Food affordability and nutritional values within the functional unit of a food LCA. An application on regional diets in Spain.

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Abstract

This study assesses the environmental impacts associated with current regional-average diets in Spain, and it evaluates the environmental benefits of adopting a diet based on the National Dietary Guidelines (NDG). To establish a fair method for diets' comparison among the different regions, a novel functional unit (FU), that considers both the nutritional and the socio-economic dimensions, was developed. Diets in north-western regions have larger impacts due to the high caloric energy and ruminant meat intake, as well as for being less affordable. The adoption of the NDG-based diet can potentially reduce the environmental impacts (GHG emissions, blue water footprint and land use) between 15 and 60% of current regional eating patterns. This study highlights the importance of properly selecting the FU, and integrating the concept of food affordability within the FU in diet LCAs.

Keywords: carbon footprint, land use, blue water, diets, sustainability, nutrition

Introduction

A more plant-based diets have been shown to have a better environmental performance (Hallström et al., 2015; Rosi et al., 2017; Walker et al., 2018). Therefore, dietary shifts towards these diets are being promoted as a key strategy to reduce the environmental impacts of the food system (Aleksandrowicz et al., 2016; Hallström et al., 2015; Heller et al., 2013; Springmann et al., 2018). However, how the environmental benefits of these dietary changes are assessed remains a methodological issue (Heller et al., 2013).

Following the Life Cycle (LC) approach, comparative studies of diets should define the function of a diet, and quantify it by the functional unit (FU), which is the basis of comparison. However, most comparative Life Cycle Assessment (LCA) studies of diets (Arrieta and González, 2018; Blas et al., 2019; He et al., 2018; Ruiter et al., 2014; Treu et al., 2017; Vanham et al., 2013) do not define their FU. In general, they follow a mass-based FU approach, thus, considering the aggregated amount of consumed or recommended food products. Nevertheless, nutrition has been considered as the main function of diets (Heller et al., 2013).

To integrate the nutrition dimension within the FU, there are two main procedures. First, and most common, the adjustment of all comparative diets to the same energy content (Castañé and Antón, 2017; Heller and Keoleian, 2015; Meier and Christen, 2013; van de Kamp et al., 2018; Veeramani et al., 2017). Second, the use of nutritional profiles or quality indices of diets to correlate them with the environmental perfomance (i.e. Vieux et al., 2012) or to integrate them within the FU (Van Kernebeek et al., 2014). However, these procedures do not allow the assessment, for example, of reducing the energy intake; which is a relevant aspect in high-income countries where caloric energy overconsumption takes place. In this regard, Batlle-Bayer et al. (2019a) proposed a novel energy- and nutrient-corrected FU for comparative LCAs of diets. First, they developed two scores to account for the energy and nutrition content of diets, and, second, they proposed to correct the environmental impacts of diets with these two scores. Applying this FU to diets within the Spanish context, the authors showed that the environmental benefits of changing diets were underestimated when using a mass-based FU.

The current study goes one step forward by adding the concept of food affordability within the FU. Affordability, defined as the cost of the diet relative to the income (Lee et al., 2013), is a fundamental pillar of sustainable diets. The Food and Agriculture Organization (FAO) of the United Nations defined sustainable diets as those with low environmental impacts, respectful to biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy (Burlingame et al., 2012). Diet LCA studies that consider an economic aspect within their assessment (Berners-lee et al., 2012; Dooren, 2018; Dooren and Aiking, 2016; Macdiarmid et al., 2012; Monsivais et al., 2015; Perignon et al., 2016; Seconda et al., 2018), only estimate the cost of diets based on food prices. However, food choices depend on food prices and affordability (Lee et al., 2013), and, therefore, when assessing the sustainability of a diet, it is crucial to know how affordable that cost of a diet is.

To our knowledge, no previous studies have proposed a method that integrates food affordability, together with the nutritional dimension, within the FU of LCA studies on diets. This study applies this novel FU to assess and compare the environmental impacts of the Spanish regional diets. Since food consumption (in type and amount) within Spain varies significantly among regions (Chocarro, 2003), regional studies, rather than national ones, are recommended (Serra-Majem et al., 2000). This article is the first one that compares the environmental performance of regional average diets, and three environmental impacts are assessed: GHG emissions, blue water footprint (BWF) and land use (LU).

Methods

Definition of the functional unit

This study defined the function of the diet as the intake of the required amounts of energy and nutrients to sustain the body function and daily activity, as well as being affordable. Based on this definition, the FU of a diet was defined as the annual food basket of representative food products, divided into 6 food categories (plant-based products, meat, fish, eggs, dairy, ready meals, sweets and beverages), consumed by a Spanish citizen that supplies the required energy and nutrients intake, and it is affordable.

For the diets to satisfy this FU, the environmental impacts (EI) resulting from the food basket were corrected by nutrition and economic attributes (c-EI; Eq.1). To do so, the methodology proposed by Batlle-Bayer et al. (2019a) . which corrects the EI by energy and nutrition values, was used and expanded by adding the term of food affordability (FA). FA is here defined by the concept of Residual Income (RI), which is the amount of available income that a person has after the deduction of personal debts, known as the consumption income, and expenses. Therefore, the RI of a diet (RI_{diet}) is here calculated as the consumption income remaining after the diet's cost (RI; Eq.3). Based on this, the Residual Income Score (RIS; Eq.2) was defined as the ratio between the RI_{diet} and the maximum value (RI_{max}), which is set to 1, assuming a zero expenditure on the diet and all the consumption income being available for other purposes. RIS is added to the former equation of Batlle-Bayer et al. (2019a) [Eq.1].

The component α in Eq.1 accounts for the energy intake. In the case of diets with lower daily energy intakes (DE_{diet}) than the recommended one (DE_{rec}), α is equal to the Energy Score (ES; Eq.4), defined as the ratio between DE_{diet} and DE_{rec}. In the opposite case, α is the inverse of the ES (Eq.5). The maximum value of α is 1, meaning DE_{diet} is equal to DE_{rec}. DE_{rec} is based on the recommendations given by the European Food Safety Authority (EFSA, 2017), and applied to the Spanish population (INE, 2018). The weighted average energy recommended value for a Spanish adult is 2,228 kcal per day.

$$\mathrm{c-EI}_{\,diet} = \frac{\mathrm{EI}_{\,diet}}{\mathrm{RIS} * \alpha * \mathrm{NS}} \qquad [Eq.1]$$

Where,

$$\mathrm{RIS} = \frac{RI_{diet}}{RI_{max}} = RI_{diet} \qquad [Eq.2]$$

$$RI_{diet} = 1 - \frac{Cost_{diet}}{Consumption\ Income} \qquad [Eq.3]$$

$$\alpha = \mathrm{ES} = \frac{DE_{diet}}{DE_{rec}} \qquad if\ DE_{diet} < DE_{rec} \qquad [Eq.4]$$

$$\alpha = \frac{1}{ES} \qquad if\ DE_{diet} \geq DE_{rec} \qquad [Eq.5]$$

$$NS = \frac{NQ_{diet}}{NQ_{rec}} \qquad [Eq. 6]$$

The Nutritional Score (NS; Eq.6) determines the level of the quality of a diet, and it is calculated as the ratio between the nutritional quality of a diet (NQ_{diet}) and the Recommended one (NQ_{rec}), which has the best score of 1. The nutritional quality is assessed using the Nutrient Rich Diet 9.3 index (NRD9.3; Van Kernebeek et al., 2014). It considers 9 encouraging nutrients (protein, fibre, Vitamins A, C and E, and minerals Ca, Fe, Mg and K) and 3 limiting nutrients (saturated fats, added sugar, and sodium) in the edible portion of all products in the food basket. NRD9.3 is the subtraction of TNR9 and TNL3 sub-scores (Eq. 7). The TNR9 is the sum of percentages of the daily recommended values (RV) of the 9 encouraging nutrients (Eq.8), and TNL3 is the sum of percentages of Maximum Recommended Values (MRV) of three limiting nutrients in the edible portion of all products in a food basket (Eq.9). The annual RV and the MRVs for all nutrients (Table 1) are based on the data published by the Environmental Food Safety Authority (EFSA, 2017).

$$NQ = NRD9.3 = TNR9 - TNL3 \qquad [Eq. 7]$$

$$TNR9 = \sum_{i=1}^{i=9} \frac{nutrient_{i,capped}}{RV_i} * 100 \qquad [Eq. 8]$$

$$TNL3 = \sum_{i=1}^{i=3} \frac{nutrient_i}{MV_i} * 100 \qquad [Eq. 9]$$

As recommended by Drewnowski et al. (2009), to avoid crediting the overconsumption of encouraging nutrients, their intakes were capped. Therefore, when the intake of a certain nutrient was larger than its RV, the intake of this nutrient was set to its RV. The MRV for saturated fats and sugar corresponds to a 10% of the total recommended energy intake (WHO, 1990).

Nutrient	RV ($kg\ yr^{-1}$)	MRV ($kg\ yr^{-1}$)
Protein	19.3	-
Dietary Fibre	9.1	-
K	1.3	-
Ca	0.3	-
Fe	0.004	-
Mg	0.13	-
Vit. A	0.0003	-
Vit. C	0.04	-
Vit. E	4.4	-
Saturated Fats	-	9.0
Added sugar	-	33.9
Na	-	0.9

Table 1. The annual recommended values (RV) and maximum recommended values (MRV) for the nutrients to calculate the NRD9.3. The values are based on the daily requirements from EFSA(EFSA, 2017)

System boundaries

The system boundaries of this study included processes from cradle-to-grave (Fig.1). Hence, all the life cycle stages of all the food products and beverages within the food basket were considered: from primary production to the municipal waste management of the food wasted during the consumption stage.

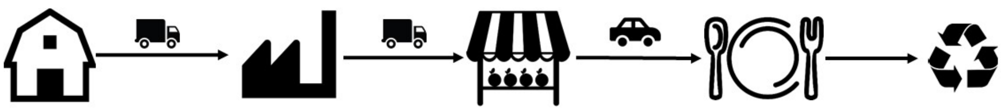

Figure 1: Diagram of the system boundaries of the study

Household food consumption.

Average annual data on in-home consumption were retrieved from the website (MAPA, 2018a) of the Spanish Ministry of Agriculture, Fisheries and Food (MAPA in Spanish). These data are the result of the Food Consumption Surveys that MAPA conducts every year. Participants, about 12,000 households, recorded daily purchases of food and beverages during the whole year using an optic reader (MAPA, 2018b). This study used the average of the annual data from 2013 to 2017 as the average food consumption of a citizen (kg food $capita^{-1}\ year^{-1}$) per region.

Out-of-home consumption

In 2017, MAPA conducted a survey on the out-of-home consumption of Spanish citizens. The purchases were recorded with a smartphone, and the average results per food category at the national level were available at MAPA's website (MAPA, 2018b). These values were assumed to be a proxy for the out-of-home consumption at the regional level. When data for a certain food product was missing, available data from other years were used (MAPA, 2007).

Regional diets

Complete regional dietary patterns for an average citizen were calculated as the sum of the regional in-home and the out-of-home consumptions (2a). The expenditure (Figure 1b) and the energy intake (Figure 2c) of the diets were calculated based on the annual regional average prices (MAPA, 2018a), and the energy (kcal) content given by the Spanish Food Composition Database (BEDCA, 2018), respectively.

The National Dietary Guidelines (NDG) diet

The NDG diet was based on the Spanish Dietary Guidelines (Tur-Marí et al., 2010), which recommends larger consumption of plant-based products and less intake of red meat and sugary products. Based on the detailed recommendations on the frequency and amount of food from the guidelines, an NDG diet was built. Details on the amount of food, cost and energy content are summarized in Figure 2.

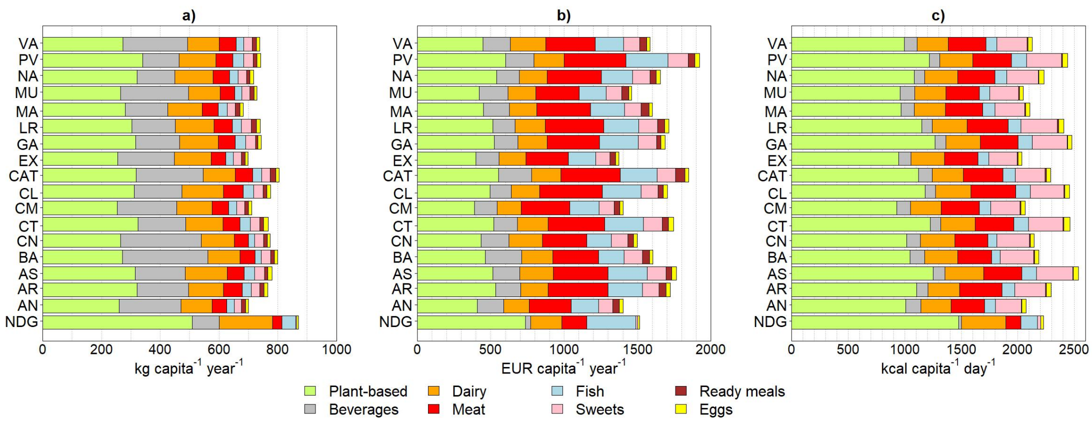

Figure 2. Annual food consumption per food category in kg (a), euros (b) and energy intake (c) for an average citizen for all the Spanish regions and the diet based on the National Dietary Guidelines (NDG). Data is based on the online available data from MAPA. Abbreviations: AN: Andalucia, AR: Aragon, AS: Asturias, BA: Baleares, CN: Canarias, CT: Cantabria, CM: Castilla La Mancha, CL: Castilla León, CAT: Catalunya, EX: Extremadura, GA: Galicia, LR: La Rioja, MA: Madrid, MU: Murcia, NA: Navarra, PV: País Vasco, VA: Valencia.

Life Cycle Inventories

LC inventories per food product considered within the food basket of a diet were built to assess the environmental impacts. The first step was to determine the countries of origin and their contribution to the national supply of each product. To do so, the Food Balance Sheets (FAO, 2019) from the FAOSTAT database were used. Next, an extensive search on input data and environmental outputs for all combinations of food products and countries was performed. The inventory of the GHG emissions for all the products considered in the food basket has been published elsewhere (Batlle-Bayer et al., 2019b), based on scientific literature. Food losses and waste along the whole food supply chain were based on Garcia-Herrero et al. (2018).

Regarding the BWF, country-specific data from Mekonnen and Hoekstra (2010b, 2010a) were used. In the case of LU, the land requirements per country and plant-based food product were based on the average country-specific crop yields from the FAOSTAT. Regarding animal-based products, crop land requirements were based on the feed required to produce them. Feed consumption was based on the studies considered in Batlle-Bayer et al (2019b).

Results

Regional diets in Spain differ in both energy level and nutritional quality. As summarized in **Table *2***, 70% of regional diets have a lower energy intake than the recommended, and they are all about 30% less nutritional than the NDG-based diet. Concerning the residual income (RI), the consumption income left after food purchases, ranges between 82% and 88%.

Diet	ES	NS	RIS
NDG	1.00	1.00	0.86
AN	0.95	0.73	0.83
AR	0.95	0.77	0.86
AS	1.05	0.61	0.85
BA	1.15	0.74	0.86
CN	1.00	0.71	0.82
CT	0.98	0.77	0.83
CM	1.12	0.73	0.84
CL	0.94	0.77	0.84

CAT	1.12	0.77	0.85
EX	1.05	0.73	0.83
GA	0.93	0.76	0.84
LR	1.12	0.74	0.85
MA	1.10	0.77	0.87
MU	0.97	0.74	0.82
NA	0.94	0.79	0.88
PV	1.02	0.77	0.86
VA	1.11	0.75	0.83

Table 2: Energy (ES), Nutritional (NS) and the Residual Income (RIS) scores for the NDG and all the regional-average diets.

Regarding the environmental impacts, the NDG-based diet is estimated to emit about 1.8 tCO_2eq (Figure 3a), to have a BWF of 141 m^3 (Figure ***3***3c) and to use around 2 ha of land (Figure ***3***3e) per year and per citizen. If these results are compared to the impacts of the current average regional diets, without any correction to the FU, and therefore, following a mass-based FU approach, several Spanish regions (CM, BA, CN, EX, MU, AN) emit fewer emissions and have lower BWF than the NDG diet. The main reason for that is their lower energy intake (around 2,100 kcal) than the recommended, as well as the relative lower consumption of ruminant meat (5 -7 kg per year) compared to other diets. Conversely, the diets of Northern regions (CL, AS, PV, CNT, GA and LR), with a daily energy overconsumption of around 2,500 kcal, and a high intake of ruminant meat (10 – 13 kg per year), have the largest values for all three environmental impacts. In regard to LU, the NDG-based diet has the best performance, meaning less land required, mainly due to the large reduction of meat consumption, which has a large contribution to the current regional diets.

When the environmental impacts of the diets are corrected to the FU, results change (Figure ***3***3 b,d,f). The NDG diet has the best performance for all three impacts, and changes in the ranking of the diets take place. For instance, AS diet becomes the highest-impact diet for all impact categories, mainly due to its low nutritional quality (Table 2).

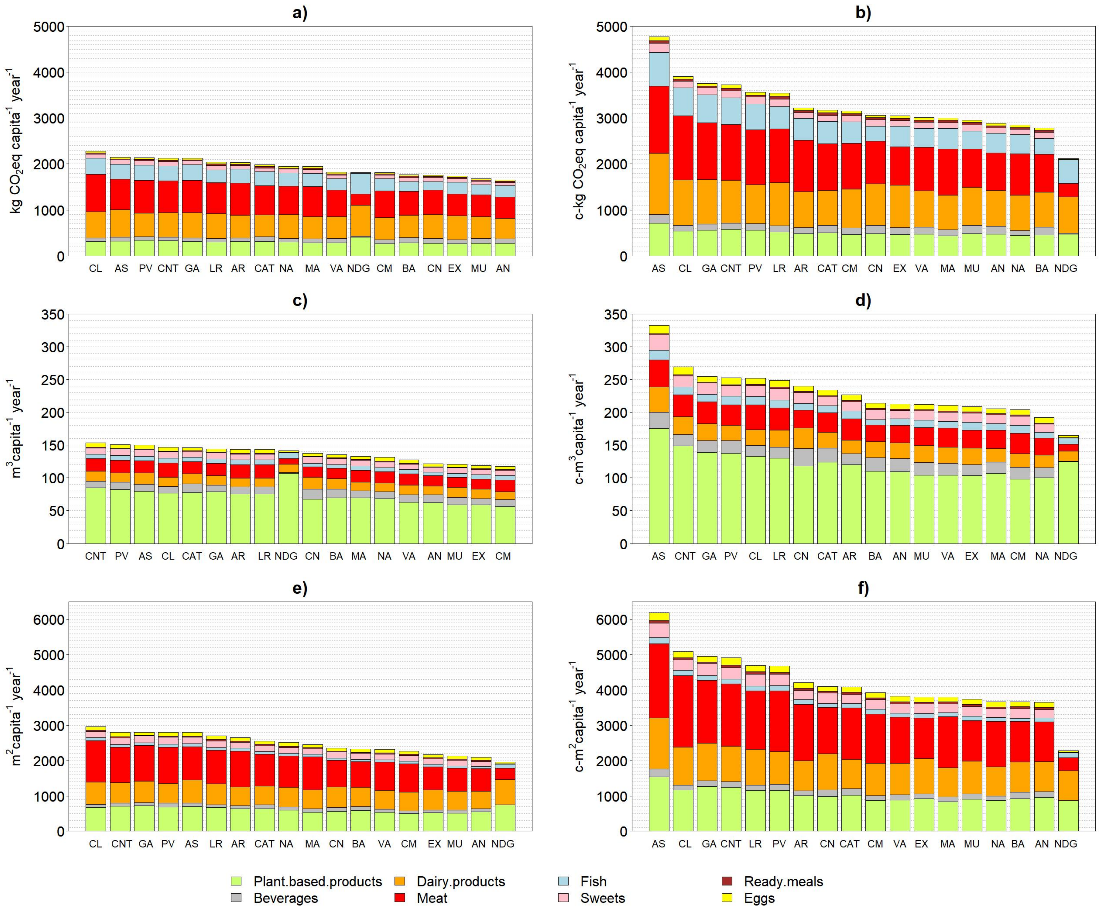

Figure 3 Average annual non-corrected (a,c,e) and corrected (b,d,f) environmental impacts for the Spanish regional diets and the NDG-based diet.

Figure *4*4 represents the relative changes of the 3 environmental impacts under the hypothetical scenario of the dietary shift from the regional eating patterns to the NDG-based diet. As a general result, using the mass-based (non-corrected) FU (Fig. 4 a,c,e), the potential environmental benefits of adopting the recommended eating pattern is underestimated for all three impact categories. There are even cases (southern Spain) that the diet shift would imply the increase of GHG emissions (Figure *4*4a) and the BWF (Figure *4*4c). This is because using a mass-based functional unit rewards underconsumption, meaning that eating less has less impact, as also discussed by Batlle-Bayer et al (2019b). Instead, applying the FU defined in this study, which penalizes the over-/under-consumption of food, the low nutritional quality and lack of affordability, all dietary shifts result in a reduction of the environmental impacts (Figure *4*4b,d,f).

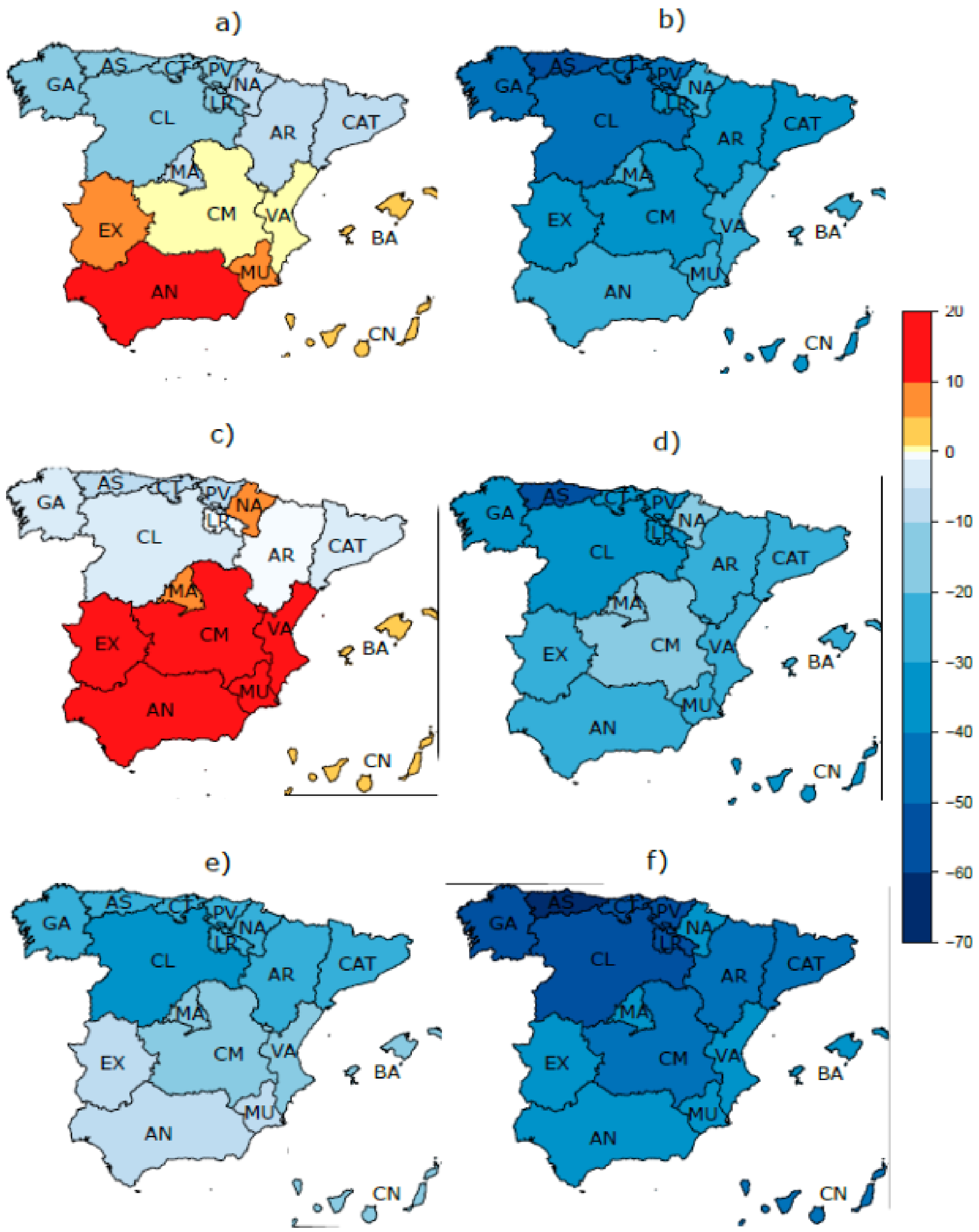

Figure 4: Relative differences (%) of (a) GHG emissions, (b) corrected-GHG emissions, (c) BWF, (d) c-BWF, (e), LU and (f) c-LU, between the average-regional diets and the NDG diet.

Discussion and conclusions

This study assessed three environmental impacts of regional dietary patterns in Spain, and it used a novel FU that considers not only nutrition (as suggested elsewhere; Batlle-Bayer et al., 2019a; Heller et al., 2013), but also food affordability. In accordance with general practices (EUROSTAT, 2018), the concept of food affordability is measured as the share of consumption income which is not spent on food, that is, "residual income". Lower residual incomes are therefore interpreted as signaling economic affordability problems of diets. To our knowledge, this has been the first attempt to introduce a socio-economic aspect within a FU of LCA of diets.

This study has several limitations. An important one is the lack of regionalized data on the out-of-home consumption. National average consumption away from home was assumed to be the same for all the regions. However, there might be large regional variability. The same occurs for food waste. Regarding the functional unit, this study did not consider the rebound effect of the purchased items with the residual income. For instance, Ivanova et al (2015) reported that "*any redirecting expenditure from the food category to any other services would cause increases in GHG emissions*". Therefore, a consequential LCA approach may be interesting for future research, in order to investigate in further detail what is the environmental impact of redirecting food expenditures to other type of purchases.

In summary, this study showed the influence of the FU on the result of the LCA of diets. By using a FU that considers both nutritional values (energy content and nutrients) and food affordability, this study confirmed the environmental benefits of reducing meat consumption, and the environmental savings of eating the required nutrition and energy intake as well. Besides, it demonstrated how different eating patterns among regions lead to different environmental results, and, in particular, to an interesting gradient from northern to southern Spain. Northwestern regions have a caloric energy overconsumption, about the double intake of ruminant meat, and less affordability, which causes a worse environmental performance. These regional differences reveal the potential need to establish regional strategies for those policies which encourage sustainable food consumption. NDGs are commonly directed to the country as a whole;

however, a more regionalized approach might be an interesting option for future initiatives.

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Author contributions

LBB wrote the main manuscript, PFP, JA, AB and RX were involved in the methodology, and all authors (AB, JA, RX, RA and PFP) reviewed the manuscript.

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