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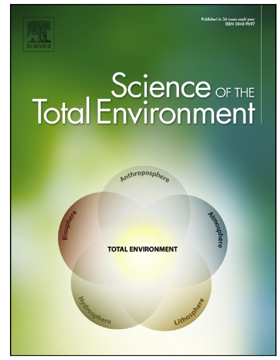

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SHORT COMMUNICATION

An energy- and nutrient-corrected functional unit to compare LCAs of diets

Laura Batlle-Bayer[1], Alba Bala[1], Elodie Lemaire[1], Jaume Albertí[1], Isabel García-Herrero[2], Rubén Aldaco[2] and Pere Fullana-i-Palmer[1]

[1]UNESCO Chair in Life Cycle and Climate Change ESCI-UPF, Universitat Pompeu Fabra. Passeig Pujades 1, 08003 Barcelona, Spain

[2]Department of Chemical and Biomolecular Engineering, University of Cantabria. Avda. De los Castros, s.n., 39005 Santander, Spain

Corresponding author: Laura Batlle-Bayer (laura.batlle@esci.upf.edu)

Highlights

- Different Functional Units (FU) of diet LCAs in the Spanish context are compared.
- Mass-based FU underestimates the effect of changes in dietary patterns.
- Diets differing in energy cannot be compared using the isocaloric approach.
- We propose an energy- and nutrient-corrected FU for diet LCAs.
- This corrected FU is recommended for future LCA studies of diets.

ABSTRACT

Dietary choices, a main driver of food production, play a significant role within the climate change arena. Consequently, there is a growing trend on publishing research assessing the environmental impacts of diets and dietary shifts, mainly following the life cycle assessment (LCA) methodology. However, several methodological issues still bring a challenge, especially in the definition of the function and the quantification of the functional unit (FU).

The FU is the reference unit of an LCA study, and it is the basis for allowing comparison among different systems. This short communication defines the function of diets as the supply of the daily required amount of calories and nutrients, and it proposes a novel FU that accounts for the energy intake and the nutritional quality of the diet. In order to compare the performance of the proposed FU to the most commonly ones used for diet LCAs (mass-based and isocaloric), dietary scenarios within the Spanish context are assessed. On the one hand, using a mass-based FU, greenhouse gas (GHG) emissions are underestimated, since the nutrition properties of food are not considered, and, on the other hand, the isocaloric substitution does not allow

comparison among diets with different levels of energy intake. In contrast, the proposed caloric- and nutrient-corrected FU allows to compare diets that differ in energy and nutritional quality in a fairer way. Finally, it is recommended to use this FU for future diet LCAs.

Keywords: nutrition, GHG emissions, energy intake, NRD9.3, dietary patterns

1. Introduction

Due to the significant role of food consumption in the climate arena (Bajželj et al., 2014; Song et al., 2018; Tilman and Clark, 2014), the scientific literature assessing the environmental impacts associated to diets has grown in recent years (Batlle-Bayer et al., 2019; He et al., 2018; Heller et al., 2018; Heller and Keoleian, 2015; Song et al., 2019, 2017; Walker et al., 2018; among others). These studies mostly follow the Life Cycle Assessment (LCA) approach, and perform dietary scenarios to compare the effect of dietary changes (Hallström et al., 2015). While LCA is considered a useful tool for this purpose (Heller et al., 2013), an agreed definition of the Functional Unit (FU) for dietary systems remains a challenge.

The FU quantifies the function of the studied system, and it is the reference unit (ISO, 2006) that allows the comparison among different systems that satisfy the same function. Therefore, a key aspect of diet-related LCA studies is how the function of diets is defined. Most studies use a quantity of mass as the FU: the daily or annual amount of food consumed or recommended per capita. However, this FU makes it difficult to compare results among diets since they may differ in the amount of food products consumed, as well as their overall nutritional quality (Batlle-Bayer et al., 2019).

Although food has multiple functions, such as giving pleasure, taste or satisfying societal relations, among others, Heller et al. (2013) suggest to use nutrition as the function of diets for LCAs. Nowadays, there are two approaches to combine nutrition with diet-related LCA studies, as reviewed by Heller et al. (2013). The first one adjusts the comparative diets to a single nutrient-based FU, such as the caloric or protein content. This is the case presented by Meier and Christen (2013) and van de Kamp et al (2018), who adjusted the diets to a daily energy intake of 2000 kcal. The second approach, besides standardizing dietary scenarios to a specific daily energy intake, uses dietary quality scores to evaluate the nutritional quality of diets, and it combines them with diet-related environmental impacts, mainly by correlating or dividing them (Hallström et al., 2018).

However, these two approaches do not allow the assessment of under- and over-caloric consumption, since comparison among diets can only be done at the same energy-intake level, known as the isocaloric substitution. In this regard, this communication proposes a new approach to standardize the FU in order to compare the GHG emissions among diets, independently of their energy content and nutritional quality. As a case study, this proposed FU is used to compare diets within the Spanish context.

2. Methods

2.1. A Caloric- and Nutrient-Corrected Functional Unit

This communication defines the main function of diets as the supply of the energy and nutrients required to sustain the body function and the daily activity of a human being. On this function, we define the FU of a diet as *the food basket that contains the daily amount of the representative food products, consumed by an adult, which supplies the daily required amount of energy and nutrients*. Once this FU is set, the GHG emissions (GHGe) resulting from the food basket are corrected (c-GHGe; Eq. 1) by the energy and the nutritional scores so that they fulfil the requirements defined in the FU.

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

Where,

$$\alpha = \ \mathrm{ES} = \frac{ADEI}{\mathrm{RDEI}} \qquad if\ ADEI < RDEI \qquad [Eq. 2]$$

$$\alpha = \frac{1}{ES} \qquad if\ ADEI \geq RDEI \qquad [Eq.3]$$

$$NS = \frac{ADNQ}{RDNQ} \qquad [Eq.4]$$

To penalize both over- and under-caloric consumption, diets' emissions are divided by the component α. For diets with a lower caloric intake than the recommended, α is equal to the Energy Score (ES) defined in (Eq.2) as the ratio between the average daily energetic intake (ADEI) and the recommended one (RDEI). In contrast, when the caloric intake is larger than the recommended, α is the inverse of the ES (Eq.3). The maximum value of α is 1, when ADEI is equal to RDEI.

The recommended daily energy intake (RDEI) is based on the recommendations published by the European Food Safety Authority (EFSA, 2017). EFSA provides the daily energy requirements based on gender and level of activity. To calculate the reference energy value for the Spanish context, data on the population and average activity level (Table 1) were retrieved from National Statistics Institute (INE, 2018). The weighted average energy recommended value for a Spanish adult is 2,228 kcal per day.

Table 1
Percentage of three activity levels according to sex and age group, and the representation of these groups within the Spanish adult population (INE, 2018).

Age	Activity level (%)						% in adult population	
	Low		*Moderate*		*Active*			
	F	M	F	M	F	M	F	M
18-29	33.4	25.6	43.3	32.2	23.3	42.2	8.0	8.2
30-39	36.8	32.7	43.0	32.1	20.2	35.2	9.8	9.9
40-49	38.1	36.8	44.3	35.7	17.6	27.5	10.7	11.0
50-59	38.1	36.8	45.9	40.5	16.0	22.8	9.3	9.2
60-69	39.0	36.5	46.7	42.6	14.2	20.9	7.2	6.7
70-79	38.8	31.7	61.2	68.3	0.0	0.0	5.5	4.5

The Nutritional Score (NS) defined in (Eq.3) is the ratio between the nutritional qualities of the Average Daily diet (ADNQ) and the Recommended one (RDNQ). Following this approach, the best score (1) is given to the recommended intake. To evaluate the nutritional quality, the

Nutrient Rich Diet 9.3 index (NRD 9.3; Van Kernebeek et al., 2014) was selected for the reasons described below. Firstly, because it is based on the widely accepted and validated nutrient profile for food products NRF9.3 (Drewnowski, 2009). Secondly, because its use for diet assessment has been growing in the last years (Batlle-Bayer et al., 2019; Esteve-Llorens et al., 2019; González-García et al., 2018).

The NRD9.3 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 calculated as the subtraction of TNR9 and TNL3 sub-scores (Eq. 4). The TNR9 is the sum of percentages of the daily recommended values (RV) of the 9 encouraging nutrients, 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. 5 and 6).].

$$NRD9.3 = TNR9 - TNL3 \qquad [Eq. 4]$$

$$TNR9 = \sum_{i=1}^{i=9} \frac{nutrient_{i,capped}}{RV_i} * 100 \qquad [Eq. 5]$$

$$TNL3 = \sum_{i=1}^{i=3} \frac{nutrient_i}{MV_i} * 100 \qquad [Eq. 6]$$

The daily recommended values (RV) and the maximum ones (MRV) for all nutrients (Table 2) are based on the data published by the EFSA (2017). In order to avoid crediting overconsumption of encouraging nutrients, their intakes were capped (Drewnowski, 2009). Hence, when a certain nutrient intake was higher than its RV, the intake of this nutrient was set to its RV.

Regarding the MRV for saturated fats (STA), EFSA (2017) does not establish one, and it recommends an as low as possible intake, while WHO (2015) defines a MRV of 10% of the total energy consumed. Here, we assume that the MRV of STA corresponds to a 10% of the total recommended energy intake (2,228 kcal). Likewise, in added sugars, no recommended values will be provided by EFSA until 2020. Thus, the same reasoning as for STA was followed, by assuming that the MRV should be based on the recommended energy intake. Table 2 summarizes all daily RV and MRVs.

Table 2
Daily recommended and maximum values (RV) for an adult (≥ 18 years)

Nutrients	Protein	Fibre	K	Ca	Fe	Mg	VitA	VitC	VitE	STA	Added sugar	Na
Units	g d^{-1}	g d^{-1}	mg d^{-1}	mg d^{-1}	mg d^{-1}	mg d^{-1}	µg d^{-1}	mg d^{-1}	mg d^{-1}	g d^{-1}	g d^{-1}	mg d^{-1}
RV	52.8	25	3500	950	11	350	700	107.5	12	24.1	90	2400

2.2. Dietary Scenarios

To evaluate the performance of the proposed FU within the assessment of diet-related GHGe, three different dietary patterns within the Spanish context are studied. These diets are based on the Current Consumption (CC) of an average Spanish citizen, and two alternative diets that follow the National Dietary Guidelines (NDG; Tur-Marí et al., 2010) and the Mediterranean diet (MED; Bach-Faig et al., 2011), respectively. The CC is based on the data from the annual surveys on *in-home* and *out-of-home* consumption carried out by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA, 2017). For the two alternative diets, a daily diet was built up based on the recommendations from the above mentioned guidelines on the quantity and frequency of food consumption. More details on the development of these diets can be found in Batlle-Bayer et al. (2019). Table 3 summarizes the caloric contribution of different food categories per diet. Based on them, daily food baskets with a range of daily energy intake (between 1500 and 3000 kcal) were developed per dietary pattern, maintaining the proportion of each food category.

Table 3:
Energy Contribution (%) of different food categories per dietary pattern: CC (Current consumption); NDG (National Dietary Guidelines); MED (Mediterranean).
Source: Batlle-Bayer et al. (2019)

Food categories		Diet Scenarios		
		CC (%)	NDG (%)	MED (%)
Animal-based products	Eggs	2	1	4
	Meat	14	5	6
	Fish	6	4	3
Dairy products		12	19	16
Plant-based products	Cereals-based products	14	26	18
	Fruit	6	11	15
	Legumes	2	4	4
	Vegetables	5	13	12
Vegetable fats		19	14	18
Sweets		12	2	2
Ready meals		2	0	0
Beverages		5	1	2

2.3. Food products' LCA data

LCA data for all the food products within the food baskets were gathered during an extensive literature review, explained in more detail in Batlle-Bayer et al. (2019). The product systems consider all the steps from the primary production to the consumption phase, and they also include the food losses along the whole supply chain, based on Garcia-Herrero et al., (2018). Assumptions in food distribution and consumer handling are based on Batlle-Bayer et al., (2019).

3. Results

3.1. The Nutritional Score

The nutritional scores (NS) of the three dietary patterns for different energy intake levels are shown in Fig.1. In all cases, the NS increases until the weighted average recommended energy intake (2,228kcal) is reached. Before this point, the NS values are lower because of the under-consumption of certain encouraging nutrients. After this point, the NS decline due to the over-consumption of limiting nutrients, especially of saturated fats. At all caloric intake levels, the CC diet scores less, mainly due to lower intake of nutrients, especially dietary fibre and vitamin A, and higher intake of saturated fats and salt.

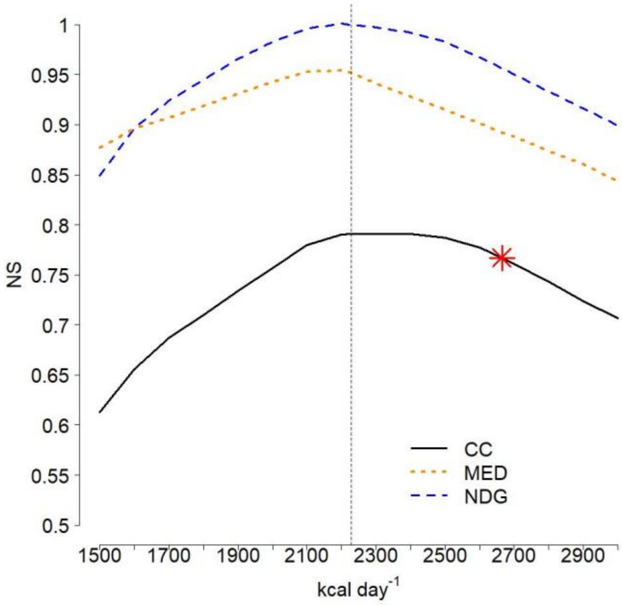

Fig. 1: Nutritional Score (NS) for the three food baskets CC: Current Consumption; NDG: National Dietary Guidelines; MED: Mediterranean diet. Dot highlighted with a red star is the NS at the current energy intake (2,665 kcal day^{-1}) for an average Spanish citizen.

3.2. GHG emissions

Using a mass-based FU (kg of food products consumed per day), the GHG emissions for all diets increase linearly with the caloric intake (Fig.2a), as shown also by empirical studies (Vieux et al., 2012; Walker et al., 2018). Following this approach can give the misleading message that eating less is better for the environment, while it can be harmful to public health if the intake of nutrients are below the recommended values. However, when these emissions are corrected to the diets´ energy (α; ES) and nutritional (NS) scores, following Eq. 1 (defined in Section 2.1), the overall picture changes (Fig.2b). For all three eating patterns, the GHG emissions are higher as we move from the recommended energy intake.

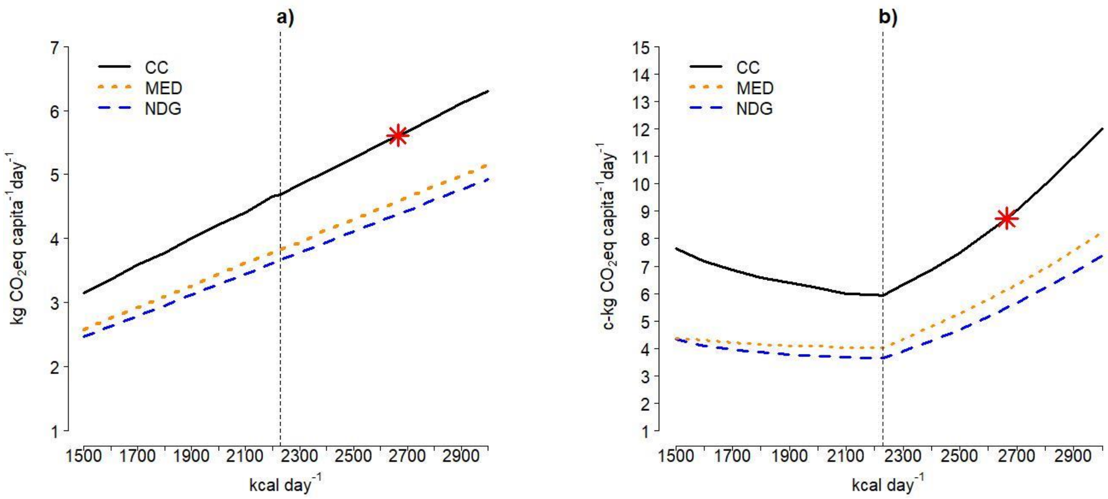

Fig. 2: a) Daily GHG emissions and b) corrected GHG emissions (c-GHGe) of the three dietary patterns at different energy intake levels. The red star is the emissions of current consumption for an average Spanish citizen.

4. Discussion & Conclusions

An appropriate definition of a FU is crucial for comparative LCA studies. Most food- and diet-related studies select a mass-based FU; however, this does not cover the main function of food in providing nutrition. Therefore, several studies (such as Sonesson et al., 2017; van Dooren et al., 2017; Van Kernebeek et al., 2014) have attempted to add nutrition within the FU. Masset et al. (2015) evaluated the changes in the results of food LCAs using two different FU (100g, 100 kcal). They reported different results depending on the FU applied, and concluded that none was the "best" to identify sustainable eating patterns, and suggest to further research the "quality-corrected" functional unit approach, which includes the nutritional quality.

The main novelty of the approach proposed in this short communication is to consider both the energy and the nutritional quality within the FU. In this manner, the GHG emissions of diets that differ in energy and nutritional intake can be compared. By means of an example, table 4 shows three scenarios of dietary changes, based on the type of the diet and the energy intake. If the CC diet shifts towards the NDG-based diet and the recommended energy intake (scenario C), the assessment will vary depending on the FU applied. For a mass-based FU, the GHG emissions' reduction is lower since no nutritional value is taken into account within the assessment. In the case of applying an isocaloric approach, diets can only be compared at the same energy intake level. Hence, scenario C cannot be directly assessed, and a previous energy adjustment of the diets is required before comparison. Finally, when using the caloric- and nutrient-corrected FU, proposed in this study, the comparison of GHG emissions among diets is energetic and nutritionally independent, and therefore it allows a proper comparison.

In conclusion, this novel approach aims to set a framework for future diet-related LCA studies by providing a proper basis for comparison. While it has been used specifically for GHG emissions in this communication, it may be applicable to any LCA-related environmental impact category. This FU has been designed specifically for attributional LCAs, and although in principle it would also be applicable to consequential LCAs, more research on that is needed.

Table 4:
Changes in GHG emissions under different dietary shift scenarios for four types of FU

Scenarios	**Type of changes**		**Reduction of GHG emissions**			
	Dietary pattern	Energy intake (kcal day^{-1})	Mass-based FU	Isocaloric-based FU	Isocaloric- & nutrient-based	Caloric- & nutrient-based FU
Baseline	*CC*	*2,665*				
A	CC	2,228	-16%	-	-	-32%
B	NDG	2,665	-22%	-22%	-37%	-37%
C	NDG	2,228	-35%	-	-	-58%

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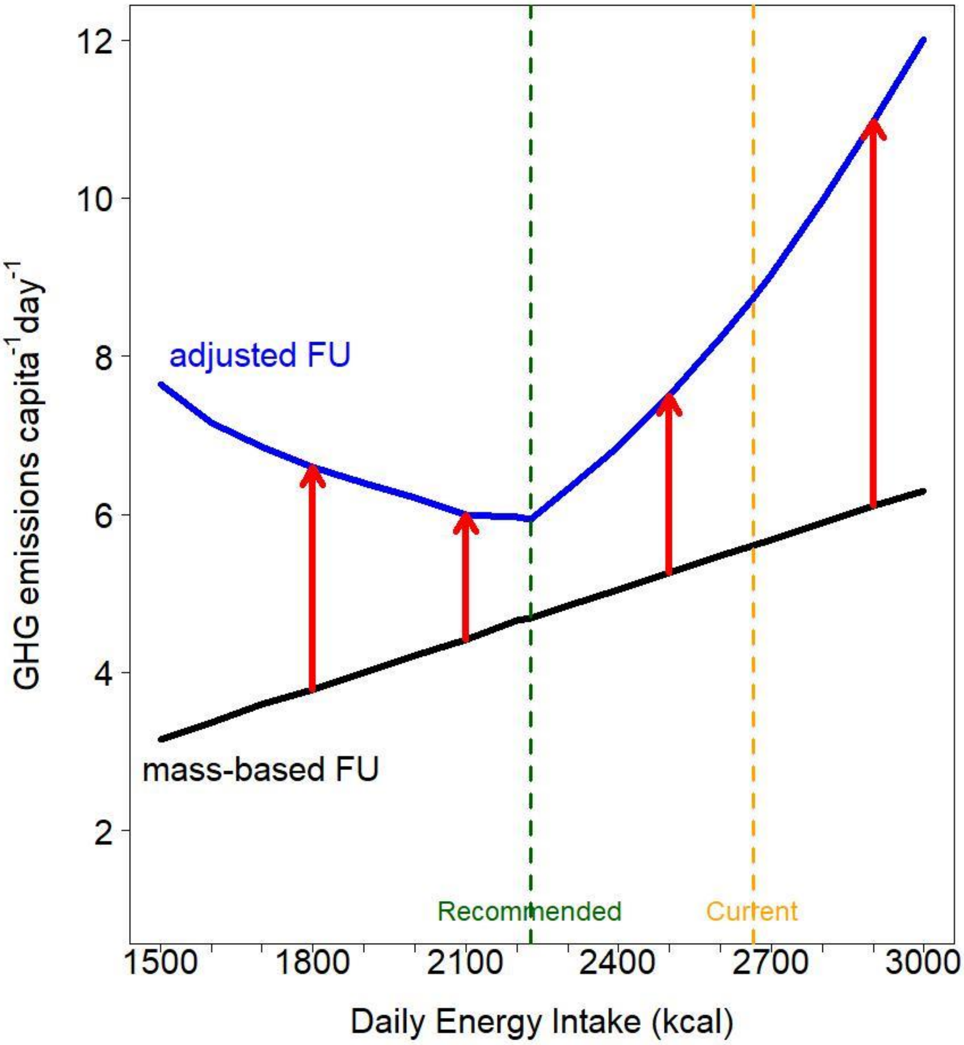

Graphical abstract