy, eggs, meat, seafood, canned food, ready meals, sweets, fats/oils, sauces, and beverages).

[Table 1 around here]

Food consumption outside of households is not considered in this study due to the scarcity of data, as well as specifications at the level of foodstuffs. In fact, about 92% of food consumption takes place at home (MAPA, 2018b).

*2.3.2. Nutritional composition*

The nutritional composition of the foodstuffs included in the study is obtained from the Spanish Food Composition Database (AECOSAN, 2018). It provides complete nutritional information on a wide variety of foods, thus covering all the information necessary for estimating the nutritional quality index (i.e., micronutrients and macronutrients). The complete nutritional composition according to the amount of food consumed in each autonomous region can be found in the supplementary material (Table S1). In addition, the energy content of the foodstuffs is also extracted from this database in order to determine the total caloric ingestion of the consumption patterns.

*2.3.3. Data for CF assessment*

Regarding the life-cycle inventory (LCI) used to estimate the CF, a total of 33 LCA studies (see Table S2 in the supplementary material) are used to provide information on the life-cycle GHG emissions associated with the production of the different foodstuffs included in the surveys reported by the Spanish Ministry of Agriculture, Fishery and Food (i.e., 101 products with their respective CF and grouped in the corresponding food category). Due to the wide variety of available LCA studies and the variation of results among them (Berners-Lee et al., 2012; Clune et al., 2017; Werner et al., 2014), moderately conservative values are selected as far as possible. The foodstuffs are evaluated from a cradle-to-gate perspective, according to the system boundaries of this study. In this sense, although the vast majority of the selected LCA studies keep the established system boundaries, there are a few ones that incorporate additional stages, such as transport, storage or waste management. In these cases, the corresponding GHG emissions associated with these stages are subtracted. Furthermore, in some cases certain foodstuffs are assimilated to others due to the lack of data to determine their environmental impacts (e.g., nectarines as peaches, milkshake as milk, cured cheese as Galician cheese, and biscuits as cereals).

*2.3.4. Socio-economic data*

The holistic vision of sustainability is completed with the selection of three socio-economic indicators: number of deaths from tumours of the digestive system, obesity-related health expenditure and number of people with food shortages. This choice derives from the application of the available guidelines for the selection of socio-economic indicators in sustainability oriented LCA + DEA studies (Iribarren et al., 2016). In this sense, the three selected indicators fulfil the requirements in terms of quantifiability, availability, quality, and specificity to the DMU (i.e., the average citizen of each autonomous region). Table 2 presents the data corresponding to these indicators expressed for the total population of each autonomous region. The first indicator involves a health and social issue and encompasses all deaths from tumours associated with the digestive tract (such as tumours of the oesophagus, stomach and colon). In this sense, up to 30% of all cancer cases worldwide are linked to poor dietary habits, reaching 70% for cancers of the gastrointestinal tract. The second socio-economic indicator indicates the health expenditure of each autonomous region due to obesity, an issue closely linked to bad dietary habits, Finally, the third socio-economic indicator includes the number of people per autonomous region who cannot afford a meal of meat, chicken or fish at least once every two days. These data are retrieved from the annual statistics available in the Spanish National Statistics Institute database (INE, 2019).

[Table 2 around here]

## 3. Results and discussion

### *3.1. Carbon footprint of diets*

The CF results for the 17 Spanish autonomous regions range from the lowest value for Balearic Islands with 905 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$ to the highest one for Asturias with 1195 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$, as displayed in Figure 2. It is a remarkable variation of 290 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$, which can be translated into 0.79 kg $CO_2$ eq per person and day. It is observed that there are significant differences between regions within the same country. The rationale behind them may be associated with differences in climate, culture and lifestyle, which derive into the consumption of foodstuffs in different quantities and with different regularity. However, a common pattern is that about 80% of the GHG emissions come from meat, dairy products, seafood, beverages and grains. Within these categories, meat and dairy products stand out, contributing to 50% of the total GHG emissions. In this way, variations in the quantity and proportions of these food categories are largely responsible for the fluctuations in CF between the Spanish regions. The remaining 10 food categories only contribute about 20% of the GHG emissions.

Figure 2 displays not only the CF results per region, but also the proportions of the above-mentioned 5 main categories. As can be observed, the regions in north-western Spain are those with the highest CF figures. In this sense, the average citizens of Asturias, Galicia and Castile-León present CFs associated to their dietary patterns of 1195, 1170 and 1158 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$, respectively. On the contrary, the regions located in the south and east of Spain involve the lowest CF values, these being 905, 926, 944 and 968 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$ for the average citizens of the Balearic Islands, the Region of Murcia, Andalusia and the Valencian Community, respectively. Significantly higher consumption of meat, dairy products and seafood is the main cause of a higher CF in the north-western regions. Thus, Asturias, Castile-León and Galicia consume on average 28%, 19% and 37% more meat, dairy and seafood, respectively, than the Balearic Islands, the Region of Murcia, Andalusia and the Valencian Community (see Table 1). Furthermore, the higher CF figure is also related to a higher caloric intake (see Figure 3); thus, although the diet energy content does not vary much between the Spanish regions, the ones with the highest CFs are those with the highest energy intakes (Asturias, Castile-León, and Galicia).

[Figure 2 around here]

Other studies from the literature reported different results in terms of CF for dietary patterns existing in Spain. Comparison between them should be prudent due to the great variability of data sources used for the collection of LCI data, as well as to the different origin of food consumption data. In this way, when reviewing other studies, it is observed that both higher and lower CF values coexist in the country. Castañé and Antón (2017) and Esteve-Llorens et al. (2019) reported CFs of 735 and 842 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$ respectively for the Mediterranean and Atlantic diets (only considering the production stage). They are remarkably low values in comparison with the Spanish average CF obtained in the present study (1024 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$). The rationale behind this finding is that in these studies the ingestion of the recommended daily food quantities was taken into account following the Mediterranean and Atlantic patterns; additionally, beverages were not included in their scope of application. Thus, when studies based on real consumption patterns are analysed, the proportions and quantities of certain food categories change considerably (e.g., higher consumption of livestock products and processed food), and consequently the CF also varies. Thus, the CF reported by Batlle-Bayer et al. (2019) and Sáez-Almendros et al. (2013) for the average Spanish dietary patterns is 1120 and 1350 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$, respectively. These values are closer to the ones reported in our study for the regions with the highest CFs. Finally, even higher values can be found for the Galician region and Spain such as 1489 and 1350 kg $CO_2$ eq·person$^{-1}$·year$^{-1}$ respectively considering only the production stage (Esteve-Llorens et al., 2019; Muñoz et al., 2010).

### *3.2. Nutrient Rich Diet 9.3 scores*

In terms of nutritional quality results, Catalonia obtains the best NRD score (371), followed by the Basque Country (370), Navarre (364) and the Valencian Community (360). On the contrary, the lowest nutritional quality indices correspond to the dietary habits from Castile-La Mancha (329), La Rioja (331) and Andalusia (332). The differences between the regions with the highest and lowest nutritional quality are moderate (≈12%).

A higher intake of fibre, vitamin C, potassium and magnesium is the main cause of the better nutritional quality of the diets in Catalonia, the Basque Country, Navarre and the Valencian Community (see Table S1 in the supplementary material). In this regard, increased intake of fibre, vitamin C, potassium and magnesium intake is directly related to a higher consumption of plant-based foodstuffs (fruits, vegetables, legumes, and nuts). Thus, when comparing NRD9.3 scores from Catalonia and Castile-La Mancha, it can be observed that the consumption of fruits and vegetables is 13% and 25% higher in the former region, respectively. Likewise, the Basque Country consumes 23% and 14% more fruit and vegetables than in Castile-La Mancha (see Table 1). Attending to nuts consumption, it is 23% and 18% higher in Catalonia and Basque Country respectively than in Castile-La Mancha. The consumption of other nutrients considered in the index, such as the harmful ones (saturated fats, sodium, and free sugar), remains relatively stable in all regions (see Table S1 in the supplementary material). In this specific case, the consumption of saturated fats and free sugars is above the recommended upper limit by 30% and 60% respectively on average for all regions. It is mainly caused by excessive consumption of non-advisable products such as sweets, ready meals, processed food, and soft drinks. On the contrary, sodium intake remains below the upper recommended limit, on average.

Figure 3 presents the complete list of NRD9.3 scores by region and its relationship to the caloric ingestion. In Figure 3, the Spanish regions are ordered in decreasing order according to their NRD9.3 result, while the diet energy content of each of them remains around an average value of 1900 kcal per person and day. In this sense, the caloric ingestion is remarkably low.

[Figure 3 around here]

As can be observed in Figure 3, although the energy intake remains stable around a mean value, the nutritional quality decreases from the highest value in Catalonia to the lowest in

Castile-La Mancha. This is directly related to the origin of energy ingestion: the greater the amount of energy coming from plant-based and low-processed foodstuffs, the higher the nutritional quality of a diet. Conversely, if an important part of the energy comes from processed food and sweets, among others, the nutritional quality is negatively affected. This is the case of Catalonia and Castile-La Mancha: the amount of fruit and vegetables consumed in the former is 20% higher than in the latter, whereas the inhabitants of Castile-La Mancha consume 10% more meat and 5% more processed food (e.g., sweets, sauces, and soft drinks).

### *3.3. Multi-criteria efficiency scores*

After the calculation of the CFs and the nutritional quality index associated with the dietary patterns of the average citizens of the Spanish autonomous regions, DEA is carried out to compute their efficiency scores and, subsequently, to identify the Spanish regions with the best-performing dietary patterns according to the selected criteria. Thus, the DEA study involves a comparison of the dietary patterns of the average citizens of the Spanish autonomous regions in terms of relative efficiency. Further comparative studies –e.g. at the international level– would require additional data and are out of the scope of this study. Table 3 presents all the input and output data that make up the DEA matrix needed to computationally calculate the multi-criteria efficiency scores. Following the trends observed in the CF results, the Balearic Islands, Andalusia, and the Region of Murcia are among the autonomous communities with the lowest number of deaths due to tumours of the digestive system (allocated to each average citizen), while Asturias presents the highest value. In the case of obesity-related health expenditure, the average expenditure per person in Spain is 91 euros, with the highest expenses in Navarre and the Basque Country and the lowest in Andalusia. Regarding food shortages, the case of the Canary Islands is highlighted, with a value significantly higher than those of the rest of the autonomous regions. Given the high variability of findings involved in the analysis, the use of DEA is convenient to collectively interpret all the information through a single sustainability (relative efficiency) index. Thus, the DEA matrix is implemented in the SBM-I-VRS model for the estimation of the multi-criteria efficiency scores using the DEA-Solver Pro software (Saitech, 2019).

[Table 3 around here]

As a result, Figure 4 shows the multi-criteria efficiency scores obtained for the dietary patterns of the 17 autonomous regions. Seven of these regions have suitable (i.e., efficient) dietary habits under the set of criteria chosen, with efficiency scores $\Phi$ of 1. These regions with the best-performing patterns correspond to Andalusia, the Balearic Islands, the Canary Islands, Catalonia, the Community of Madrid, Navarre, and the Basque Country. Furthermore, all the autonomous regions, with the exception of Asturias, show multi-criteria efficiency scores above 0.60 and the average efficiency score of the sample is 0.84, which indicates the presence of relatively good dietary habits in Spain. This fact could be motivated by the great influence of the Mediterranean diet in practically all the autonomous regions of Spain. In the case of Asturias, which presents the lowest efficiency score ($\Phi$ = 0.57), the relatively low score may be linked to the high amounts of meat consumed in this region.

The analysis of the potential relationship between multi-criteria efficiency and certain parameters of interest (such as meat intake, average income, and unemployment rate) does not show clear trends, except in the case of low intakes of meat. In this regard, the lowest meat consumption levels within the sample are found to be always associated with efficient dietary patterns. However, it should be noted that efficient dietary habits do not always imply low meat consumption.

[Figure 4 around here]

Given the high number of autonomous regions deemed efficient, a super-efficiency analysis is also carried out to further discriminate among the efficient dietary patterns in Spain (Iribarren et al., 2010). The implementation of a super-efficiency DEA model is highly recommended within this context, ranking efficient DMUs by assigning efficiency scores greater than 1. An input-oriented slacks-based measure of super-efficiency model with variables return to scale (Super-SBM-I-VRS) is used for the discrimination between the efficient dietary patterns (Tone, 2002). Through this analysis, the average citizen of Navarre is identified as the best-performer reference, followed at a distance by the Canary Islands and Catalonia. This more accurate identification of the best-performers can be especially useful to decision- and policy-makers when it comes to setting benchmarks as reference or target values towards sustainable diets.

## 4. Conclusions

The set of criteria chosen in this study served as valuable metrics for measuring the sustainability efficiency of dietary patterns associated with a set of regions. In this sense, the collection of socio-economic data and the calculation of the carbon footprint and the Nutrient Rich Diet index 9.3 provided significant insights into how sustainable the dietary habits in Spain are. In order to interpret in a combined way these multiple cross-cutting criteria, the coupled use of DEA within the methodological framework proposed in this work proved to be feasible and valuable for the sustainability efficiency assessment of dietary habits. The application of this methodological framework to the case study of dietary patterns in Spain allowed the identification of seven regions with the most suitable dietary patterns according to the selected sustainability criteria. In fact, all the Spanish autonomous communities, except one, presented multi-criteria efficiency scores above 0.60, which concludes the presence of relatively good dietary habits in Spain. This finding is probably motivated by the great influence of the Mediterranean nutritional patterns in all Spanish regions. In particular, through a super-efficiency analysis, Navarre emerged as the region of reference when it comes to setting sustainable dietary habits. Overall, beyond the case study of Spain, the proposed methodology could contribute to defining sound guidelines and policies based on the performance of regions with efficient (i.e., sustainable) dietary patterns.

## Acknowledgements

This research has been supported by a project granted by Xunta de Galicia (project ref. ED431F 2016/001). Dr. S.G-G. would like to express her gratitude to the Spanish Ministry of Economy and Competitiveness for financial support (Grant reference RYC-2014-14984). The authors X.E-L., M.T.M., G.F. & S.G-G. belong to the Galician Competitive Research Group GRC 2013-032 as well as to CRETUS (AGRUP2015/02), co-funded by Xunta de Galicia and FEDER (EU). Dr. D.I. would like to thank the Spanish Ministry of Economy, Industry and Competitiveness for financial support (ENE2015-74607-JIN AEI/FEDER/UE). Dr. M.M-G. states that thanks are due for the financial support to CESAM (UID/AMB/50017/2019), to FCT/MCTES through national funds, and the co-funding by the FEDER, within the PT2020 Partnership Agreement and Compete 2020.

**Supplementary material**

Data on food consumption by group for each autonomous community (year 2016) are available online.

**References**

AECOSAN, 2018. Spanish Food Composition Database [WWW Document].

Annunziata, A., Agovino, M., Mariani, A., 2019. Sustainability of Italian families' food practices: Mediterranean diet adherence combined with organic and local food consumption. J. Clean. Prod. 206, 86–96. https://doi.org/10.1016/j.jclepro.2018.09.155

Appelhans, B.M., Milliron, B.J., Woolf, K., Johnson, T.J., Pagoto, S.L., Schneider, K.L., Whited, M.C., Ventrelle, J.C., 2012. Socioeconomic status, energy cost, and nutrient content of supermarket food purchases. Am. J. Prev. Med. 42, 398–402. https://doi.org/10.1016/j.amepre.2011.12.007

Arrieta, E.M., González, A.D., 2018. Impact of current, National Dietary Guidelines and alternative diets on greenhouse gas emissions in Argentina. Food Policy 79, 58–66. https://doi.org/10.1016/j.foodpol.2018.05.003

Bach-Faig, A., Fuentes-Bol, C., Ramos, D., Carrasco, J.L., Roman, B., Bertomeu, I.F., Cristià, E., Geleva, D., Serra-Majem, L., 2011. The Mediterranean diet in Spain: Adherence trends during the past two decades using the Mediterranean Adequacy Index. Public Health Nutr. 14, 622–628. https://doi.org/10.1017/S1368980010002752

Batlle-Bayer, L., Bala, A., García-Herrero, I., Lemaire, E., Song, G., Aldaco, R., Fullana-i-Palmer, P., 2019. National Dietary Guidelines: a potential tool to reduce greenhouse gas emissions of current dietary patterns. The case of Spain. J. Clean. Prod. 213, 588–598. https://doi.org/10.1016/j.jclepro.2018.12.215

Berners-Lee, M., Hoolohan, C., Cammack, H., Hewitt, C.N., 2012. The relative greenhouse gas impacts of realistic dietary choices. Energy Policy 43, 184–190. https://doi.org/10.1016/j.enpol.2011.12.054

Carbajal, Á., 2013. Dieta en España. Consumo de alimentos y manual de nutrición y dietética. Madrid.

Castañé, S., Antón, A., 2017. Assessment of the nutritional quality and environmental impact of two food diets: A Mediterranean and a vegan diet. J. Clean. Prod. 167, 929–937. https://doi.org/10.1016/j.jclepro.2017.04.121

Cencic, A., Chingwaru, W., 2010. The role of functional foods, nutraceuticals, and food supplements in intestinal health. Nutrients 2, 611–625. https://doi.org/10.3390/nu2060611

Clune, S., Crossin, E., Verghese, K., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. J. Clean. Prod. 140, 766–783. https://doi.org/10.1016/j.jclepro.2016.04.082

Cooper, W.W., Seiford, L.M., Tone, K., 2007. Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software. Springer, New York De Ruiter, H., Kastner, T., Nonhebel, S., 2014. European dietary patterns and their associated land use: Variation between and within countries. Food Policy 44, 158–166. https://doi.org/10.1016/j.foodpol.2013.12.002

Drewnowski, A., 2010. The cost of US foods as related to their nutritive value. Am. J. Clin. Nutr. 1181–1188. https://doi.org/10.3945/ajcn.2010.29300.1

Duchin, F., 2005. Sustainable consumption of food - A framework for analyzing scenarios about changes in diets. J. Ind. Ecol. 9, 99–114. https://doi.org/10.1162/1088198054084707

Esteve-Llorens, X., Darriba, C., Moreira, M.T., Feijoo, G., González-García, S., 2019. Towards an environmentally sustainable and healthy Atlantic dietary pattern: Life cycle carbon footprint and nutritional quality. Sci. Total Environ. 646, 704–715. https://doi.org/10.1016/j.scitotenv.2018.07.264

FAO/WHO, 2017. Codex Alimentarius.

FAO, 2010. Biodiversity and sustainable diets united against hunger. Rome.

Friel, S., Dangour, A.D., Garnett, T., Lock, K., Chalabi, Z., Roberts, I., Butler, A., Butler, C.D., Waage, J., McMichael, A.J., Haines, A., 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. Lancet 374, 2016–2025. https://doi.org/10.1016/S0140-6736(09)61753-0

González-García, Sara, Esteve-Llorens, X., Moreira, M.T., Feijoo, G., 2018. Carbon footprint and nutritional quality of different human dietary choices. Sci. Total Environ. 644, 77–94. https://doi.org/10.1016/j.scitotenv.2018.06.339

González-García, S., Esteve-Llorens, X., Moreira, M.T., Feijoo, G., 2018. Carbon footprint and nutritional quality of different human dietary choices. Sci. Total Environ. 644. https://doi.org/10.1016/j.scitotenv.2018.06.339

Hallström, E., Carlsson-Kanyama, A., Börjesson, P., 2015. Environmental impact of dietary change: A systematic review. J. Clean. Prod. 91, 1–11. https://doi.org/10.1016/j.jclepro.2014.12.008

Handbury, J., Rahkovsky, I.M., Schnell, M., 2015. What Drives Nutritional Disparities? Retail Access and Food Purchases Across the Socioeconomic Spectrum. Ssrn. https://doi.org/10.2139/ssrn.2632216

Heller, M.C., Keoleian, G.A., Willett, W.C., 2013. Toward a life cycle-based, diet-level framework for food environmental impact and nutritional quality assessment: a critical review. Env. Sci Technol 47, 12632–12647. https://doi.org/10.1021/es4025113

INE, 2019. Spanish Statistical Office database. https://www.ine.es/ (accessed 01 April 2019)

Iribarren, D., Vázquez-Rowe, I., Moreira, M.T., Feijoo, G., 2010. Further potentials in the joint implementation of life cycle assessment and data envelopment analysis. Sci. Total. Environ. 408, 5265–5272. https://doi.org/10.1016/j.scitotenv.2010.07.078

Iribarren, D., Martín-Gamboa, M., Dufour, J., 2013. Environmental benchmarking of wind farms according to their operational performance. Energy 61, 589–597. https://doi.org/10.1016/j.energy.2013.09.005

Iribarren, D., Martín-Gamboa, M., O'Mahony, T., Dufour, J., 2016. Screening of socio-economic indicators for sustainability assessment: a combined life cycle assessment and data envelopment analysis approach. Int. J. Life Cycle Assess. 21, 202–214. https://doi.org/10.1007/s11367-015-1002-8ISO 14040, 2006. Environmental management — Life cycle assessment — Principles and framework, Iso 14040. Switzerland. https://doi.org/10.1136/bmj.332.7550.1107

Lee, J.H., Ralston, R.A., Truby, H., 2011. Influence of food cost on diet quality and risk factors for chronic disease: A systematic review. Nutr. Diet. 68, 248–261. https://doi.org/10.1111/j.1747-0080.2011.01554.x

Lozano, S., Iribarren, D., Moreira, M.T., Feijoo, G., 2010. Environmental impact efficiency in mussel cultivation. Resour. Conserv. Recycl. 54, 1269–1277. https://doi.org/10.1016/j.resconrec.2010.04.004MAPA, 2018a. Household consumption database - Base de datos de consumo en hogares [WWW Document]. URL https://www.mapa.gob.es (accessed 4.12.19).

MAPA, 2018b. Report on food consumption in Spain - Informe del consumo de alimentación en España, Gobierno de España. Madrid (Spain). https://doi.org/http://www.magrama.gob.es/es/alimentacion/temas/consumo-y-comercializacion-y-distribucion-alimentaria/informeconsumoalimentacion2014_tcm7-382148.pdf

MAPAMA, 2017. Report on food consumption in Spain - Informe del consumo de alimentación en España. Madrid, Spain.

Martin, M., Brandão, M., 2017. Evaluating the environmental consequences of Swedish food consumption and dietary choices. Sustain. 9. https://doi.org/10.3390/su9122227

Martín-Gamboa, M., Iribarren, D., García-Gusano, D., Dufour, J., 2017. A review of life-cycle approaches coupled with data envelopment analysis within multi-criteria decision analysis for sustainability assessment of energy systems. J. Clean. Prod. 150, 164–174. https://doi.org/10.1016/j.jclepro.2017.03.017

Martín-Gamboa, M., Iribarren, D., García-Gusano, D., Dufour, J., 2019. Enhanced prioritisation of prospective scenarios for power generation in Spain: How and which one?. Energy 169, 369–379. https://doi.org/10.1016/j.energy.2018.12.057Meybeck, A., Gitz, V., 2017. Conference on “Sustainable food consumption” Sustainable diets within sustainable food systems. Proc. Nutr. Soc. 76, 1–11. https://doi.org/10.1017/S0029665116000653

Muñoz, I., Milà I Canals, L., Fernández-Alba, A.R., 2010. Life cycle assessment of the average Spanish diet including human excretion. Int. J. Life Cycle Assess. 15, 794–805. https://doi.org/10.1007/s11367-010-0188-z

Niles, M., Esquivel, J., Ahuja, R., Mango, N., 2017. Climate Change & Food Systems: Assessing Impacts and Opportunities. Washington. https://doi.org/10.13140/RG.2.2.28895.46248

Payne, C.L.R., Scarborough, P., Cobiac, L., 2016. Do low-carbon-emission diets lead to higher nutritional quality and positive health outcomes ? A systematic review of the literature 19, 2654–2661. https://doi.org/10.1017/S1368980016000495

Pechey, R., Jebb, S.A., Kelly, M.P., Almiron-Roig, E., Conde, S., Nakamura, R., Shemilt, I., Suhrcke, M., Marteau, T.M., 2013. Socioeconomic differences in purchases of more vs. less healthy foods and beverages: Analysis of over 25,000 British households in 2010. Soc. Sci. Med. 92, 22–26. https://doi.org/10.1016/j.socscimed.2013.05.012

Pechey, R., Monsivais, P., Ng, Y.L., Marteau, T.M., 2015. Why don't poor men eat fruit? Socioeconomic differences in motivations for fruit consumption. Appetite 84, 271–279. https://doi.org/10.1016/j.appet.2014.10.022

Ritchie, H., Reay, D.S., Higgins, P., 2018. The impact of global dietary guidelines on climate change. Glob. Environ. Chang. 49, 46–55. https://doi.org/10.1016/j.gloenvcha.2018.02.005

Sáez-Almendros, S., Obrador, B., Bach-Faig, Serra-Majem, L., 2013. Environmental footprints of Mediterranean versus Western dietary patterns: beyond the health benefits of the Mediterranean diet. Environ. Heal. 12, 1–8. https://doi.org/10.1186/1476-069X-12-118

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., De Vries, W., Vermeulen, S.J., Herrero, M., Carlson, K.M., Jonell, M., Troell, M., DeClerck, F., Gordon, L.J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., Godfray, H.C.J., Tilman, D., Rockström, J., Willett, W., 2018. Options for keeping the food system within environmental limits. Nature. https://doi.org/10.1038/s41586-018-0594-0

Springmann, M., Godfray, H.C.J., Rayner, M., Scarborough, P., 2016. Analysis and valuation of the health and climate change cobenefits of dietary change 113, 1–6. https://doi.org/10.1073/pnas.1523119113

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., De Vries, W., De Wit, C.A., Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sörlin, S., 2015. Planetary boundaries: Guiding human development on a changing planet. Science (80-. ). 347. https://doi.org/10.1126/science.1259855

Thøgersen, J., 2017. Sustainable food consumption in the nexus between national context and private lifestyle: A multi-level study. Food Qual. Prefer. 55, 16–25. https://doi.org/10.1016/j.foodqual.2016.08.006

Tone, K., 2001. A slacks-based measure of efficiency in data envelopment analysis. Eur. J. Oper. Res. 130, 498–509. https://doi.org/10.1016/S0377-2217(99)00407-5

Tone, K., 2002. A slacks-based measure of super-efficiency in data envelopment analysis. Eur. J. Oper. Res. 143, 32–41. https://doi.org/10.1016/S0377-2217(01)00324-1United Nations, 2017. World Population Prospects 2017 [WWW Document]. World Popul. Proj. to Reach 9.8 billion 2050, 11.2 billion 2100.

Van Dooren, C., Marinussen, M., Blonk, H., Aiking, H., Vellinga, P., 2014. Exploring dietary guidelines based on ecological and nutritional values: A comparison of six dietary patterns. Food Policy 44, 36–46. https://doi.org/10.1016/j.foodpol.2013.11.002

Van Kernebeek, H.R.J., Oosting, S.J., Feskens, E.J.M., Gerber, P.J., De Boer, I.J.M., 2014. The effect of nutritional quality on comparing environmental impacts of human diets. J. Clean. Prod. 73, 88–99. https://doi.org/10.1016/j.jclepro.2013.11.028

Varela-Moreiras, G., Ávila, J.M., Cuadrado, C., del Pozo, S., Ruiz, E., Moreiras, O., 2010. Evaluation of food consumption and dietary patterns in Spain by the Food Consumption Survey: Updated information. Eur. J. Clin. Nutr. 64, S37–S43. https://doi.org/10.1038/ejcn.2010.208

Vaz Velho, M., Pinheiro, R., Sofia, A., 2016. The Atlantic Diet – Origin and features. Int. J. Food Stud. 5, 106–119. https://doi.org/10.7455/ijfs/5.1.2016.a10

Vermeulen, S.J., Campbell, B.M., Ingram, J.S.I., 2012. Climate Change and Food Systems Sonja. Annu. Rev. Environ. Resour. 37, 195–222. https://doi.org/10.1146/annurev-environ-020411-130608

Werner, L.B., Flysjö, A., Tholstrup, T., 2014. Greenhouse gas emissions of realistic dietary choices in Denmark: The carbon footprint and nutritional value of dairy products. Food Nutr. Res. 58. https://doi.org/10.3402/fnr.v58.20687

**Table and figure captions**

Table 1. Amount of food eaten per person and year in each autonomous region (kg·person$^{-1}$·y$^{-1}$).

Table 2. Socio-economic indicators (data for the total population of each Spanish autonomous region).

Table 3. DEA matrix (data attributed to the average citizen of each Spanish autonomous region).

Figure 1. Methodological framework for the multi-criteria efficiency assessment of diets.

Figure 2. Carbon footprint of diets for each Spanish autonomous region.

Figure 3. Nutritional Rich Diet 9.3 (NRD9.3) scores, combined with the caloric intake per Spanish autonomous region.

Figure 4. Efficiency scores of regional dietary patterns in Spain.

**Table 1.** Amount of food eaten per person and year in each autonomous region (kg·person$^{-1}$·y$^{-1}$).

| FOOD CATEGORY | ANDALUSIA | ARAGÓN | ASTURIAS | BALEARIC ISLANDS | CANARY ISLANDS | CANTABRIA | CASTILE AND LEÓN | CASTILE-LA MANCHA | CATALONIA | VALENCIAN COMMUNITY | EXTREMADURA | GALICIA | COMMUNITY OF MADRID | REGION OF MURCIA | CHARTERED COMMUNITY OF NAVARRE | BASQUE COUNTRY | LA RIOJA | MEAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FRUITS** | 83.16 | 102.7 | 115.6 | 88.4 | 92.7 | 94.9 | 113.1 | 86.8 | 99.4 | 84.5 | 84.0 | 109.23 | 94.4 | 84.67 | 111.4 | 112.4 | 77.2 | 96.12 |
| **VEGETABLES** | 85.2 | 86.2 | 95.78 | 85.78 | 90.3 | 77.78 | 80.6 | 77.2 | 101.01 | 91.0 | 84.2 | 93.3 | 83.0 | 88.6 | 93.8 | 89.8 | 68.3 | 86.6 |
| **GRAINS** | 51.4 | 51.2 | 66.5 | 49.3 | 49.6 | 53.8 | 62.5 | 58.4 | 51.1 | 52.6 | 52.3 | 65.6 | 45.8 | 50.9 | 61.6 | 59.9 | 53.7 | 55.7 |
| **LEGUMES** | 2.7 | 3.5 | 4.2 | 2.7 | 2.8 | 3.6 | 2.8 | 2.8 | 3.6 | 2.9 | 3.1 | 2.4 | 2.6 | 2.8 | 2.9 | 3.4 | 2.7 | 3.0 |
| **NUTS** | 4.2 | 6.2 | 5.6 | 5.5 | 4.8 | 4.3 | 4.5 | 4.4 | 6.9 | 5.3 | 4.6 | 4.8 | 4.5 | 4.6 | 4.5 | 4.5 | 4.3 | 4.9 |
| **DAIRY** | 91.9 | 103.6 | 129.5 | 81.9 | 99.5 | 100.5 | 124.3 | 108.1 | 86.2 | 90.6 | 110.7 | 115.7 | 95.5 | 90.6 | 107.7 | 100.7 | 100.7 | 102.2 |
| **EGGS** | 7.7 | 10.1 | 9.9 | 7.7 | 7.4 | 10.1 | 9.6 | 8.2 | 7.9 | 8.4 | 7.5 | 7.9 | 7.6 | 7.2 | 8.9 | 9.3 | 8.5 | 8.5 |
| **MEAT** | 39.2 | 49.3 | 47.4 | 35.6 | 31.8 | 40.1 | 51.2 | 45.3 | 41.9 | 41.8 | 40.8 | 45.6 | 39.9 | 39.0 | 42.0 | 41.9 | 41.1 | 42.0 |
| **SEAFOOD** | 17.6 | 21.7 | 25.5 | 14.3 | 14.3 | 22.1 | 25.6 | 19.7 | 20.1 | 18.5 | 17.5 | 27.7 | 19.9 | 15.9 | 18.6 | 23.8 | 19.4 | 20.1 |
| **CANNED FOOD** | 15.8 | 15.6 | 16.4 | 13.0 | 15.0 | 16.4 | 16.5 | 17.4 | 14.1 | 15.2 | 17.0 | 15.5 | 15.6 | 15.9 | 14.1 | 17.6 | 14.2 | 15.6 |
| **READY MEALS** | 10.9 | 11.4 | 10.4 | 10.0 | 9.6 | 9.9 | 9.9 | 11.1 | 14.0 | 11.3 | 10.5 | 6.2 | 11.7 | 10.6 | 8.2 | 9.3 | 13.0 | 10.5 |
| **SWEETS** | 6.2 | 7.0 | 10.1 | 7.3 | 9.1 | 7.4 | 8.8 | 7.4 | 6.9 | 7.0 | 7.3 | 10.9 | 6.1 | 7.4 | 7.5 | 7.7 | 8.3 | 7.7 |
| **OILS/FATS** | 11.3 | 12.2 | 15.7 | 11.5 | 13.0 | 14.9 | 14.9 | 9.7 | 11.9 | 9.0 | 10.2 | 17.6 | 10.7 | 8.6 | 10.2 | 13.5 | 14.3 | 12.3 |
| **SAUCES** | 1.9 | 1.5 | 1.9 | 1.3 | 2.4 | 2.1 | 1.6 | 2.0 | 1.3 | 1.5 | 2.0 | 1.3 | 1.4 | 1.9 | 1.7 | 1.6 | 1.3 | 1.7 |
| **BEVERAGES** | 91.5 | 64.6 | 67.8 | 82.1 | 90.5 | 55.3 | 63.6 | 91.5 | 73.9 | 75.1 | 79.5 | 69.0 | 74.8 | 83.9 | 62.8 | 62.9 | 53.2 | 73.1 |
| **TOTAL** | 521.3 | 547.2 | 622.3 | 496.4 | 532.5 | 512.9 | 589.6 | 550.1 | 540.2 | 514.7 | 531.1 | 592.7 | 513.7 | 512.5 | 555.8 | 558.4 | 480.1 | 539.5 |

**Table 2**. Socio-economic indicators (data for the total population of each Spanish autonomous region).

| DMU | Number of deaths from tumours of the digestive system | Health expenditure related to obesity (M€) | Number of people with food shortages |
|---|---|---|---|
| **Andalusia** | 4224 | 618.24 | 218,629 |
| **Aragón** | 962 | 125.92 | 22,373 |
| **Asturias** | 971 | 105.95 | 49,645 |
| **Balearic Islands** | 523 | 98.78 | 10,358 |
| **Canary Islands** | 951 | 186.72 | 284,450 |
| **Cantabria** | 447 | 56.30 | 6396 |
| **Castile and León** | 2173 | 229.84 | 34,102 |
| **Castile-La Mancha** | 1272 | 183.78 | 93,883 |
| **Catalonia** | 4313 | 594.36 | 215,793 |
| **Valencian Community** | 2865 | 413.87 | 143,117 |
| **Extremadura** | 732 | 109.65 | 14,008 |
| **Galicia** | 2286 | 245.05 | 29,811 |
| **Community of Madrid** | 3279 | 525.75 | 77,720 |
| **Region of Murcia** | 695 | 122.79 | 64,811 |
| **Chartered Community of Navarre** | 380 | 69.50 | 1921 |
| **Basque Country** | 1620 | 245.18 | 43,346 |
| **La Rioja** | 219 | 25.60 | 12,192 |

**Table 3**. DEA matrix (data attributed to the average citizen of each Spanish autonomous region).

| DMU | Number of deaths from tumours of the digestive system | Health expenditure related to obesity (€) | Number of people with food shortages | Carbon footprint (kg $CO_2$ eq) | NRD9.3 |
|---|---|---|---|---|---|
| **Andalusia** | $5.02 \cdot 10^{-4}$ | 73.50 | $2.60 \cdot 10^{-2}$ | 943.85 | 332.03 |
| **Aragón** | $7.31 \cdot 10^{-4}$ | 95.70 | $1.70 \cdot 10^{-2}$ | 1054.93 | 350.82 |
| **Asturias** | $9.39 \cdot 10^{-4}$ | 102.40 | $4.80 \cdot 10^{-2}$ | 1195.15 | 351.42 |
| **Balearic Islands** | $4.54 \cdot 10^{-4}$ | 85.80 | $9.00 \cdot 10^{-3}$ | 904.53 | 351.95 |
| **Canary Islands** | $4.41 \cdot 10^{-4}$ | 86.60 | 0.13 | 1010.60 | 346.76 |
| **Cantabria** | $7.69 \cdot 10^{-4}$ | 96.80 | $1.10 \cdot 10^{-2}$ | 1031.83 | 351.57 |
| **Castile and León** | $8.92 \cdot 10^{-4}$ | 94.40 | $1.40 \cdot 10^{-2}$ | 1158.17 | 345.03 |
| **Castile-La Mancha** | $6.23 \cdot 10^{-4}$ | 90.00 | $4.60 \cdot 10^{-2}$ | 1027.38 | 328.82 |
| **Catalonia** | $5.80 \cdot 10^{-4}$ | 79.90 | $2.90 \cdot 10^{-2}$ | 1010.63 | 370.57 |
| **Valencian Community** | $5.81 \cdot 10^{-4}$ | 83.90 | $2.90 \cdot 10^{-2}$ | 968.42 | 360.44 |
| **Extremadura** | $6.79 \cdot 10^{-4}$ | 101.80 | $1.30 \cdot 10^{-2}$ | 973.28 | 345.16 |
| **Galicia** | $8.44 \cdot 10^{-4}$ | 90.40 | $1.10 \cdot 10^{-2}$ | 1169.54 | 355.94 |
| **Community of Madrid** | $5.06 \cdot 10^{-4}$ | 81.20 | $1.20 \cdot 10^{-2}$ | 1012.50 | 355.09 |
| **Region of Murcia** | $4.72 \cdot 10^{-4}$ | 83.40 | $4.40 \cdot 10^{-2}$ | 926.34 | 342.09 |
| **Chartered Community of Navarre** | $5.93 \cdot 10^{-4}$ | 108.50 | $3.00 \cdot 10^{-3}$ | 975.63 | 364.17 |
| **Basque Country** | $7.47 \cdot 10^{-4}$ | 113.10 | $2.00 \cdot 10^{-2}$ | 1088.16 | 369.84 |
| **La Rioja** | $7.01 \cdot 10^{-4}$ | 81.90 | $3.90 \cdot 10^{-2}$ | 953.42 | 330.81 |

**Figure 1.** Methodological framework for the multi-criteria efficiency assessment of diets.

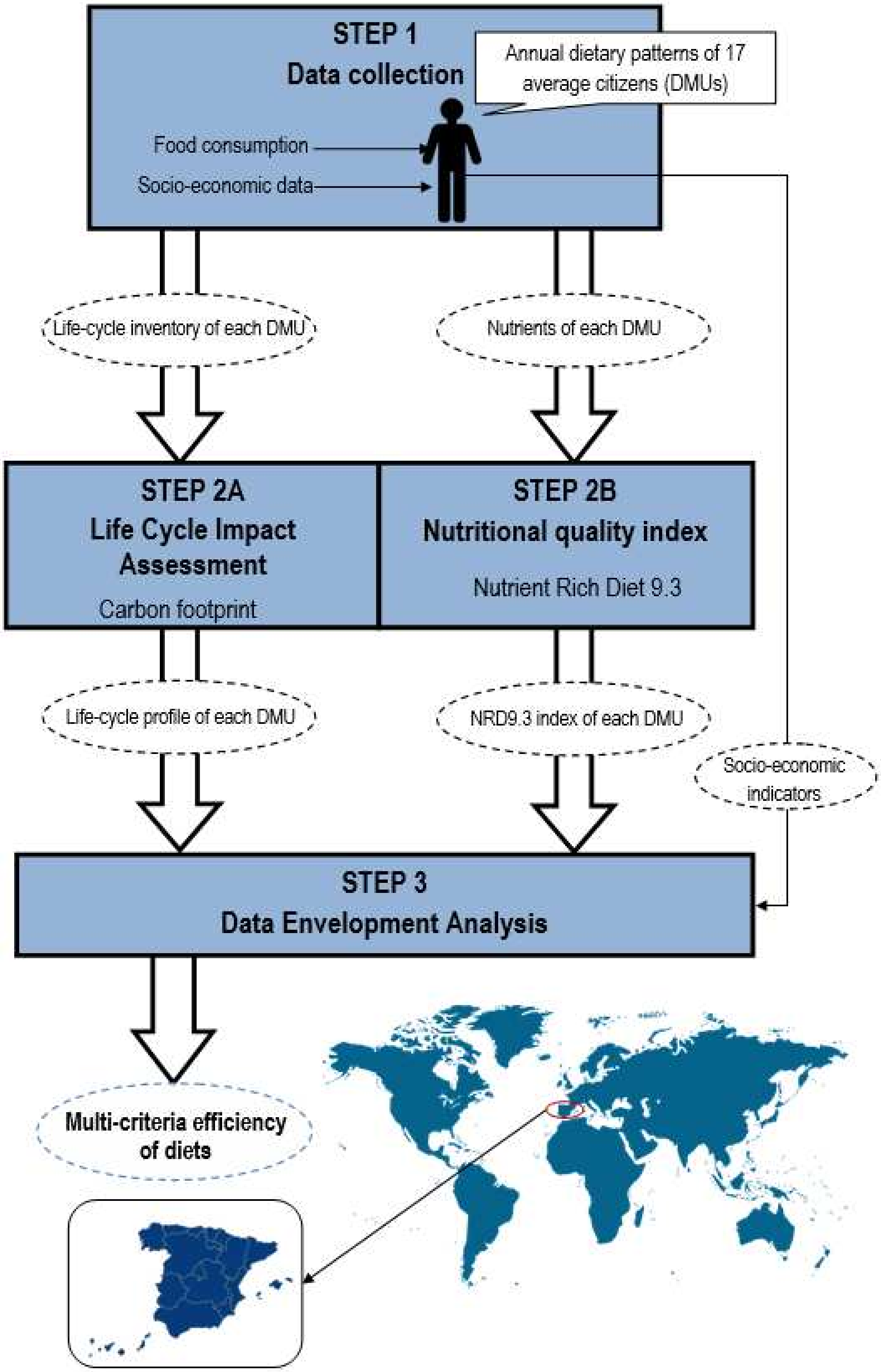


**Figure 2.** Carbon footprint of diets for each Spanish autonomous region.

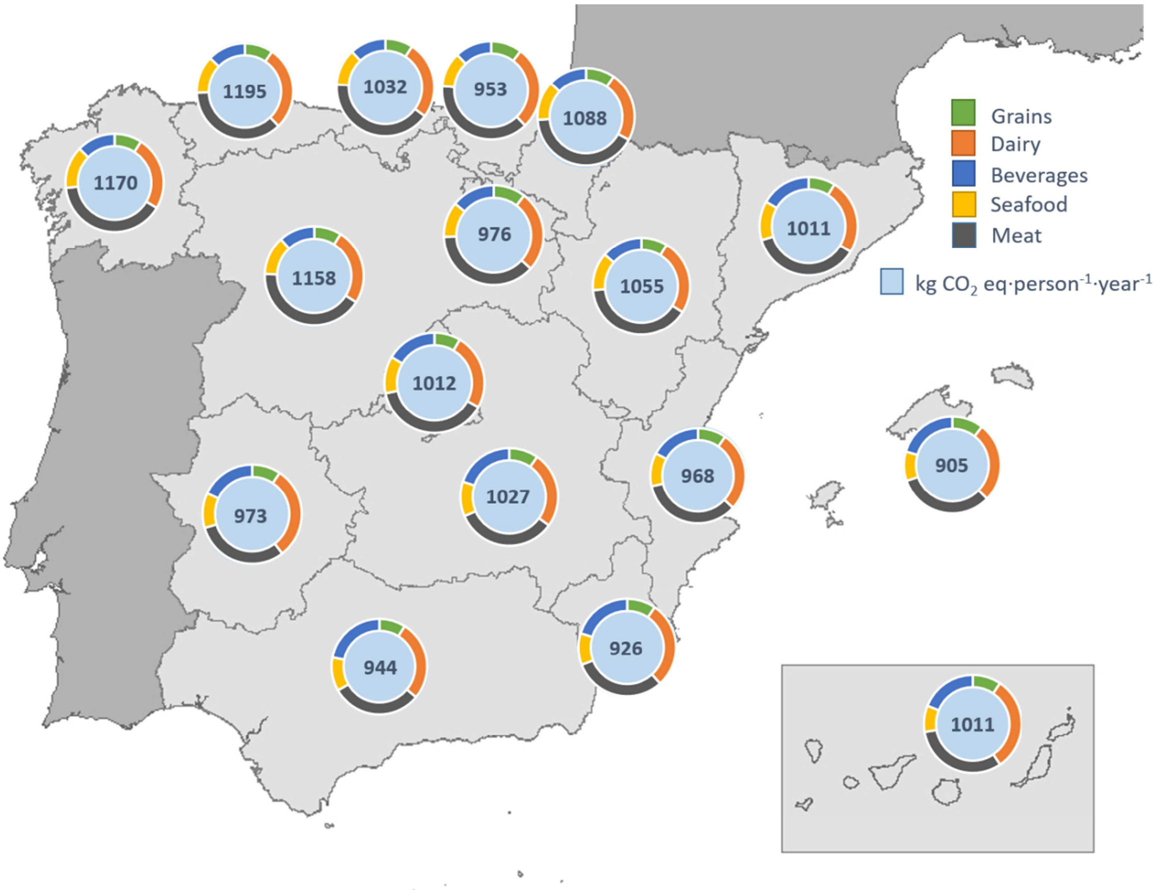


**Figure 3.** Nutritional Rich Diet 9.3 (NRD9.3) scores, combined with the caloric intake per Spanish autonomous region.)

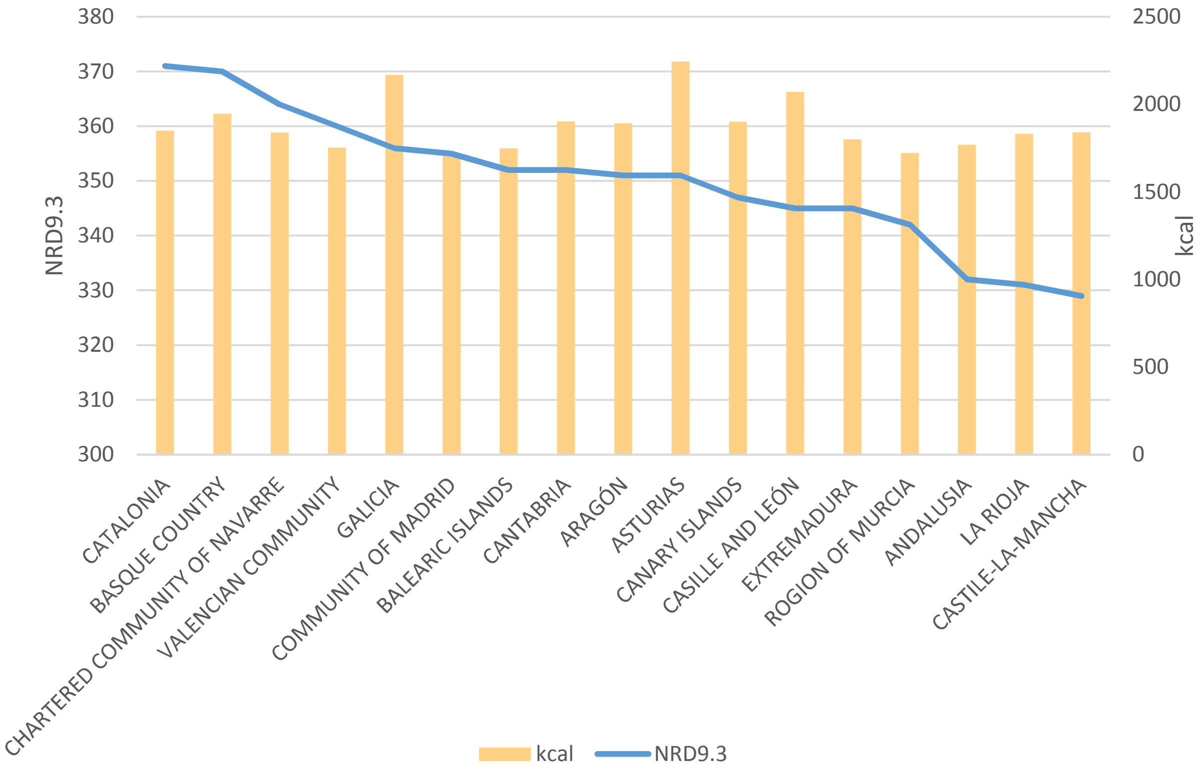
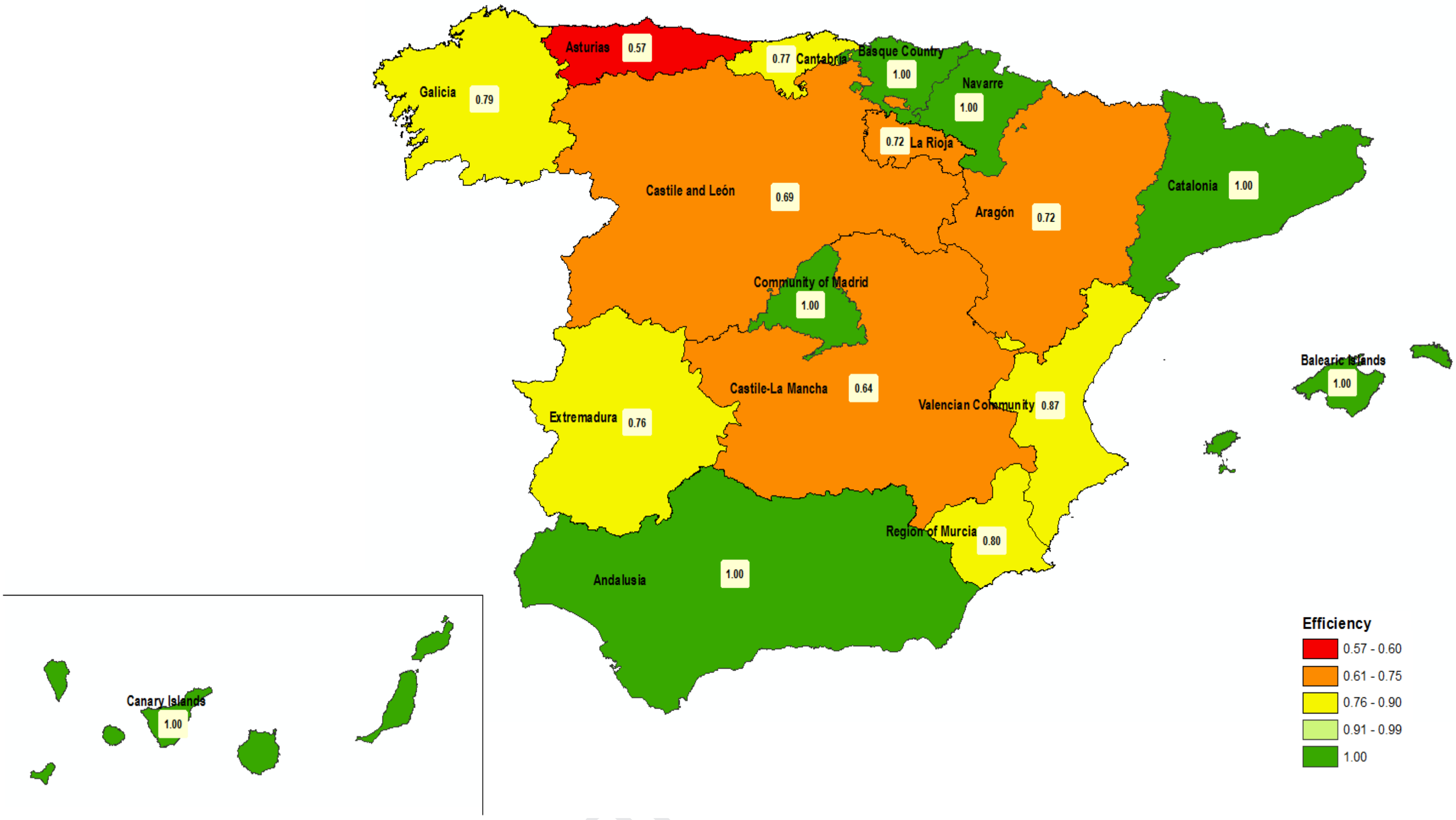


**Figure 4.** Efficiency scores of regional dietary patterns in Spain.



**Efficiency assessment of diets in the Spanish regions: a multi-criteria cross-cutting approach**

Xavier Esteve-Llorens[1]*, Mario Martín-Gamboa[2], Diego Iribarren[3], Maria Teresa Moreira[1], Gumersindo Feijoo[1], Sara González-García[1].

[1]Department of Chemical Engineering, Institute of Technology, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Galicia, Spain

[2]Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal

[3]Systems Analysis Unit, IMDEA Energy. 28935 – Móstoles, Spain.

*Corresponding author: Xavier Esteve-Llorens. E-mail: Xavier.esteve.llorens@usc.es

***Highlights***

- Novel methodological framework for evaluating the efficiency of regional diets
- Feasibility proven through a case study of 17 average citizens of Spanish regions
- Multi-dimensional analysis with environmental, nutritional and socio-economic data
- Identification of the regions with the most suitable dietary habits
- The average Spanish citizen adopts sustainable dietary habits