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# Environmental Impacts of Plant-Based Diets: How Does Organic Food Consumption Contribute to Environmental Sustainability?

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**Background:** Studies investigating diet-related environmental impacts have rarely considered the production method of the foods consumed. The objective of the present study, based on the NutriNet-Santé cohort, was to investigate the relationship between a provegetarian score and diet-related environmental impacts. We also evaluated potential effect modifications on the association between a provegetarian score and the environmental impacts of organic food consumption.

**Methods:** Food intake and organic food consumption ratios were obtained from 34,442 French adults using a food frequency questionnaire, which included information on organic food consumption for each group. To characterize the overall structure of the diets, a provegetarian score was used to identify preferences for plant-based products as opposed to animal-based products. Moreover, three environmental indicators were used to assess diet-related environmental impacts: greenhouse gas (GHG) emissions, cumulative energy demand (CED), and land occupation. Environmental impacts were assessed using production life cycle assessment (LCA) at the farm level. Associations between provegetarian score quintiles, the level of organic food consumption, and environmental indicators were analyzed using ANCOVAs adjusted for energy, sex, and age.

**Results:** Participants with diets rich in plant-based foods (fifth quintile) were more likely to be older urban dwellers, to hold a higher degree in education, and to be characterized by an overall healthier lifestyle and diet. A higher provegetarian score was associated with lower environmental impacts (GHG emissions$_{Q5vsQ1}$ = 838/1,664 kg $CO_{2eq}$/year, −49.6%, $P < 0.0001$; CED$_{Q5vsQ1}$ = 4,853/6,775 MJ/year, −26.9%, $P < 0.0001$; land

**Abbreviations:** GHG, greenhouse gas; CED, cumulative energy demand; LCA, life cycle analysis; Q, quintile; PUFA, polyunsaturated acid; MUFA, monounsaturated acid; SFA, saturated fatty acid.

occupation$_{Q5vsQ1}$ = 2,420/4,138 m$^2$/year, −41.5%, $P < 0.0001$). Organic food consumption was also an important modulator of the relationship between provegetarian dietary patterns and environmental impacts but only among participants with diets rich in plant-based products.

**Conclusion:** Future field studies should endeavor to integrate all the components of a sustainable diet, i.e., both diet composition and production methods.

**Keywords: provegetarian dietary pattern, organic food consumption, eco-friendly farming, diet-related environmental impact, sustainability**

## INTRODUCTION

According to the Food and Agricultural Organization (FAO), adopting sustainable diets at a global level is urgently needed (1). Sustainable diets should include a large share of ecologically based, local and minimally processed products and limited consumption of animal products. Sustainable diets are also healthy in terms of both nutrition and sanitary quality (1). Regarding the environmental aspects of a sustainable diet, a shift from current dietary patterns toward more environmentally friendly habits appears necessary. Environmentally friendly habits include reducing the consumption of animal products and increasing the consumption of plant products (2). Indeed, livestock is considered to be responsible for 18% of the greenhouse gas (GHG) emissions from anthropogenic sources at the global level, and this pattern is comparable at the country level in France (3). More specifically, beef and milk production represent 41 and 20% of the emissions from livestock, respectively (3). Livestock requires substantial energy for multiple activities such as the production of feed, breeding activities, production and spread of fertilizers, electricity use, and operating costs of farm buildings (4). Intensive livestock production is also responsible for a large part of the loss in biodiversity due to important land use for grass and feed crops (5). Conversely, extensive livestock farming is suggested to have positive effects on biodiversity. Studies investigating these issues have consistently reported that decreasing the consumption of animal products would have a considerable beneficial impact on the environment (6, 7).

The FAO also mentions that alternative modes of production may be important to the promotion and development of sustainable diets. Organic agriculture is defined as a system that relies on ecosystem services rather than external agricultural inputs (8). It is generally considered a more environmentally friendly production model that enhances the quality of soil leading to higher plant and fauna diversity and lower nitrate leaching. Nevertheless, disparities in agro-ecological practices still remain (9–12). The sustainability of organic food systems and their ability to feed the global population have often been questioned mostly due to their usually lower crop yields (13, 14). It is now largely recognized that organic production requires less energy inputs than conventional systems (15–17), although benefits in terms of GHG reduction are not straightforward (18). Moreover, firm conclusions about conventional and organic systems are moderated by the functional unit (18–20).

Despite ample literature on environmentally sustainable diets, few studies have considered both dietary patterns and production modes. It is, therefore, of interest to study both parameters simultaneously to be able to estimate the extent to which organic food consumption affects diet-related environmental impacts. It is of considerable interest to consider both plant-based and organic foods, which are consumed by vegetarians in Western countries (21).

A review of Aleksandrowicz et al. revealed that the change from a traditional western diet to alternative dietary patterns (e.g., Mediterranean, vegetarian, or vegan) normally provides benefits for both individual health and the environment (22). The reductions in environmental footprints should generally be proportional to the magnitude of the restriction of animal-based products (22). Despite lower environmental impacts when compared to omnivorous diets (23), vegan or vegetarian diets are still not culturally accepted, particularly in France, where meat-based meals and cheese are an integral part of the traditional diet (24). In this context, the provegetarian score (25), which characterizes diets by the level of plant and animal product consumption, and not directly by animal product exclusion, is highly relevant in the French environment.

Thus, the first objective of this study is to estimate diet-related environmental effects according to the provegetarian score. Second, we focused on studying the moderating effects of organic food consumption according to the level of plant-based food consumption. Data are based on a large sample from the NutriNet-Santé study within the framework of the BioNutriNet project, which enabled us to collect food consumption data and environmental data on both organic and conventional products.

## MATERIALS AND METHODS

### Study Population

The subjects are adult volunteer participants from the prospective NutriNet-Santé cohort, which was launched in May 2009 in France. The NutriNet-Santé study has been previously described in detail in another study (26). At inclusion in the cohort and yearly thereafter, the participants completed three 24-h randomly distributed accounts that were provided over a period of 15 days. They were also asked to complete a set of questionnaires about their sociodemographics, anthropometrics, health status, and lifestyle characteristics. Participants were also regularly invited to complete complementary questionnaires. In 2014, participants were asked to provide information on their organic

food consumption as well as their motives and attitudes toward organic foods.

## Data Collection

### Sociodemographic and Lifestyle Characteristics

The yearly updated inclusion questionnaire provided data on sociodemographic characteristics including age, sex, highest achieved degree (lower than high school, high school, or post-secondary graduate), location (rural community, urban unit with a population smaller than 20,000 inhabitants, between 20,000 and 200,000 inhabitants, or higher than 200,000 inhabitants), and monthly income per household unit (lower than 900 euros, between 900 and 1,200 euros, between 1,200 and 1,800 euros, between 1,800 and 2,700 euros, and higher than 2,700 euros). The monthly income per household unit was obtained by dividing monthly income by consumption units (CU); the first adult in the household represents 1 CU, other persons older than 14 represent 0.5 CU, and other persons younger than 14 years represent 0.3 CU (27).

This set of data also provided lifestyle characteristics such as physical activity (measured by the IPAQ–International Physical Activity Questionnaire) (28–30), smoking status (never, former, and current smoker), and alcohol intake (never, moderate, or frequent drinker). Moderate alcohol consumption was defined as an intake lower than 20 g/day for women and lower than 30 g/day for men (31).

### Dietary Data and Organic Food Consumption

Between June and December 2014, participants were asked to complete an optional organic food semi-quantitative frequency questionnaire (Org-FFQ) based on the original validated Nutrinet FFQ (32). The Org-FFQ collected information on consumption frequencies (yearly, monthly, weekly, and daily units) and portion sizes for 264 food and beverage items over a year. The total food intake was estimated by multiplying the consumption frequency and portion size for each item. To estimate the share of organic food consumption in the diet, for each item in the Org-FFQ, participants indicated how often they consumed that item in an organic form. Organic food frequency was assessed using a 5-point ordinal scale, "never," "rarely," "half of the time," "often," and "always," which were weighted as 0, 0.25, 0.5, 0.75, and 1, respectively, and yielded an estimate of the proportion of organic food consumed in an individual diet. The contribution of organic food consumption to the diet was calculated by dividing the total organic food intake (g/day) by the total food intake (g/day) excluding water. This ratio was multiplied by 100 to obtain the contribution of organic food as a percentage of weight.

The development of the Org-FFQ and sensitivity analyses for the allocation of arbitrary weightings has been described in another study (21).

The NutriNet-Santé food composition database (33) was used to estimate daily nutrient intake independently of the production method. To assess the nutritional quality of dietary patterns, two indicators were assessed at the individual level: the PANDiet (based on the probability of adequate nutrient intake for 24 nutrients) (34) and the mPNNS-GS (modified French national nutrition and health programme (Programme National Nutrition Santé), with the PNNS-guidelines score based on the adherence to the PNNS recommendations excluding physical activity) (35).

### Environmental Data

The methodology for the environmental evaluation of individual diets is described in detail in the Presentation S1 in Supplementary Material. Data were collected *via* the French diagnostic tool DIALECTE (36) using the life cycle assessment method (LCA) (37, 38) at the farm level (from agricultural inputs and animal feed production to harvest). To date, DIALECTE is the only French database that covers such a large panel of data for both organic and conventional agricultural products. This study considers the three environmental indicators available: (1) GHG emissions were estimated including carbon dioxide, methane and nitrous oxide emissions and were expressed in kilogram $CO_2$ equivalent per day. (2) The cumulative energy demand (CED) indicator was defined as the consumption of renewable and unrenewable energy in megajoules per day according to the CED method (39). (3) Finally, land occupation was defined as the area in square meters needed per day. The environmental database includes information on 62 raw agricultural products based on measurements from 2,086 farms in France and on 30 raw agricultural products based on information from the literature. Among these farms, 46% follow certified organic agricultural practices (as defined by European regulations).

For each participant, organic and conventional food consumption was multiplied by the environmental impact of each product to estimate the impact of the overall diet for each participant.

## Construction of the Provegetarian Score

The provegetarian score was developed to reflect the proportion of plant-based food consumed in a diet (25). Components of the provegetarian score include seven vegetable food groups and five animal food groups (25) (Table S1 in Supplementary Material). Sex-specific adjustment for total energy intake was made for the consumption of each food group using the residual method (40). Energy-adjusted, sex-specific quintile values for each plant component were calculated by allocating 1 to 5 points. For animal food groups, the quintile values were reversed (from 5 for the first quintile to 1 for the fifth quintile). Finally, the provegetarian score was obtained by summing the quintile value of each vegetable food group and the reverse quintile value of each animal food group. The score ranges from 12 (low consumption of plant food) to 60 (high consumption of plant food).

## Data Treatment and Statistical Analysis

Among the 37,685 participants who completed the Org-FFQ, participants with missing sociodemographic data or aberrant data were excluded ($N = 1{,}390$). To detect under reporting and over reporting, energy requirements were calculated for each individual using physical activity level (IPAQ) and basal metabolic rate, estimated by Schofield's equation (41) and taking into account age, sex, and BMI. The ratio of energy intake to energy requirement was calculated, and participants with a ratio below 0.35 or above 1.93 were excluded ($N = 1{,}099$). Finally, only participants living in mainland France and having complete data to calculate

the nutritional quality scores were included. The final sample included 34,442 participants, with 22,813 women and 7,569 men.

Sociodemographic and lifestyle characteristics along with food and nutrient intakes were presented across the provegetarian score quintiles. For descriptive purposes, nutrient and food data were adjusted for total energy intake by sex using the residual method (40). Means, SDs and percentages were provided as appropriate. *P* values referred to the Mantel–Haenzel chi-square trend test for categorical variables and to the linear contrast test (ANCOVA) for continuous variables.

The contributions (as percentages) of different food groups to diet-related GHG emissions and CED across provegetarian score quintiles are presented. All *P*-trends were obtained with linear contrast tests (ANCOVA).

As an interaction between the provegetarian score and organic food consumption was observed ($P \leq 0.0001$), data were stratified by the level of organic food consumption. Associations between the provegetarian score and environmental impacts for the overall sample and the stratified tertiles of the contribution of organic consumption to the whole diet were estimated using ANCOVA adjusted with Dunett's test. All models were adjusted for sex, age, and energy intake. In addition, the ratio of organic food consumption as a continuous variable was included in the stratified analyses to account for residual confounding. The ordinal margins option was used. In all the analyses, the environmental indicators were log-transformed to improve the normality of the distributions. The data are presented as adjusted means with their 95% confidence intervals. Unadjusted models are provided in the Table S2 in Supplementary Material. Two-sided tests and a *P*-value <0.05 were used for statistical significance.

All analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA).

# RESULTS

## Individual Characteristics

**Table 1** presents sociodemographic and lifestyle characteristics of the participants across provegetarian score quintiles. No difference in the sex distribution of participants across the quintiles was observed. Participants with higher provegetarian scores were more likely to be highly educated, physically active, non-smokers, and moderate or non-drinkers. The Q5 of the provegetarian score (reflecting high consumption of plant food) included the highest proportion of participants with the lowest monthly income per household unit (<900 euros), while Q4 included the highest proportion of participants with the highest monthly income (>2,700 euros). The highest proportion of participants living in population-dense urban units was found in the Q4. Finally, the largest share of vegetarians was included in the Q5 of the provegetarian diet (8.3% in Q5 versus 0.2% in Q1).

## Food and Nutrients Intake by Provegetarian Score Quintile

**Tables 2** and **3** present food groups and nutrient intake across provegetarian score quintiles. By construction, the consumption of animal-based products decreased while the consumption of plant-based products increased across quintiles. Participants in the highest quintile also consumed less fast food products (hamburgers, pizzas, and sandwiches), sweets, and alcohol and had a higher intake of salad dressings, popcorn, or nuts. Overall, considering nutrient intake, a higher provegetarian score was associated with a lower overall protein intake but a higher proportion of plant protein (50.5% in Q5 versus 22.2% in Q1) and a higher polyunsaturated fatty acid (PUFA) and monounsaturated fatty acid (MUFA) intake as well as a lower saturated fatty acid intake and higher n-6/n-3 PUFA ratio. The intake of carbohydrates and fiber increased across provegetarian score quintiles. Participants in the Q5 of the provegetarian score also displayed the highest level of organic food consumption, as organic food represented a 50% share of their total food consumption.

Considering vitamins and minerals, iron intake increased across the quintiles of the provegetarian score while haem iron decreased. As expected, participants in the Q5 of the provegetarian score also exhibited a higher intake of most micronutrients (β-carotene, B1, B6, B9, C, E, K vitamins, and minerals Mg, K, and Mn). According to both the mPNNS-GS and PANDiet scores, participants in the last quintile showed the highest adherence to the French dietary guidelines.

## Environmental Impacts by Provegetarian Score Quintile

After the adjustment for energy intake, age, and sex, diet-related GHG emissions, CED, and land occupation decreased across the provegetarian score quintiles by −49.6, −26.9, and −41.5%, respectively, between Q5 and Q1 (**Table 4**). For all indicators, a linear association was observed ($P < 0.0001$). This reflects that the richer a diet is in plant products, the lower the environmental impacts are. For informational purposes, crude means and SDs of environmental indicators across the quintiles of the provegetarian score are presented in Figure S1 in Supplementary Material.

## Contribution of Food Groups to Diet-Related GHG Emissions, CED, and Land Occupation by Provegetarian Score Quintile

**Figure 1** indicates that the main contributor to diet-related GHG emissions across the different provegetarian score categories was animal-based products, particularly ruminant meat consumption. Animal products were responsible for approximately 80% of the dietary GHG emissions for diets rich in animal products (Q1 of the provegetarian score), between 70 and 80% for diets moderate in animal products and approximately 60% for diets rich in plant products (Q5 of the provegetarian score). Specifically, ruminant meat represented approximately half of the diet-related GHG emissions, regardless of the type of diet considered.

Concerning the CED (**Figure 2**), consumption of fruits, and vegetables was the major contributor (except for Q1 and Q2). Estimates of the contribution of monogastric meat and ruminant meat to diet-related CED were similar.

Finally, **Figure 3** presents land occupation by food group and by quintile. The results were closer than those for GHG emissions,

**TABLE 1** | Sociodemographic and lifestyle characteristics by provegetarian score quintile, *N* = 34,442, BioNutriNet study, 2014.[a]

| | Q1 | Q2 | Q3 | Q4 | Q5 | *P*-trend[b] |
|---|---|---|---|---|---|---|
| *N* (%) | (17.8) | (23.6) | (20.2) | (16.8) | (21.6) | |
| **Provegetarian score** | | | | | | |
| Mean | 27.4 (2.5) | 32.6 (1.1) | 36.0 (0.8) | 38.9 (0.8) | 44.5 (3.5) | <0.0001 |
| Median (IQR) | 28 (3) | 33 (2) | 36 (2) | 39 (2) | 44 (2) | |
| **Sex (%)** | | | | | | |
| Female | 75.8 | 75.5 | 75.2 | 75.3 | 76.0 | 0.81 |
| Male | 24.2 | 24.5 | 24.8 | 24.7 | 24.0 | |
| **Age (years)** | 52.0 (14.0) | 53.0 (14.1) | 53.5 (14.0) | 54.5 (13.6) | 53.4 (14.1) | <0.0001 |
| **Education level (%)** | | | | | | |
| <High-school diploma | 21.6 | 21.5 | 21.5 | 21.0 | 19.1 | <0.0001 |
| High-school diploma | 15.9 | 15.4 | 14.3 | 13.8 | 14.1 | |
| Post-secondary graduate | 62.5 | 63.1 | 64.1 | 65.2 | 66.8 | |
| **Monthly income per household unit (%)** | | | | | | |
| Refuse to declare | 5.8 | 6.2 | 6.3 | 5.7 | 7.1 | 0.01 |
| <900 euros | 7.4 | 6.6 | 6.0 | 6.3 | 8.7 | |
| 900–1,200 euros | 5.2 | 4.4 | 4.6 | 4.4 | 4.7 | |
| 1,200–1,800 euros | 24.2 | 23.1 | 23.6 | 22.1 | 22.4 | |
| 1,800–2,700 euros | 27.3 | 27.7 | 26.7 | 27.7 | 26.9 | |
| >2,700 euros | 30.1 | 31.9 | 32.9 | 33.7 | 30.3 | |
| **Location (%)** | | | | | | |
| Rural community | 22.9 | 23.2 | 22.3 | 20.7 | 22.3 | 0.11 |
| Urban unit with a population of <20,000 inhabitants | 16.1 | 15.4 | 15.7 | 15.0 | 15.2 | |
| Urban unit with a population of 20,000–200,000 inhabitants | 17.8 | 18.5 | 18.4 | 18.8 | 19.0 | |
| Urban unit with a population of >200,000 inhabitants | 43.2 | 42.9 | 43.6 | 45.6 | 43.5 | |
| **Physical activity (%)** | | | | | | |
| Missing value | 11.6 | 11.5 | 10.9 | 10.3 | 9.9 | <0.0001 |
| Low | 22.9 | 21.7 | 19.5 | 17.4 | 15.2 | |
| Medium | 35.3 | 36.3 | 37.2 | 37.2 | 37.2 | |
| High | 30.2 | 30.5 | 32.4 | 35.1 | 37.6 | |
| **Smoking status (%)** | | | | | | |
| Non-smoker | 48.6 | 48.5 | 48.4 | 48.6 | 49.3 | 0.04 |
| Former smoker | 13.3 | 11.6 | 11.2 | 9.7 | 9.0 | |
| Smoker | 38.0 | 39.8 | 40.5 | 41.7 | 41.7 | |
| **Alcohol intake (%)** | | | | | | |
| Non-drinker | 4.9 | 4.8 | 5.2 | 4.6 | 7.9 | <0.0001 |
| Moderate drinker (<20 g/day for women and <30 g/day for men) | 83.5 | 86.0 | 86.1 | 88.0 | 85.8 | |
| High drinker (>20 g/day for women and >30 g/day for men) | 11.6 | 9.2 | 8.7 | 7.4 | 6.4 | |
| **Diet (%)** | | | | | | |
| Vegetarians | 0.18 | 0.39 | 0.83 | 1.46 | 8.27 | <0.0001 |
| Vegans | 0.00 | 0.01 | 0.04 | 0.12 | 5.28 | |

*IQR, interquartile range; Q, quintile of provegetarian score.*
[a]*Values are presented as the mean (SD) or as a percentage.*
[b]*Values based on linear contrast test or* $\chi^2$.

showing a high contribution of animal products specifically ruminant meat to land occupation.

Moreover, the contribution of carbohydrates and oil to GHG emissions and CED increased across the provegetarian score quintiles. Of note, the contribution from cheese consumption was more important than from the contribution from dairy products and milk across quintiles.

## Diet-Related Environmental Impacts Considering both the Provegetarian Score and the Level of Organic Food Consumption

**Table 4** presents the association between the provegetarian score and the environmental impacts stratified by the level of organic food consumption. Similar linear trends were observed between the provegetarian score and environmental impacts across the different levels of organic food consumption. Considering diet-related environmental impacts in diets that contained low or moderate (Q1, Q2, and Q3) amounts of plant products (i.e., ≥70% animal protein for protein intake and ≥45% animal lipid for lipid intake), the level of organic food consumption did not significantly modify the association between the provegetarian score and the environmental impacts (GHG: $P_{Q2vsQ1} = 0.97$ and $P_{Q3vsQ1} = 0.28$; CED: $P_{Q2vsQ1} = 0.94$ and $P_{Q3vsQ1} = 0.10$; land occupation $P_{Q2vsQ1} = 0.78$ and $P_{Q3vsQ1} = 0.97$). However, for diets rich in plant foods (Q4 and Q5), the differences in the environmental impacts across the provegetarian score quintiles increased across the organic food ratio tertiles ($P < 0.0001$ except for land occupation $P_{Q4vsQ1} = 0.01$).

**TABLE 2** | Food and nutrient intake by provegetarian score quintile, *N* = 34,442, BioNutriNet study, 2014.[a]

| | Q1 | Q2 | Q3 | Q4 | Q5 | *P*-trend[b] |
|---|---|---|---|---|---|---|
| **Nutrients intake** | | | | | | |
| Energy intake without alcohol (kcal/day) | 2,218.8 (638.5) | 1,969.9 (597.1) | 1,885.6 (614.0) | 1,868.2 (599.6) | 1,982.9 (613.6) | <0.0001 |
| Proteins (%)[c] | 20.7 (3.6) | 19.5 (3.3) | 18.5 (3.2) | 17.5 (2.9) | 15.6 (2.9) | <0.0001 |
| Plant proteins (% protein)[c] | 22.2 (6.3) | 27.0 (7.3) | 31.3 (8.3) | 36.1 (9.3) | 50.5 (17.9) | <0.0001 |
| Animal proteins (% protein)[c] | 77.8 (6.3) | 73.0 (7.3) | 68.8 (8.3) | 63.9 (9.3) | 49.5 (17.9) | <0.0001 |
| Lipids (%)[c] | 41.2 (6.4) | 40.2 (6.7) | 39.8 (7.1) | 39.9 (7.2) | 40.2 (7.5) | <0.0001 |
| Plant lipid (% of lipid)[c] | 34.4 (10.4) | 40.7 (10.8) | 46.1 (11.5) | 51.2 (12.0) | 63.3 (15.0) | <0.0001 |
| Animal lipid (% of lipid)[c] | 65.6 (10.4) | 59.3 (10.8) | 53.9 (11.5) | 48.8 (12.0) | 36.7 (15.0) | <0.0001 |
| PUFA (%)[c] | 5.6 (1.7) | 6.1 (2.0) | 6.4 (2.3) | 6.9 (2.4) | 8.3 (3.0) | <0.0001 |
| MUFA (%)[c] | 15.4 (3.2) | 15.5 (3.6) | 15.8 (4.0) | 16.2 (4.2) | 17.1 (4.6) | <0.0001 |
| SFA (%)[c] | 17.0 (3.5) | 15.6 (3.1) | 14.6 (3.1) | 13.8 (3.0) | 12.0 (3.1) | <0.0001 |
| Omega 3 (%)[c] | 2.0 (0.9) | 2.2 (1.0) | 2.3 (1.1) | 2.5 (1.2) | 3.0 (1.6) | <0.0001 |
| Omega 6 (%)[c] | 10.9 (3.0) | 12.1 (3.5) | 13.0 (3.9) | 14.0 (4.0) | 16.8 (5.1) | <0.0001 |
| Ratio n-6/n-3 | 6.3 (2.7) | 6.5 (3.0) | 6.6 (3.1) | 6.5 (3.1) | 6.7 (3.3) | <0.0001 |
| Carbohydrates (%)[c] | 35.3 (7.1) | 37.5 (7.2) | 39.0 (7.2) | 40.0 (7.3) | 41.9 (7.6) | <0.0001 |
| Fibers (%)[c] | 1.7 (0.5) | 2.0 (0.6) | 2.2 (0.6) | 2.5 (0.7) | 3.0 (0.8) | <0.0001 |
| Alcohol (g/day) | 9.9 (14.8) | 8.9 (12.6) | 8.5 (13.2) | 7.95 (10.7) | 7.17 (10.3) | <0.0001 |
| **Food consumption (g or ml/day)[d]** | | | | | | |
| Vegetables and fruits | 424.4 (301.7) | 564.3 (314.9) | 660.6 (346.0) | 734.8 (354.1) | 881.7 (420.0) | <0.0001 |
| Meat | 165.3 (85.4) | 139.4 (65.8) | 123.3 (60.2) | 109.2 (54.2) | 71.9 (54.8) | <0.0001 |
| Ruminant (%) | 36.0 (15.7) | 35.4 (16.0) | 35.3 (15.9) | 34.2 (16.4) | 32.1 (18.1) | <0.0001 |
| Pork (%) | 42.1 (15.9) | 41.8 (16.2) | 41.1 (16.6) | 41.4 (17.4) | 40.8 (19.9) | <0.0001 |
| Poultry (%) | 20.7 (13.9) | 21.4 (14.5) | 22.1 (15.5) | 22.9 (16.1) | 25.5 (19.3) | <0.0001 |
| Rabbit (%) | 1.2 (2.4) | 1.4 (2.7) | 1.5 (2.7) | 1.5 (2.6) | 1.6 (3.7) | <0.0001 |
| Eggs | 13.5 (15.2) | 11.2 (11.7) | 10.1 (10.8) | 9.4 (9.8) | 8.4 (11.0) | <0.0001 |
| Fish | 53.6 (56.3) | 49.3 (39.1) | 47.1 (39.8) | 45.4 (34.3) | 37.4 (38.0) | <0.0001 |
| Dairy products | 320.6 (248.1) | 265.7 (209.3) | 227.6 (184.4) | 185.5 (161.0) | 112.1 (145.0) | <0.0001 |
| Starchy food | 159.9 (82.4) | 179.1 (86.7) | 189.8 (89.1) | 194.6 (91.4) | 213.1 (110.6) | <0.0001 |
| Whole cereal products | 33.3 (54.2) | 47.0 (62.0) | 54.0 (62.4) | 63.7 (68.0) | 84.1 (81.7) | <0.0001 |
| Soy products | 1.1 (54.2) | 8.5 (61.7) | 16.2 (76.8) | 27.2 (97.7) | 70.6 (140.7) | <0.0001 |
| Fast food | 38.7 (48.1) | 36.1 (31.6) | 33.9 (33.1) | 32.7 (29.0) | 27.3 (24.2) | <0.0001 |
| Nuts | 2.00 (8.63) | 4.03 (8.93) | 5.39 (10.79) | 7.14 (13.19) | 11.36 (15.25) | <0.0001 |
| Extra food (excluding nuts) | 9.55 (9.26) | 9.84 (9.80) | 9.93 (9.51) | 9.59 (9.99) | 8.50 (9.07) | <0.0001 |
| Sweet products | 80.6 (60.6) | 77.3 (52.6) | 74.0 (46.3) | 69.7 (41.2) | 61.9 (39.1) | <0.0001 |
| Oil | 8.9 (12.2) | 13.0 (12.5) | 15.8 (13.3) | 18.3 (14.1) | 22.7 (15.5) | <0.0001 |
| Butter | 8.6 (7.9) | 7.4 (6.7) | 6.7 (6.2) | 6.2 (6.1) | 4.5 (5.6) | <0.0001 |
| Other fats | 2.4 (4.6) | 2.3 (4.7) | 2.4 (4.8) | 2.1 (3.9) | 2.1 (4.6) | 0.1 |
| Non-alcoholic drink | 1571 (769) | 1600 (763) | 1590 (739) | 1607 (731) | 1591 (755) | 0.1 |
| Alcoholic drink | 180.7 (162.6) | 177.7 (142.6) | 174.0 (144.4) | 170.5 (118.5) | 158.1 (114.8) | <0.0001 |
| **Level of organic food consumption (in % of weight)** | 18.2 (19.8) | 22.5 (22.2) | 26.3 (24.2) | 32.1 (26.4) | 48.2 (30.7) | <0.0001 |
| Median of organic food consumption | 12 | 17 | 21 | 26 | 48 | |
| IQR | 26 | 32 | 36 | 41 | 53 | |
| **mPNNS score (/13.5)** | 7.6 (1.87) | 8.3 (1.73) | 8.6 (1.67) | 8.8 (1.66) | 8.8 (1.68) | <0.0001 |

*PUFA, polyunsaturated fatty acid; MUFA, monounsaturated fatty acid; SFA, saturated fatty acid; IQR, interquartile range; Q, quintile of provegetarian score.*

[a]*Values are presented as the mean (SD).*

[b]*Values based on a linear contrast test.*

[c]*As percent of energy intake.*

[d]*Values adjusted on the energy intake.*

## DISCUSSION

In our study, participants with a high provegetarian score were characterized by an overall healthier lifestyle, including healthier diets, as reflected by higher PANDiet and mPNNS-GS scores. Diets rich in plant products displayed lower environmental impacts (GHG emissions, CED and land occupation). Moreover, the consumption level of organic products was shown to have a positive moderating effect on diet-related environmental impacts only in diets rich in plant-based food.

Overall, a higher provegetarian score was associated with lower environmental impacts, particularly GHG emissions, across all levels of organic food consumption. These results at the individual diet level were expected since livestock is the most substantial agricultural contributor to GHG emissions, demands high energy inputs, and requires important land resources (42–44).

Similar results for GHG emissions were documented in the EPIC-Oxford observational study. However, the estimations were not adjusted for energy intake, and the LCA did not consider the production mode even though it included all stages of production, transformation, and distribution. The authors showed that a diet rich in animal products emitted 2.5 times as much GHG than a vegan diet. For women and men, GHG emissions from the diets of meat-eaters were 46 and 51% higher, respectively, than those of fish-eaters (or pesco-vegetarians), and 50 and 54% higher, respectively, than those of vegetarians (45). Other studies

**TABLE 3** | Consumption of micronutrients by provegetarian score quintile, *N* = 34,442, BioNutriNet study, 2014.[a]

| | Q1 | Q2 | Q3 | Q4 | Q5 | *P*-trend[b] |
|---|---|---|---|---|---|---|
| **Vitamins**[c] | | | | | | |
| Retinol (μg/day) | 769.42 (1,530.30) | 667.23 (1,052.50) | 590.84 (420.54) | 558.82 (362.70) | 432.86 (353.49) | <0.0001 |
| β-carotene (μg/day) | 2,685.90 (2,025.9) | 3,579.01 (3,040.9) | 4,175.05 (2,459.7) | 4,677.09 (2,956.2) | 5,872.50 (3,443.6) | <0.0001 |
| Vitamin B1 (mg/day) | 1.33 (0.40) | 1.35 (0.40) | 1.35 (0.38) | 1.37 (0.38) | 1.48 (0.52) | <0.0001 |
| Vitamin B2 (mg/day) | 2.47 (0.70) | 2.31 (0.61) | 2.20 (0.55) | 2.13 (0.52) | 1.99 (0.51) | <0.0001 |
| Vitamin B3 (mg/day) | 26.61 (8.44) | 26.21 (7.29) | 25.70 (6.68) | 25.64 (6.41) | 24.23 (6.30) | <0.0001 |
| Vitamin B5 (mg/day) | 6.76 (1.65) | 6.54 (1.44) | 6.39 (1.33) | 6.26 (1.23) | 6.06 (1.19) | <0.0001 |
| Vitamin B6 (mg/day) | 1.91 (0.50) | 1.96 (0.47) | 1.99 (0.46) | 2.04 (0.46) | 2.17 (0.56) | <0.0001 |
| Vitamin B9 (μg/day) | 317.56 (122.44) | 359.11 (123.69) | 385.77 (116.52) | 410.20 (123.12) | 482.06 (157.47) | <0.0001 |
| Vitamin B12 (μg/day) | 8.69 (9.07) | 7.67 (6.41) | 6.96 (3.14) | 6.57 (2.77) | 5.23 (2.93) | <0.0001 |
| Vitamin C (mg/day) | 104.49 (70.41) | 126.24 (70.54) | 141.66 (81.21) | 151.66 (78.85) | 174.60 (90.83) | <0.0001 |
| Vitamin D (μg/day) | 3.55 (2.22) | 3.24 (1.63) | 3.08 (1.70) | 2.97 (1.47) | 2.54 (1.63) | <0.0001 |
| Vitamin E (mg/day) | 9.66 (4.36) | 11.59 (4.37) | 12.74 (4.63) | 13.76 (4.63) | 16.44 (5.67) | <0.0001 |
| Vitamin K (μg/day) | 142.59 (122.15) | 187.11 (143.88) | 217.57 (140.31) | 244.35 (205.46) | 310.09 (201.96) | <0.0001 |
| **Minerals**[c] | | | | | | |
| Ca (mg/day) | 1,172 (391) | 1,094 (329) | 1,044 (304) | 998 (282) | 915 (261) | <0.0001 |
| Fe (mg/day) | 14.23 (3.78) | 14.92 (3.44) | 15.25 (3.25) | 15.83 (3.40) | 17.36 (4.00) | <0.0001 |
| Haem Fe (mg/day) | 1.97 (1.62) | 1.68 (0.85) | 1.50 (0.75) | 1.36 (0.67) | 0.94 (0.65) | <0.0001 |
| I (μg/day) | 160.20 (280.37) | 177.08 (211.47) | 193.07 (275.48) | 203.11 (309.02) | 329.66 (710.17) | <0.0001 |
| Mg (mg/day) | 444.43 (138.26) | 470.93 (134.19) | 482.83 (130.29) | 502.58 (132.78) | 540.85 (140.23) | <0.0001 |
| P (mg/day) | 1,550.19 (315.86) | 1,471.20 (270.59) | 1,420.12 (255.63) | 1,379.49 (238.06) | 1,322.24 (234.55) | <0.0001 |
| K (mg/day) | 3,508.30 (840.07) | 3,645.63 (825.93) | 3,726.91 (831.23) | 3,802.52 (835.48) | 3,961.31 (904.80) | <0.0001 |
| Na (mg/day) | 2,739.20 (592.86) | 2,641.56 (492.86) | 2,570.26 (491.03) | 2,515.43 (475.96) | 2,290.61 (550.78) | <0.0001 |
| Cu (mg/day) | 1.74 (1.48) | 1.90 (1.09) | 1.98 (0.58) | 2.10 (0.54) | 2.38 (0.62) | <0.0001 |
| Zn (mg/day) | 13.98 (3.13) | 13.30 (2.60) | 12.81 (2.31) | 12.52 (2.19) | 11.85 (2.23) | <0.0001 |
| Mn (mg/day) | 3.65 (1.93) | 4.40 (1.95) | 4.84 (1.91) | 5.32 (2.01) | 6.53 (2.47) | <0.0001 |
| Se (μg/day) | 83.19 (26.28) | 80.68 (20.30) | 78.94 (20.02) | 78.04 (18.69) | 75.43 (19.51) | <0.0001 |
| **PANDiet score (/100)** | 62.43 (5.13) | 64.90 (5.99) | 66.37 (6.72) | 67.99 (7.07) | 71.12 (7.13) | <0.0001 |

[a]*Values are presented as the mean (SD).*
[b]*Values based on a linear contrast test.*
[c]*Energy-adjusted mean (SD).*

documented similar trends in regards to environmental impacts of modeled substitutions for meat (46–48). For instance, the modeled substitution in the EPIC-Netherlands cohort demonstrated that substituting meat with 35 g/d of different combinations of plant products including potatoes, pasta, vegetables, nuts, and milky desserts could reduce GHG emissions up to 12% (49). In a recent review, authors concluded that the isocaloric substitution of meat by starchy food, fruits, nuts, and vegetables was more sustainable in terms of GHG emissions. However, in that same review, production modes (more or less agro-ecological modes) were not distinguished (43).

Livestock results in GHG emissions such as nitrous oxide, carbon dioxide, and methane due to high-energy feed production, concentrating production and enteric fermentation of ruminants (3). However, impacts related to ruminant meat are higher when compared to monogastric animals because of methane emissions and the need for substantial livestock feed production needed (43, 50, 51). As consumers in the Q5 of the provegetarian score ate less meat, especially ruminant meat, compared to participants in the other quintiles, the difference in GHG emissions is further increased. A previous study showed that a diet in which ruminant meat is replaced by monogastric meat (pork or poultry) reduced GHG emissions from 20 to 35% and land-use impacts from 30 to 50% (50).

In another study, the CED was computed at the farm level using the LCA method, and it was shown that a 60% decrease in daily meat consumption that is replaced by planted-based products led to an up to 38% decrease in CED, according to various scenarios of self-sufficiency in Austria (48). The review by Perignon et al., which covers 10 cohort studies on the environmental impact of observed individual diets, demonstrates that low-meat diets are more environmentally friendly (43).

Livestock farming requires a substantial input of fossil energy due to farm facilities and production of feed (3). Moreover, plant products have higher energy efficiency when considering the ratio of outputs/inputs for each calorie (52). Regarding the CED by food group and by quintile, there is no clear difference in the CED contribution between ruminant meat and monogastric meat. Considering the level of consumption, food group contribution to CED is probably driven more by the difference in intake than energy use for the different types of meat since the differences they are less noticeable than for GHG emissions (53).

Finally, similar results on land use were found when the average Danish diet was replaced by the new Nordic diet containing 35% less meat with a 24% decrease in diet-related land use. In the model performed for the EPIC-Netherlands cohort, the substitution of meat with 35 g/d of plant products led to an up to 12% decrease in land use (49). Moreover, the review of Hallström et al., which included 14 original studies (mainly based on modeling methods), showed that vegan diets reduced land use up to 60 and 50% for men and women, respectively (50). In fact, livestock farming is the largest user of land due to the total area need for grazing and feed crop production (5).

**TABLE 4** | Association between provegetarian score tertile and environmental impacts according to the level of organic food consumption, BioNutriNet study, 2014.

| | Overall | | Level of contribution of organic food to the diet | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Low (0.03) | | Medium (0.23) | | High (0.63) | | |
| | Mean[a] | 95% CL | Mean[a] | 95% CL | Mean[a] | 95% CL | Mean[a] | 95% CL | |
| **Greenhouse gas emissions (CO2eq/day)** | | | | | | | | | |
| Q1 provegetarian score | 4.56 | (4.51–4.60) | 4.59 | (4.53–4.65) | 4.56 | (4.48–4.63) | 4.10 | (3.99–4.22) | |
| Q2 provegetarian score | 4.05 | (4.01–4.08) | 4.13 | (4.08–4.18) | 4.05 | (4.00–4.10) | 3.74 | (3.66–3.81) | |
| Q3 provegetarian score | 3.62 | (3.62–3.66) | 3.73 | (3.68–3.78) | 3.68 | (3.63–3.74) | 3.34 | (3.28–3.41) | |
| Q4 provegetarian score | 3.23 | (3.20–3.27) | 3.45 | (3.39–3.51) | 3.38 | (3.33–3.43) | 2.94 | (2.89–2.99) | |
| Q5 provegetarian score | 2.27 | (1.33–2.29) | 2.93 | (2.87–2.99) | 2.72 | (2.67–2.76) | 2.12 | (2.09–2.14) | |
| P[b] interaction | | | | | | | | | <0.0001 |
| P[c] Q1 vs Q2 | | | | | | | | | 0.9711 |
| P[c] Q1 vs Q3 | | | | | | | | | 0.2764 |
| P[c] Q1 vs Q4 | | | | | | | | | <0.0001 |
| P[c] Q1 vs Q5 | | | | | | | | | <0.0001 |
| **Cumulative energy demand (MJ/day)** | | | | | | | | | |
| Q1 provegetarian score | 18.55 | (18.43–18.67) | 18.58 | (18.40–18.75) | 18.58 | (18.39–18.78) | 17.33 | (17.05–17.63) | |
| Q2 provegetarian score | 17.43 | (17.33–17.53) | 17.62 | (17.47–17.77) | 17.47 | (17.32–17.63) | 16.53 | (16.32–16.73) | |
| Q3 provegetarian score | 16.48 | (15.52–16.58) | 16.87 | (16.70–17.04) | 16.62 | (16.47–16.78) | 15.59 | (15.41–15.77) | |
| Q4 provegetarian score | 15.62 | (15.52–15.73) | 16.42 | (16.21–16.63) | 16.10 | (15.93–16.27) | 14.62 | (14.45–14.78) | |
| Q5 provegetarian score | 13.29 | (13.21–13.37) | 15.56 | (15.33–15.79) | 14.72 | (14.56–14.89) | 12.66 | (12.56–12.76) | |
| P[b] interaction | | | | | | | | | <0.0001 |
| P[c] Q1 vs Q2 | | | | | | | | | 0.9417 |
| P[c] Q1 vs Q3 | | | | | | | | | 0.1044 |
| P[c] Q1 vs Q4 | | | | | | | | | <0.0001 |
| P[c] Q1 vs Q5 | | | | | | | | | <0.0001 |
| **Land occupation ($m^2$/day)** | | | | | | | | | |
| Q1 provegetarian score | 11.33 | (11.14–11.41) | 10.94 | (10.78–11.10) | 11.58 | (11.39–11.78) | 11.66 | (11.36–11.96) | |
| Q2 provegetarian score | 10.26 | (10.17–10.35) | 9.89 | (9.76–10.03) | 10.31 | (10.17–10.45) | 10.64 | (10.45–10.85) | |
| Q3 provegetarian score | 9.34 | (9.26–9.43) | 8.95 | (8.81–9.09) | 9.43 | (9.29–9.57) | 9.61 | (9.44–9.79) | |
| Q4 provegetarian score | 8.51 | (8.42–8.60) | 8.26 | (8.10–8.43) | 8.68 | (8.54–8.83) | 8.50 | (8.35–8.65) | |
| Q5 provegetarian score | 6.63 | (6.57–6.69) | 7.03 | (6.87–7.19) | 7.09 | (6.97–7.21) | 6.49 | (6.41–6.57) | |
| P[b] interaction | | | | | | | | | <0.0001 |
| P[c] Q1 vs Q2 | | | | | | | | | 0.7782 |
| P[c] Q1 vs Q3 | | | | | | | | | 0.9696 |
| P[c] Q1 vs Q4 | | | | | | | | | 0.0111 |
| P[c] Q1 vs Q5 | | | | | | | | | <0.0001 |

*Models are adjusted on sex, age, and energy intake.*

*[a]Adjusted means were obtained with ANOVA models by the level of organic food contribution in the diet. P-trends across the provegetarian score quintile are all <0.0001 and were obtained with a linear contrast test by the level of organic food contribution in the diet.*

*[b]P for interaction between provegetarian score quintiles and the level contribution of organic food to the diet.*

*[c]P-linear trend of Q*v.Q1 of provegetarian score. It reflects the linearity of the difference between the first and the other quintiles of the provegetarian score across the levels of organic consumption.*

It is worth noting that beyond the benefits to the environment, diets rich in plant products also provide important nutritional and health benefits (54, 55).

We showed that introducing organic food to one's diet had a significant positive environmental effect on GHG emissions in only diets rich in plant products. However, when considering a diet with a moderate amount of plant products, this effect was not substantial.

The weak moderating effect of the organic consumption in a diet with a moderate amount of plant products can be explained by several hypotheses. First, no difference in GHG emissions was reported for both conventional and organic beef and milk production systems (20). In addition, GHG emissions from chicken and pork organic farming practices are higher because feed production is more substantial due to a longer cycle of production and a lower growth rate (in relation to a lower feed-efficiency conversion) (20). Moreover, GHG emissions from organic pork farming practices can be higher because of the high level of nitrous oxide emissions from straw litter (19). However, the differences between chicken and pork production systems have not yet been consistently measured, and further research is needed to improve the reliability of calculating GHG emissions for different farming practices. Second, organic farming results in lower GHG emissions when emissions are expressed by units of area, and no clear trends emerge when they are expressed by units of product weight (18). Finally, organic practices have obvious beneficial effects on GHG emissions in terms of plant production because of the exclusion of synthetic fertilizers that result in high $N_2O$ and $CO_2$ emissions (19, 56). Finally, the proportion of organic food consumption in the diet may be too low in the first provegetarian score quintiles to detect differences in GHG emissions. Considering the CED indicator, the ratio of organic food in the diet positively affects diet-related environmental impacts with increasing effects across provegetarian score quintiles. Organic practices prohibit the use

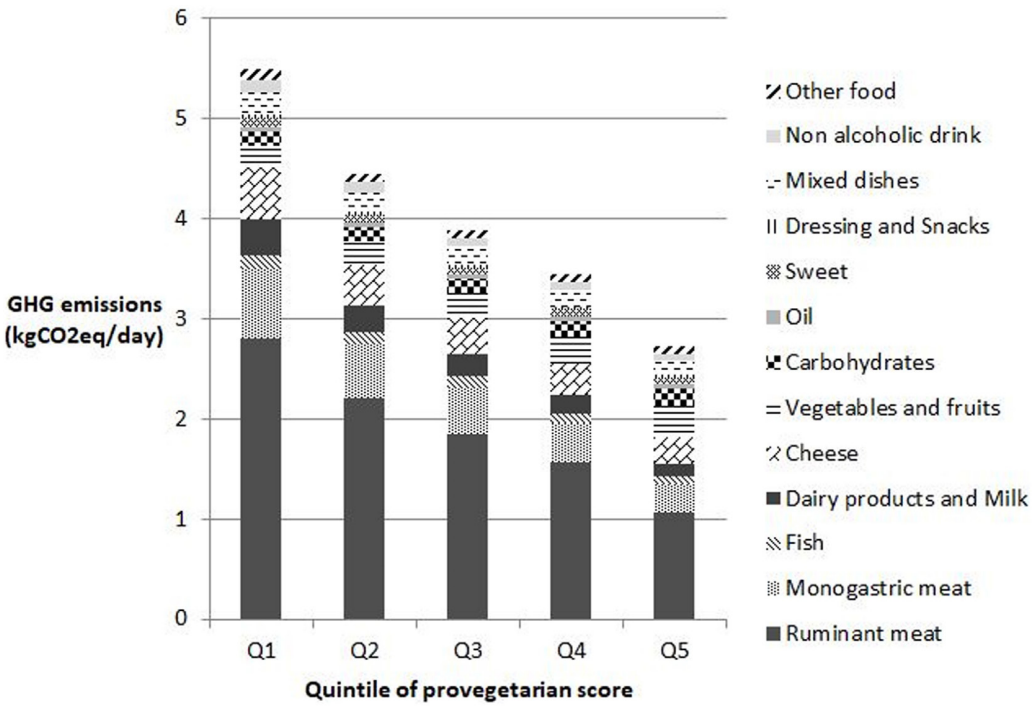


**FIGURE 1** | Greenhouse gas (GHG) emissions by food group and by quintile of provegetarian score. Other food group includes whole products, soy products, eggs, butter, other fats, and alcohol. Food group impacts are all significant (*P*-trend < 0.05).

of synthetic fertilizers which induce high costs in energy for their production and require the use of less mineral fertilizers and feed concentrates (56). However, some studies have determined that CED can be up to 40% higher in organic farming than in conventional systems (19). Another explanation relies on the fact that among the high consumers of organic foods, plant-based food consumption was higher overall. However, the correlation coefficient between the provegetarian score and the level of organic food consumption was estimated to be 0.4.

Regarding land occupation, the level of organic food consumption had a positive impact on diets rich in plant products and had no impact on diets with moderate level of plant product intake. These findings are noteworthy since organic systems require relatively more land (20, 56, 57) than conventional production systems. These lower crop yields are due to lower total nitrogen inputs per hectare (20). Our results may be explained by the fact that in the Q5 of the provegetarian score, consumers that eat a substantial amount of organic food exhibited higher plant-based consumption than their conventional counterparts and thus may have exhibited a lower consumption of meat. Moreover, according to Pimentel and Pimentel, grains and some legumes, which were highly consumed by participants in the Q5 of the provegetarian score, are produced more efficiently than fruits and vegetables (42). This may have led to a reduction in the negative impact of organic production on plant production yields. The absence of a differential effect of organic food consumption on land use for a diet with a moderate amount of plant products may be related to the fact that the ratio of organic foods in the diet is too low to detect any association, which is the same for GHG emissions. These findings regarding land occupation need further investigation since future improvements of management techniques and crop varieties may reduce the difference in crop yields between organic and conventional systems (9). Although this was not evaluated in our study, organic systems generally offer environmental services, do not use pesticides, increase resilience of agriculture and can mitigate the future effects of climate change on yields (58).

The limitations of this study should be noted. An extrapolation of these results to the general population should be done with caution as the participants who completed the BioNutriNet questionnaires were probably more concerned with nutrition and health-related issues. It should be noted that the percentage of participants with a very high consumption of organic foods, as observed in our study, is likely to be minimal in France. The use of a food frequency questionnaire may be prone to incorrectly estimating habitual diets, which is similar to other self-reported food consumption tools (59). Moreover, the effects of the systems of production on the environment should be considered with caution. Indeed, among similar systems of production, effects can be largely different due to climate conditions, soil types and farm management (18, 56). Other indicators such as pesticide use, leaching, and soil quality would have been relevant to addressing the environmental impacts of production systems (60, 61). In addition, our data included neither the origin nor the seasonality of food products, which may impact environmental assessments. Furthermore,

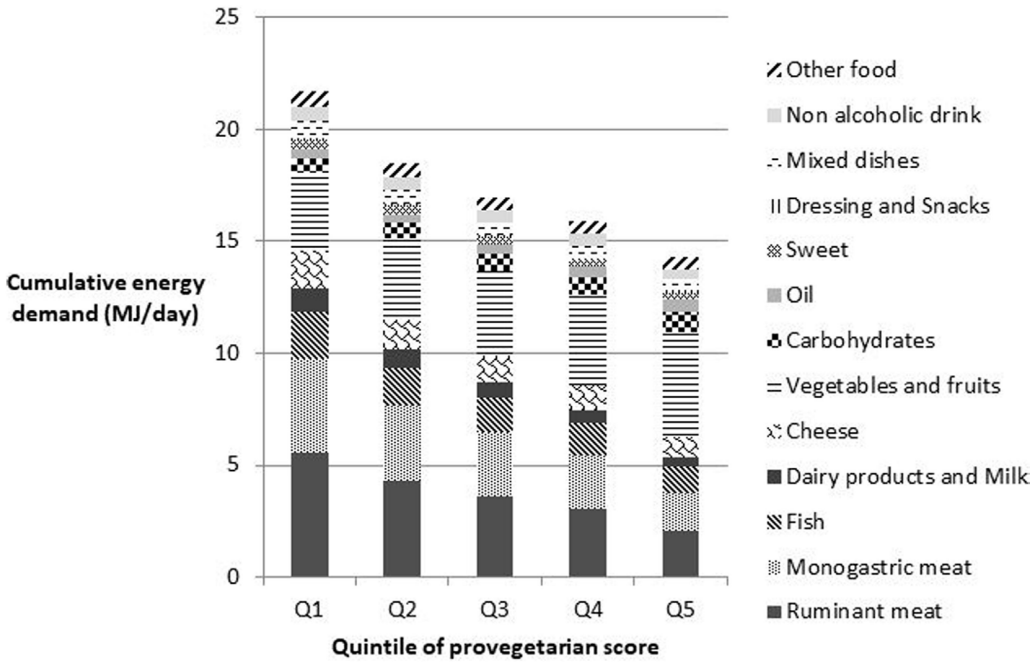


**FIGURE 2** | Cumulative energy demand by food group and by quintile of provegetarian score. Other food group includes whole products, soy products, eggs, butter, other fats, and alcohol. Food group impacts are all significant (*P*-trend < 0.05).

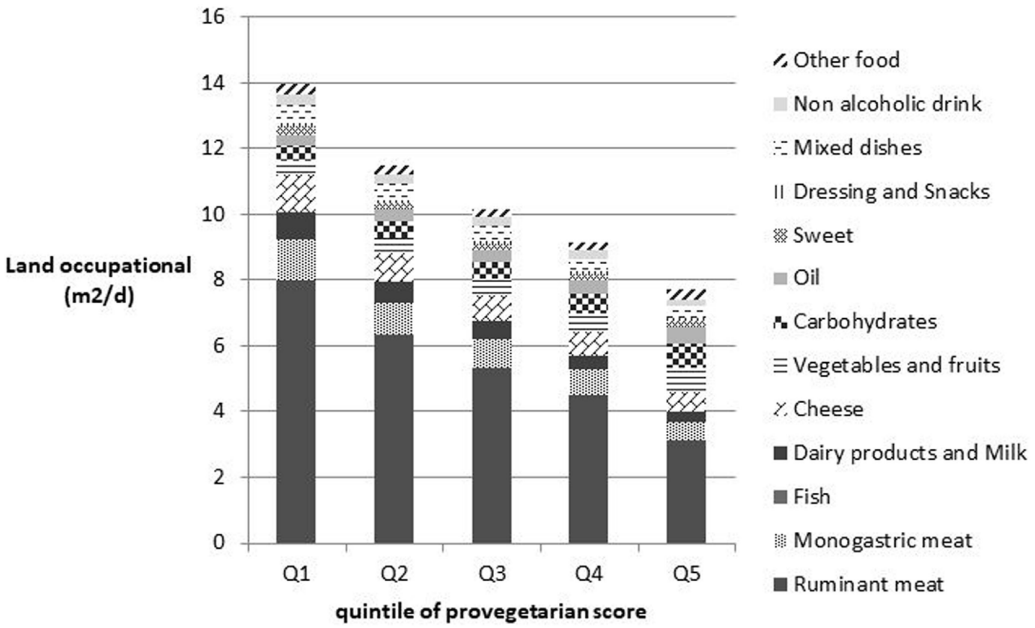


**FIGURE 3** | Land occupation by food group and by quintile of provegetarian score. Other food group includes whole products, soy products, eggs, butter, other fats, and alcohol. Food group impacts are all significant (*P*-trend < 0.05).

environmental impacts were assessed at the farm level and did not consider all of the production, transformation and distribution stages.

However, our study also presents notable strengths. First, to the best of our knowledge, this is the first study to distinguish production modes in the assessment of food consumption

and several subsequent environmental impacts. This is also the first study to investigate moderating effects of organic food consumption on the environmental impact of observed diets. Modeling studies do not necessarily consider isocaloric or representative substitutions. For example, replacing meat with fruit and legumes may not appear entirely realistic. Meat would probably be replaced by energy-dense products such as cereals, potatoes, and legumes. Moreover, these modeling studies rely on small cohorts. Therefore, it was crucial to focus on actual diets assessed in a large cohort to confirm or refute the results from modeling studies. Concerning the strengths of this study, our study is based on a large sample, which allows a wide diversity of dietary behaviors to be considered and in particular eco-friendly behaviors, using accurate environmental and consumption data. The provegetarian score also presents several advantages when compared to other dietary indexes commonly used in the literature such as the Mediterranean diet score (62). Indeed, while the Mediterranean diet recommends limiting milk and red meat, it also recommends consuming fish even though a major part of the fishing industry is not sustainable (63) and degrades maritime ecosystem functions by altering the food chain and fish habitats (64). Finally, the provegetarian score reflects different emerging dietary patterns (e.g., flexitarian diets) that tend to reduce consumption of animal products.

In conclusion, diet-related GHG emissions, CED, and land occupation indicators are negatively associated with a plant-based diet, regardless of the level of organic food consumption. Furthermore, the consumption of organic food showed additional beneficial impacts only in diets rich in plant products. This study demonstrates that the environmental impacts of diets should not only be evaluated in terms of dietary patterns but also should integrate production systems.

## ETHICS STATEMENT

The design was conducted according to the guidelines laid down in the Declaration of Helsinki and was approved by the Institutional Review Board of the French Institute for Health and Medical Research (IRB INSERM no. 0000388FWA00005831) and the "Commission Nationale de l'Informatique et des Libertés" (CNIL no. 908450 and no. 909216). All participants signed an electronic informed consent.

## AUTHOR CONTRIBUTIONS

EK-G, SH, PP, and DL designed the research; CL, LS, BA, BL, PP, DL, JB, and EK-G conducted the research; CL, LS, BA, JB, and EK analyzed the data; and CL and EK wrote the paper. CL, LS, BA, BL, PP, DL, JB, and EK were involved in interpreting the results and editing the manuscript. CL, LS, and EK had primary responsibility for the final content. All authors read and approved the final manuscript.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at http://www.frontiersin.org/articles/10.3389/fnut.2018.00008/full#supplementary-material.

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