Nutritional quality and carbon footprint of university students' diets: results from the EHU12/24 study

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Abstract

Objective: To evaluate diets in terms of nutritional characteristics and quality from the perspectives of health, greenhouse gas emissions (GHGE) and possible associations with each other in a representative sample of students at a public university.

Design: Cross-sectional. Dietary intake was evaluated with a validated FFQ, and diet quality was assessed through the Healthy Eating Index (HEI-2010) and MedDietScore (MDS). GHGE data were obtained from the literature. In addition, sex, socio-economic status (SES) and body fat (BF) status were analysed as covariates.

Setting: Basque Autonomous Community, Spain.

Participants: Totally, 26 165 healthy adults aged 18–28 years.

Results: Student diets were characterised by low consumption of carbohydrates (38·72 % of total energy intake (TEI)) and a high intake of lipids (39·08 % of TEI). Over half of the participants had low dietary quality. The low-emitting diets were more likely to be consumed by subjects with low HEI-2010 scores (β: 0·039 kg eCO$_2$/1000 kcal/d) and high MDS scores (β: −0·023 kg eCO$_2$/1000 kcal/d), after controlling for sex, SES and BF status. Both the low-emitting and healthy diets were more likely to be consumed by women and by those with normal BF percentage.

Conclusions: UPV/EHU university students' diets were characterised by moderate quality from a nutritional perspective and moderate variation in the size of carbon footprints. In this population, diets of the highest quality were not always those with the lowest diet-related GHGE; this relationship depended in part on the constructs and scoring criteria of diet quality indices used.

The growing concern about climate change and food security has led to an increased interest in sustainable and healthy diets[1,2]. According to the FAO, sustainable diets are 'protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy, while optimising natural and human resources'[3]. To date, many authors have assessed the carbon footprint related to dietary habits, that is, diet-related greenhouse gas emissions (GHGE)[4–6]. However, addressing the sustainable diet concept implies not only assessing the environmental dimension but also the health nutrition, affordability and acceptability dimensions[3]. The sustainability of diets is not easy to assess because it requires high-quality indicators for each dimension as well as the ability to link them.

The health nutrition dimension or nutritional sustainability is generally assessed through nutritional quality indicators and/or health outcomes[7]. In this sense, some studies have modelled more environmentally friendly diets

using food-based[5,8] or nutrient-based[9,10] recommendations or predictive public health models[11,12]. In other cases, the health and environmental consequences of adopting dietary patterns such as the Mediterranean diet (MD)[13] have been explored. Many studies have indicated that healthier diets are generally lower in their environmental impact; thus, higher-quality diets have been associated with lower GHGE[14,15]. However, other authors have not found the same results, showing that sustainability dimensions such as the GHGE and the health nutrition dimension of diet were not necessarily compatible with one another[16–20], perhaps related to the known inverse relationship between nutrition and dietary energy density[21,22].

Even though high-nutritional quality diets have been characterised by a high content of low-GHGE foods (expressed per 100 g), in the end these diets had a greater impact than low-quality diets because they contained higher food quantities[7]. Obviously, additional studies providing insight into the relationships between GHGE of diets and nutritional sustainability are needed. So far, few studies have used cohort data to establish possible associations between environmental and health nutrition dimensions of sustainability. The main advantage of the present study compared to other similar research on the general population[23,24] is the use of observational cohort data to analyse carbon footprints of diets, not just national averages as is often done.

Moreover, in particular communities such as young adults attending a university, who have different consumption patterns and nutritional requirements compared with the general adult population[25–28], associations between diet-related GHGE and nutritional sustainability may be different. To our knowledge, no previous studies have analysed these two sustainability dimensions of university students' diets. The aims of the present study were therefore to evaluate the following in the diets of students of the University of the Basque Country (UPV/EHU): (1) the health nutrition dimension (nutritional characteristics and dietary quality); (2) the level of agreement between multiple measures of dietary quality used; (3) the environmental dimension (using the indicator GHGE); (4) possible associations between environmental and health nutrition dimensions of sustainability; and (5) possible predictors of the two sustainability dimensions examined.

Considering the health benefits of sustainable diets, such as reduction in excess weight and obesity levels[29,30], and the high sensitivity of young adults to issues related to the environment[31], the results of the present study could be used for planning food-based dietary guidelines and intervention strategies. These guidelines and strategies will contribute to improving dietary quality while simultaneously reducing dietary emissions and could take advantage of the naturally occurring opportunities offered by this stage of life to induce behavioural changes[32]. Moreover, university students are likely to constitute a significant proportion of the socio-economic elite of the future; thus, their habits and behaviours are most likely to become the norm[33], rendering this population interesting to investigate.

Methods

Subjects and study design

This study is a component of the EHU12/24 project, which is an observational cohort study designed to assess the prevalence of excess body fat (BF) and major risks of developing obesity, following to a standardised protocol and involving a representative sample of the UPV/EHU student population[34]. The study design, sampling and procedures of EHU12/24 have been described in detail elsewhere[34]. In this paper, we present results on eating habits and certain factors potentially associated with a healthier and low-GHGE diet.

Briefly, the survey was conducted from February 2014 to May 2017 on a cohort of 603 university students (59·5 % women) aged between 18 and 28 years (with an average age of 20·9 (2·1) years), after excluding 93 participants because of missing data on variables relevant to this study, following a standardised protocol. Moreover, we assigned a weight to each participant such that the computed statistics based on the gathered data could be more representative of the population from which the data were retrieved[35].

Dietary intake assessment

Diet was assessed using a short FFQ (SFFQ), which is a modified and validated version of the Rodríguez *et al.* questionnaire[36]. This adaptation was validated with multiple 24-h recalls in the Basque general population[37]. It consisted of 67 items and requires the subjects to recall the frequency of consumption of one standard serving[38] of each food item. The daily intake of each food item was determined based on the average consumption frequency and the amount of each food item consumed. For items that included several foods, each food's contribution was estimated with weighting coefficients that were obtained from the usual consumption data[39]. Moreover, the respondents were also able to record the consumption of other foods or drinks that were not included on the food list.

All food items that were consumed were entered into DIAL 2·12[40], a type of dietary assessment software, to estimate energy and nutrient intake expressed as percentages of total energy intake (TEI) in the case of macronutrients and as absolute amounts and per 1000 kcal for other compounds. The macronutrient intake levels were compared with corresponding acceptable macronutrient distribution ranges[41]. Lipid consumption was evaluated using the nutritional objectives for the Spanish population[41].

In addition, as has been described previously[34], we checked if students under- or overestimated their dietary intake using the method proposed by Goldberg[42] and modified by Black[43]. A physical activity level of 1·55[44] was used to estimate the energy requirement. These results suggested that 38 % of participants under-reported their intake and 2·1 % over-reported their intake. These analyses were conducted solely to identify possible under- and over-reporters, but misreports were not excluded because, as other authors have suggested, the exclusion of misreports introduces unknown bias because subjects who report inaccurately are systematically different from plausible reporters regarding lifestyle and nutritional status[45].

The adequacy of energy and nutrient intake and adherence to food-based dietary guidelines were evaluated using the Healthy Eating Index-2010 (HEI-2010)[46] and the MedDietScore (MDS)[47]. The former index is a measure of diet quality used to assess how well a set of food items aligns with key recommendations of the Dietary Guidelines for Americans. Although specific to US dietary guidelines, the HEI-2010 has been widely used in European populations and even in studies involving European university students[48,49] which allows us to compare results. We used HEI-2010 instead of HEI-2015 for many reasons. First, HEI-2010 has been applied previously with other university student populations[48,49], which allows us to establish comparisons with these data sets. The second reason is that HEI-2010 includes assessment of alcohol consumption (within the 'empty calories' component), while HEI-2015 does not include it. In the present study, the evaluation of alcohol consumption in the context of diet quality is of interest because university students usually consume large amounts of alcoholic drinks[50,51], even higher quantities than their non-college attending peers[52]. The HEI-2010 consists of twelve components, including nine on adequacy and three on moderation, that are scored per 1000 kcal. The theoretical range of the HEI-2010 is from 0 to 100. We scored data with the simple HEI-scoring algorithm method[53].

The other quality index used, the MDS is an index that estimates the level of adherence to the MD pattern and is associated with biomarkers of CVD risk[47]. This score has eleven main components; each are scored separately but not by energy. For the consumption of foods considered to deviate from this dietary pattern, the scores were assigned on a reverse scale (scores 5 to 0). The total score (sum) ranges between 0 and 55. Higher values of this score indicate greater adherence to the MD pattern.

Finally, diet-related GHGE data obtained from the literature were used as indicators for environmental sustainability. A literature review was performed using PubMed to identify articles from 2000 to 2015 that provide data on the quantity of GHGE (from cradle to retail gate), expressed as kg eCO_2/kg, corresponding to each type of food product. Supplemental Table 1 summarises the GHGE data applied to estimate the kg eCO_2/person/d by considering dietary intake from the SFFQ, using GHGE data from the literature review[4,17,54–58]. Briefly, the data were selected considering geographical proximity; that is, in the case in which we have access to multiple data sets on the same food item, the one with the closest geographical proximity to our location was selected.

In addition, the latter stage of the life cycle was incorporated into the values where this was not accounted for in the study used as a source of information (transport from retail to consumer and waste at the consumer level). Data on home transport, estimated as 0·1 kg eCO_2/kg of food[59,60], and waste at the consumer level taken from FAO[61] were applied to those records that did not include the GHGE corresponding to home transport and/or waste. Regarding 'food waste', these values included losses and waste at the household level, that is, inedible fractions of food, cooking loss/gain, and also plate waste. The SFFQ food items were classified according to the same criteria used in other studies investigating the GHGE of diets[55]. The GHGE related to dietary habits of each participant was estimated considering the amount of every item consumed per d and the specific GHGE value of each of them.

Covariates

Demographic data (sex) and socio-economic status (SES) (based on parents' educational level and crowding index (CRI)) were registered retrospectively with the National Health Questionnaire[62] through face-to-face interviews. The CRI was estimated as the ratio of the number of household members to the number of rooms used for sleeping[63], with a lower CRI associated with a higher SES. To facilitate the analysis, the two last covariates were dichotomised: parents' educational level (at least one of the parents had attended university or not) and CRI (score greater than 1 or else less than or equal to 1). Moreover, information regarding the bachelor's or postgraduate degree each student was pursuing was also recorded. The participants were classified according to the knowledge area of the degree for which they were studying based on the criteria proposed by the Spanish Ministry of Education, Culture and Sport[64], and this variable was dichotomized into Health Sciences and non-Health Sciences.

Additionally, anthropometric data included measurements of skinfold thickness (bicipital, tricipital, subscapular and suprailiac). A detailed description of the anthropometric measurements in the EHU12/24 study has already been published[34]. The BF % was calculated with skinfold data using the Siri-age-sex equation[65] as recommended by the Spanish Society of Obesity Research[66], and the density was estimated using the Durnin and Womersley formula[67]. Each subject's BF % was classified using the criteria proposed by Bray et al.[68].

Hypotheses

Based on the literature data[20,23,69–73], the following hypotheses were raised: (i) diets of UPV/EHU university students are characterised by a low degree of adequacy to reference intakes and consequently low dietary quality; (ii) this dietary quality shows high variation depending on the index used; (iii) variation in the size of carbon footprints is high; (iv) low-GHGE diets are associated with a high degree of adequacy to reference intakes of nutrients and food groups; and (v) women, those with high SES, and those with normal BF percentage are more likely to follow low-emitting and healthy diets.

Statistical analysis

Data were analysed using SPSS for Windows (version 22.0, SPSS Inc.) and are reported as the mean values, standard deviation, CI and frequencies. All the results were weighted to ensure the representativeness of the UPV/EHU university students' population using weighting coefficients provided by the list of students enrolled in 2012–2013[74]. The symmetry of the distribution of continuous variables was determined by a Kolmogorov–Smirnov–Lilliefors test. Differences in variables were assessed with the Mann–Whitney *U* test (the variables were not normally distributed, due to data being weighted and the large sample size; thus, small deviations rendered the variables not normally distributed), as shown in Tables 1, 2 and 3. Categorical variables were analysed using χ^2 tests, as shown in Table 4.

The κ coefficient was calculated to investigate the degree of agreement between the two dietary quality indices (see online Supplemental Table 2). For the κ coefficient analysis, we divided the dietary quality data into two categories, based on definitions from HEI-2010 and MDS authors. HEI-2010 was used to classify dietary quality into the following categories: 'needs improvement' (0–80 points) and 'good' (> 80 points), and dietary quality was classified by MDS into the categories: 'low adherence to MD' (0–34 points) and 'high adherence' (> 35 points). The cut-off point for MDS was established taking into account that scores below 34 points were associated with higher risk of CHD, with relative odds ≥ 1.42[47].

Covariates associated with high scores based on HEI-2010 and MDS were identified using binary logistic regression models (see online Supplemental Table 3). In these models, we considered the following covariates: SES and BF status. The effect of each covariate was adjusted

Table 1 HEI-2010 and MDS in the study population: students of the University of the Basque Country (UPV/EHU), EHU12/24 study

	Total (*n* 26 165)*		Men (*n* 10 607)		Women (*n* 15 558)		
	Mean	SD	Mean	SD	Mean	SD	*P*†
HEI-2010 components (score range)							
Total fruit (0–5)	3·48	1·63	3·31	1·68	3·60	1·59	***
Whole fruit (0–5)	3·99	1·58	3·80	1·65	4·11	1·52	***
Total vegetables (0–5)	1·76	1·06	1·55	1·02	1·90	1·06	***
Greens and beans (0–5)	4·69	0·82	4·53	1·02	4·79	0·64	***
Whole grains (0–10)	2·28	3·25	1·80	2·88	2·61	3·44	***
Dairy (0–10)	5·36	2·49	5·34	2·36	5·37	2·57	**
Total protein foods (0–5)	4·27	0·95	4·43	0·77	4·17	1·04	***
Seafood and plant proteins (0–5)	3·23	1·32	3·18	1·34	3·27	1·30	***
Fatty acids (0–10)	6·83	2·34	6·94	2·22	6·76	2·42	***
Refined grains (0–10	8·92	1·88	8·61	2·09	9·14	1·68	***
Sodium (0–10)	9·95	0·56	9·93	0·73	9·96	0·40	***
'Empty energy' (0–20)	19·72	0·87	19·81	0·57	19·65	1·02	***
Total score (0–100)	74·48	8·00	73·25	7·95	75·32	7·92	***
MDS components (score range)‡							
Non-refined cereals	2·21	2·31	1·95	2·26	2·37	2·33	***
Potatoes	2·01	1·41	2·27	1·50	1·83	1·32	***
Fruits	4·51	1·21	4·49	1·22	4·52	1·20	**
Vegetables	4·60	0·93	4·52	1·01	4·66	0·87	***
Legumes	2·15	1·09	2·25	1·08	2·08	1·09	***
Fish	2·77	1·43	2·86	1·39	2·71	1·45	***
Red meat and products	2·33	1·36	1·91	1·26	2·62	1·34	***
Poultry	2·52	1·38	2·35	1·40	2·64	1·35	***
Full-fat dairy products	1·48	1·90	1·21	1·82	1·66	1·93	***
Olive oil	4·75	0·95	4·68	1·11	4·79	0·83	NS
Alcoholic beverages	4·20	1·81	4·23	1·76	4·18	1·84	NS
Total score	33·53	5·47	32·74	5·20	34·07	5·58	***

HEI, Healthy Eating Index; MDS, MedDietScore.
*Survey results were weighted using the weighting coefficients provided by the UPV/EHU.
†Sex differences.
‡Each component can contribute five points to the total score, the theoretical range is 0–55 and reverse scale was applied to four components of the MDS (red meat and products, poultry, full-fat dairy products and alcoholic beverages).
**$P < 0.01$.
***$P < 0.001$.

Table 2 Nutrient and alcohol intakes in the study population and of those consuming low- and high-GHGE diets: students of the University of the Basque Country (UPV/EHU), EHU12/24 study

Variables	Low-GHGE diet* (n 5207)‡		High-GHGE diet* (n 5217)‡		P†
	Mean	SD	Mean	SD	
GHGE, kg eCO$_2$/1000 kcal	0·16	0·02	0·31	0·06	***
Proteins (% TEI)	12·65	1·75	17·97	2·93	***
Carbohydrates (% TEI)	39·88	5·80	38·07	5·39	***
Lipids (% TEI)	40·12	7·38	37·07	5·67	***
SFA (% TEI)	13·73	3·36	11·88	2·65	***
MUFA (% TEI)	17·14	4·51	15·75	3·43	***
PUFA (% TEI)	6·31	3·35	6·00	2·06	***
Linoleic acid (% TEI)	5·35	3·23	4·62	1·87	***
α-linolenic acid (% TEI)	0·55	0·23	0·65	0·20	***
Cholesterol (mg/1000 kcal)	121·52	45·02	181·20	86·78	***
Fibre (g/1000 kcal)	10·93	5·32	12·93	4·10	***
Alcohol (g/1000 kcal)	5·30	5·77	3·83	4·66	***

GHGE, greenhouse gas emissions; TEI, total energy intake.
*Low-GHGE diets are defined as those in the lowest quintile of GHGE (kg eCO$_2$/1000 kcal/d). High-GHGE diets are defined as those in the highest quintile of GHGE per 1000 kcal/d.
†Determined by Mann–Whitney U test.
‡Survey results were weighted using the weighting coefficients provided by the UPV/EHU.
***$P < 0.001$.

Table 3 HEI-2010 and MDS in the study population and of those consuming low- and high-GHGE diets: students of the University of the Basque Country (UPV/EHU), EHU12/24 study

	Low-GHGE diet* (n 5231)†		High-GHGE diet* (n 5246)†		P‡
	Mean	SD	Mean	SD	
HEI-2010 components (score range)§					
Total fruit (0–5)	2·91	1·68	4·02	1·57	***
Whole fruit (0–5)	3·54	1·78	4·39	1·40	***
Total vegetables (0–5)	1·40	0·99	2·32	1·29	***
Greens and beans (0–5)	4·8	0·8	4·5	1·0	***
Whole grains (0–10)	2·01	3·05	2·59	3·30	***
Dairy (0–10)	4·27	2·43	6·12	2·54	***
Total protein foods (0–5)	3·36	1·07	4·88	0·34	***
Seafood and plant proteins (0–5)	3·01	1·24	3·75	1·36	***
Fatty acids (0–10)	6·51	2·74	7·27	1·95	***
Refined grains (0–10)	8·59	2·12	9·37	1·41	***
Sodium (0–10)	10·0	0·00	9·98	0·23	***
'Empty energy' (0–20)	19·69	1·16	19·61	0·99	***
Total score (0–100)	69·77	7·61	79·12	7·22	***
MDS components (score range)‖					
Non-refined cereals	2·11	2·27	2·45	2·33	***
Potatoes	2·08	1·33	2·01	1·53	***
Fruits	4·26	1·43	4·57	1·22	***
Vegetables	4·38	1·10	4·71	0·82	***
Legumes	3·72	2·18	2·37	1·21	***
Fish	2·07	1·30	3·24	1·52	***
Red meat and products	3·15	1·13	1·51	1·21	***
Poultry	3·22	1·13	1·77	1·45	***
Full-fat dairy products	1·64	1·91	2·06	2·08	***
Olive oil	4·66	1·13	4·71	1·05	NS
Alcoholic beverages	4·21	1·75	3·72	2·18	***
Total score	34·16	6·41	32·76	5·57	***

HEI, Healthy Eating Index; MDS, MedDietScore; GHGE, greenhouse gas emissions.
*Low-GHGE diets are defined as those in the lowest quintile of GHGE (kg eCO$_2$/1000 kcal/d). High-GHGE diets are defined as those in the highest quintile of GHGE per 1000 kcal/d.
†Survey results were weighted using the weighting coefficients provided by the UPV/EHU.
‡Determined by Mann–Whitney U test.
§The HEI is an overall index of diet quality based on the Dietary Guidelines for Americans. The 2010 version was used for this analysis[46].
‖Each component can contribute five points to the total score and the theoretical range is 0–55, and reverse scale was applied to four components of the MDS (red meat and products, poultry, full-fat dairy products, and alcoholic beverages)[47].
***$P < 0.001$.

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Table 4 General characteristics of the study population and of those consuming low- and high-GHGE diets: students of the University of the Basque Country (UPV/EHU), EHU12/24 study

	Low-GHGE diet* (*n* 5207)‡	High-GHGE diet* (*n* 5217)	
	%		*P*†
Sex			
Female	61·7	57·2	
Male	38·3	42·8	***
BF % classification			
Overweight/obese	7·0	15·7	
Not overweight/obese	93·0	84·3	***
Parental educational level§			
College graduate	50·9	48·3	
< College graduate	49·1	51·7	**
CRI‖			
> 1	48·5	69·9	
<= 1	51·5	30·1	***

GHGE, greenhouse gas emissions; BF, body fat; CRI, crowding index.
*Diets in EHU12/24 study were ranked by GHGE (kg eCO$_2$/1000 kcal/d) and divided into quintiles. Those in the lowest quintile of GHGE were defined as low-GHGE diets, whereas those in the top quintile were defined as high-GHGE diets.
†Determined by χ^2 test.
‡Survey results were weighted using the weighting coefficients provided by the UPV/EHU.
§To facilitate the data analysis, parents' educational levels were regrouped as: at least one of the parents university education or not.
‖To facilitate the data analysis, CRI was regrouped as: score greater than 1; less than or equal to 1.
**$P < 0.01$.
***$P < 0.001$.

by sex in both diet quality indices and by daily energy intake only for MDS. To focus on food choices independent of energy requirements, individual diets were ranked according to GHGE per 1000 kcal. Those in the first (lowest) and fifth (highest) quintile groups were compared by the variables described above in Tables 2–5. Throughout the paper, we refer to these quintile groups as the low- and high-GHGE diets, respectively. Finally, ordinary least-squares regression was used to assess the independent effect of dietary quality on dietary GHGE after controlling for demographic and socio-economic variables described

above, as well as BF status (Table 5). All tests were two-tailed, and *P* values < 0·05 were considered statistically significant.

Results

The study population was characterised predominantly by non-Health Sciences students (86·1 %) with normal BF percentage (85·6 %). Moreover, more than half the population had at least one parent without university education (53·5 %) and a CRI lower than or equal to 1 (59·1 %). Concerning nutrient intake, the results showed a high consumption of protein and fats, especially SFA and cholesterol, compared with the acceptable macronutrient distribution ranges (see online Supplemental Table 4). In addition, a low intake of carbohydrates and fibre, as well as a moderate consumption of alcohol, was observed in comparison with the acceptable macronutrient distribution ranges.

Dietary quality as assessed by HEI-2010 received a score of 74·48 out of a maximum of 100, with differences between sexes ($P < 0.001$) (Table 1). About a quarter (24·6 %) of the total sample was classified as having a good diet (> 80 points), and the rest was classified as 'needs improvement'. In general, the food groups for which subjects received the lowest scores were total vegetables and whole grains. The scores for the majority of HEI-2010 components were higher in women than in men ($P < 0.01$). Total MDS score was 33·53 out of a maximum of 55 and differed between sexes ($P < 0.001$). Approximately 43·5 % of the participants were classified as showing a high adherence to the MD pattern, and the remainder were classified as 'low adherence'. Furthermore, in five of the eleven MDS components, the scores were higher for women than men ($P < 0.001$).

Comparison of the results obtained from the two dietary quality methods (HEI-2010 and MDS) showed a fair

Table 5 Relationships between dietary GHGE per 1000 kcal and dietary quality indices (HEI-2010 and MDS) in the study population: students of the University of the Basque Country (UPV/EHU), EHU12/24 study

Dietary quality index	Unadjusted models*			Models controlling for demographic and socio-economic variables†			Models controlling for demographic, socio-economic variables and BF status‡		
	Coef	SE§	*P*	Coef	SE§	*P*	Coef	SE§	*P*
HEI-2010 51–80 points‖	0·039	0·001	***	0·039	0·001	***	0·039	0·001	***
MDS 0–34 points¶	−0·025	0·001	***	−0·024	0·001	***	−0·023	0·001	***

GHGE, greenhouse gas emissions; HEI, Healthy Eating Index; BF, body fat; MDS, MedDietScore.
*The dependent variable in all models is GHGE (kg eCO$_2$/1000 kcal/d). Each row represents a separate set of models. For unadjusted models, the dietary GHGE is regressed solely on the corresponding dietary quality index.
†Models controlling for demographic and socio-economic variables including sex, parental educational level and crowding index (CRI).
‡The final model set included these variables plus BF status.
§Coef is the β coefficient in each of these models and represents the mean difference in dietary GHGE (kg eCO$_2$/1000 kcal/d) between those with HEI or MDS scores below adequate and those with adequate scores. For example, in the unadjusted model, individuals who needed to improve their dietary quality according to the HEI had a mean dietary GHGE that was lower than those who followed a healthy diet according to the HEI by 0·039 kg eCO$_2$/1000 kcal/d.
‖Needs improvement (no participant scored less than 51).
¶Low adherence.
***$P < 0.001$.

agreement ($\kappa = 0.332$) (see online Supplemental Table 2). On the other hand, in addition to sex, other factors, including socio-economic and BF status, influenced dietary quality (see online Supplemental Table 3). Specifically, non-excessive adiposity was associated with higher scores for both dietary quality indices ($P < 0.001$), having parents with a high educational level was associated with higher MDS ($P < 0.01$), and having a CRI lower than or equal to 1 was associated with higher HEI scores ($P < 0.001$).

Values for GHGE were 4·71 kg eCO$_2$/d (95 % CI (4·69, 4·73)) and 0·23 kg eCO$_2$/1000 kcal (95 % CI (0·22, 0·23)). The study population was divided into quintile groups, and the cumulative GHGE from the lowest quintile group represented 14·3 % of the total GHGE from the diet, whereas the top group accounted for 27·3 %. Comparison of the demographic, socio-economic and other characteristics between the top and bottom quintiles revealed significant differences with respect to sex, parental educational level, CRI and BF status (Table 4). In particular, the low-emitting diets were more likely to be consumed by women ($P < 0.001$), those with CRI higher than 1 ($P = 0.029$), and those without excessive BF ($P < 0.001$).

The nutrient composition of the low- and high-GHGE groups is reported in Table 2. High-GHGE diets included higher concentrations of certain nutrients (proteins and α-linolenic acid), cholesterol and fibre, whereas low-GHGE diets contained significantly greater quantities of the remaining nutrients and components of diet evaluated. The food groups with the greatest contributions to GHGE were red meat and deli meat, followed by fruits and vegetables and milk and dairy products (see online Supplemental Table 5). The high-GHGE diets were characterised by greater percentages of contributions from fruit and vegetables, red meat and deli meat, eggs and white meats and fish and shellfish food groups to total GHGE than were the low-GHGE diets (see online Supplemental Table 5). Overall evaluation of food composition of these diets showed that total HEI scores for the high-GHGE diets were significantly higher than those for the low-GHGE diets (Table 3). The high-GHGE diets also scored higher on all HEI components with the exception of the greens and beans component. Nevertheless, an inverse relationship was found between MDS scores and GHGE of diets; MDS scores for the low-GHGE diets were significantly higher than values for high-GHGE diets. Low-GHGE diets scored significantly higher for the potatoes, legumes, red meat and products, poultry and alcoholic beverages components of the MDS.

Finally, we examined possible associations between dietary quality from a health perspective and carbon footprints in the study population, through ordinary least-squares regressions (Table 5). Low-quality diets according to HEI had significantly lower GHGE compared to high-quality diets. In contrast, high-quality diets according to MDS had significantly lower GHGE compared to low-quality diets. These associations were still significant after controlling for sex, parental educational level, CRI and BF status.

Discussion

In the present study, we analysed the health nutrition dimension and carbon footprints and possible associations between them, as well as possible predictors of these two sustainability dimensions, in university students' diets. From a nutritional standpoint, student diets were characterised by high consumption of protein and fats, especially SFA and cholesterol, a low intake of carbohydrates and fibre, and a moderate consumption of alcohol. These characteristics are typical of the Western dietary pattern that is associated with higher obesity risk[75–77] and are consistent with characteristics other researchers have identified among European university students[78–81].

With respect to diet quality as analysed by HEI-2010 and MDS, the mean scores and the percentages of subjects classified as scoring highly were greater than values reported by other authors for the same diet quality indices[48,49,82]. In addition, the two diet quality indices analysed displayed fair agreement within the study population, probably due to differences in number of components, contribution of each component, and scoring criteria, as other authors have pointed out[71]. The higher scores for dietary quality indices in women than in men confirm the findings of other studies of university students[48,83]. This sex difference could be related to greater health concern[84] and to dissatisfaction with appearance and body weight[85], as well as to stronger beliefs related to nutrition in women than in men both in university[86] and non-university populations[87].

In addition to sex, other factors, including socio-economic and BF status, were associated with dietary quality. Predictably, and in agreement with other cross-sectional studies[73,88], an inverse association between diet quality and BF % was found. In prospective researches, dietary quality has also been found to be an important determinant for obesity in adults[73,89].

Our findings were also consistent with results of previous studies[90,91] showing an association between dietary quality and SES. In particular, those participants with highly educated parents scored higher on MDS, and those with a CRI less than or equal to 1 received higher HEI scores. In this sense, other authors have found evidence of substantial mediation by diet quality of the association between SES and obesity[91,92].

Regarding dietary habits from a sustainability perspective, our mean estimate of diet-related GHGE was 4·71 kg eCO$_2$/d, which is consistent with values reported in other European countries, such as France (4·1 kg eCO$_2$/d)[16], the Netherlands (women: 3·7 kg eCO$_2$/d; men: 4·8 kg eCO$_2$/d)[93], Ireland (6·5 kg eCO$_2$/d)[94] and

Sweden (women: 4·1 kg eCO$_2$/d; men: 5·5 kg eCO$_2$/d)[95]. These discrepancies could be due not only to differences in dietary assessment methods and participant characteristics (such as age range and dietary habits) but also to differences in data sources used and in system boundaries within the emission factors adopted[94].

Our results showed a moderate variation in size of carbon footprints of diets compared to the variation recorded by other authors[23]. Ranked in ascending order of GHGE/1000 kcal, we found that diets in the highest quintile contributed 27·3 % of total dietary emissions, 1·91 times the 14·3 % of emissions from the lowest quintile. Moreover, as with dietary quality indices, the carbon footprint was associated with sex, SES and BF status. Specifically, low-emitting diets were more likely to be consumed by women, those with lower SES, and those without excessive BF. Rose et al.[23] also observed that, even when standardised for energy intake, diets in the lowest GHGE quintile group were more likely to be consumed by women. This result could be related to a greater concern among women than men about food sustainability dimensions such as ethics and environment and local production; these food choice motives in turn are positively associated with healthy dietary patterns[96].

Relative to SES, those with higher SES exhibited high diet-related GHGE levels, which is inconsistent with our hypothesis that students with high SES are more likely to follow low-emitting and healthy diets. In this sense, it should be pointed out that other authors have observed that high-nutritional quality is associated with a higher cost as well as with greater environmental impact[72,97,98], even though healthy and sustainable diets are not necessarily more expensive than other ones[10]. On the other hand, our results suggest that students with excessive BF, in addition to showing lower dietary quality, also have higher GHGE associated with their diets. These results are consistent with those of Seconda et al.[99] who observed that a sustainable diet, from environmental, nutritional, economic and sociocultural perspectives, exerts a potential protective role against weight gain, being overweight and obesity. Moreover, Vieux et al.[55] found that when energy intake was reduced to meet individual energetic needs, diet-associated GHGE was reduced by up to 10 %. In view of these data, we consider that interventions focused on adapting energy intake to expenditure may be beneficial to both health and environment, and both reasons may contribute to adherence to dietetic recommendations.

Regarding the contributions of food groups to the GHGE, as have other authors[100–102], we observed that red meat and deli meats were the top contributors to diet-related GHGE. Moreover, high-GHGE diets contained greater percentage contributions from the red meat and deli meat group to total GHGE than did low-GHGE diets. This result is consistent with the findings of previous studies in the Netherlands[93], Ireland[94] and France[55] and provides further evidence that reducing meat consumption could

lower diet-related GHGE[103]. Moreover, over 50 % of GHGE from high-GHGE diets derived from animal protein foods (red meat and deli meats, eggs and white meats and fish and shellfish). Considering these results, efforts to reduce the environmental impact of diet and improve health could focus on decreasing slightly the consumption of animal-based foods (taking into account that protein contributed approximately 15 % to TEI). In any case, the consumption of animal-based foods is rooted in current Western culture; therefore, lowering their consumption will not be easy and could result in unfavourable nutritional consequences (especially in groups at risk for inadequate intake). Avoidance or lower intake of animal foods such as red meat may also contribute to nutritional inadequacy of several micronutrients such as Fe, Zn and vitamin B$_{12}$[104].

Nevertheless, the second food group in terms of contribution to diet-related GHGE was fruits and vegetables, and high-GHGE diets contained greater percentage contributions from this food group to total GHGE than did low-GHGE diets. This last result regarding vegetable intake is consistent with findings of Sugimoto et al.[105] and confirms that intake of certain plant-based foods can also be associated with high GHGE, depending on the amount and type of products selected[106].

With respect to the potential association between diet quality and diet-related GHGE, students with the highest HEI-2010 scores tended to have high diet-related GHGE as well, while those with the lowest MDS tended to have high GHGE. These associations were still significant after controlling for sex, SES indicators and BF status. HEI-2010 results were in agreement with findings of other studies[16] that suggest that diets with the highest dietary quality are currently not those with the lowest diet-related GHGE. The lower impact of the MD is also in accordance with the results of other authors[107], who have estimated that the Mediterranean option provides GHGE savings of 16 % and the same effect as reducing meat consumption by 50 %. Additional studies have pointed to this dietary pattern as an example of a healthy and low-emitting diet[108].

The differences in the association of GHGE with HEI-2010 and with MDS, in the present study, could be related to discrepancies in constructs and scoring criteria for diet quality indices used. In fact, 40 % of the HEI-2010 score corresponds to food groups that contributed the most to GHGE of university students' diets, in particular the five food groups (red meat and deli meat, fruits and vegetables, milk and dairy products, eggs and white meat and fish and shellfish) with the greatest contributions to emissions. The above-mentioned food groups relate to the following components of HEI-2010: total fruit, whole fruit, total vegetables, greens and beans, dairy, total protein foods, and seafood and plant proteins. However, in the case of MDS, the intake of red meat and products, poultry and full-fat dairy products, which have a weight of 27 % of the total score, have inverse scores. The higher the intake of these food groups, the lower the MDS score,

whereas with HEI, these components score positively (the components total protein foods, meat and beans and milk can come to score up to 25 % of the max score of HEI-2010).

These methodological differences between HEI-2010 and MDS could explain, at least in part, the controversial association between diet-related GHGE and dietary quality. In recent studies, other authors have also reported that the relationship between diet quality and environmental sustainability depends on how diet quality is measured[109]. The reality is that healthy diets do not always imply low GHGE[16,106,109]. As other authors have noted 'diet quality and environmental sustainability are not necessarily interdependent, and improving diet quality and reducing environmental impact are efforts that should be pursued concurrently'[110]. Therefore, as recently suggested by Reinhardt et al.[111], more research is needed to identify incongruities or trade-offs between healthy and sustainable diets and the economic and social implications thereof, with the purpose of developing new dietary guidelines that will meet the needs of both current and future populations. These new dietary guidelines would help to inform policy solutions addressing two of the greatest threats to population health: non-communicable diseases and climate change[112].

Our study has several limitations worth noting. First, the data on dietary habits were self-reported, which is assumed to introduce some degree of under-reporting, especially in specific groups of the population defined by weight or sex[113,114]. However, FFQ can provide valid information on intake for a large number of nutrients[115], and there is no alternative without limitations. Second, in the methodology for analysing GHGE related to dietary habits, we did not consider several steps in the life cycles of products because of the lack of data on cooking methods and geographic origin and seasonality of foods. In this sense, it should be noted that it is extremely difficult and expensive to analyse all steps of the life cycle of food at the population level. It should also be noted that the GHGE data were applied considering dietary intake from the SFFQ, that is, consumed foods, so there could be biases associated with the fact that GHGE's values included cooking loss/gain. In any case, the method used for determining GHGE is a feasible alternative that has been applied in previous studies quantifying GHGE[54,55,116]. Third, the university students' diets were assessed by focusing on two sustainability dimensions, and further investigation should consider the use of indices such as Sustainable Diet Index which include other dimensions of sustainability such as economic and sociocultural aspects[99]. Moreover, only one of the relevant environmental indicators associated with food consumption was used; it would be convenient to consider multiple measures of sustainability. We plan to assess these additional environmental impacts in the future to make broader conclusions about the present study.

Finally, the lack of control of certain possible confounding variables (food choice motive dimensions, for example) and other conditions (such as place of habitual residence) that may have affected the food consumption should be noted. We do not think that the above limitations lead to major flaws in the results. The strengths of the present study are that it incorporated a set of protocolised measurements in a representative sample of university students and that it combined the analysis of the health nutrition dimension and carbon footprints of consumption simultaneously, the use of multiple dietary quality measures, and the inclusion in the analysis of potential determinants of dietary habits (such as socio-demographic ones).

Conclusions

UPV/EHU university students' diets were characterised by moderate dietary quality and moderate variation in the size of carbon footprints. In this population, diets of the highest quality were not always those with the lowest diet-related GHGE; this relationship depended in part on the constructs and scoring criteria of diet quality indices used. The results of this study translated into practice indicate that university students can choose to reduce GHGE and improve health most effectively through the reduction of animal-based foods, adapting energy intake and following an MD pattern.

Acknowledgements

the final version of the manuscript. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Ethical Committee on Human Research of the UPV/EHU (CEISH/193/2013/ARROYO IZAGA). Written informed consent was obtained from all subjects.

Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980021002640

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