

## Article

# Environmental Indicators of Vegan and Vegetarian Diets: A Pilot Study in a Group of Young Adult Female Consumers in Poland

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**Abstract:** It has been broadly reported that the production of animal-derived foods significantly contributes to the environmental footprint of the agri-food sector, considering, among others, such indicators as land use, greenhouse gas emissions, and the water footprint. However, the environmental sustainability aspects of whole diets (i.e., more plant-based vs. meat-containing) have been studied so far to a limited extent, in many cases not taking into consideration various regional settings, which to a great extent determine meat- and other animal-derived foods' substitutes consumed by vegetarians and vegans. The aim of this study was therefore to assess the environmental indicators of vegetarian, vegan, and meat-containing diets of a selected group of Polish consumers. Based on three-day food records of 24 respondents and the published data on the environmental footprint of a range of foodstuffs, the three dietary environmental indicators were calculated. In addition, the results were standardized in terms of dietary protein intake and energy value. The study showed the elimination of meat and other animal-derived foods from the respondents' diet was predominantly motivated by their concerns related to animal welfare issues, which appeared to be a stronger factor than the willingness to reduce the diets' environmental footprint. Following the results standardization, the studied vegetarian and vegan diets were characterized by 47.0% and 64.4% lower carbon footprint, 32.2% and 60.9% lower land use indicators, and 37.1% and 62.9% lower water footprints, respectively, compared to the meat-containing diet. Animal-derived foods, including milk and dairy, appeared to be the main contributors to all three environmental footprint indicators of both the meat-containing and the vegetarian diets. In the vegan group, the environmental footprint was found to be mainly influenced by the consumption of legumes and legume-based foods, cereal products, potatoes, sugar, products containing cocoa and vegetables, with nuts showing especially significant contribution to the fresh water consumption. The study confirms moving towards more plant-based diet has a potential to significantly reduce the diet's environmental footprint. It also contributes to creating a 'roadmap' for consumers, to encourage them to plan their diets responsibly, taking into consideration both the health and the environmental sustainability aspects.

**Keywords:** vegetarian diet; vegan diet; sustainable food system; environment; environmental footprint; carbon footprint; water footprint; land use; sustainability



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## 1. Introduction

Vegetarianism encompasses a total elimination of meat, fish, and any meat-based products from the diet, while veganism means a complete elimination of all animal-derived

products, including milk, dairy products, and eggs [1,2]. Diets characterized by the reduction or elimination of foods of animal origin have been recently growing in popularity [3,4]. Among the main motivations for adopting a vegetarian or a vegan diet, consumers most frequently mention ethical (related to the farm animal welfare), health, and environmental reasons [4–7]. It is important to investigate various health and sustainability dimensions of such diets, as part of a broader context of food systems transformation and potential for reaching the Sustainable Development Goals (SDGs) [8–10].

A significant reduction in the consumption of animal-derived products, especially red meat, by Western civilizations, is one of the main recommendations within the planetary health diet developed by the EAT-Lancet Commission on Food, Planet, Health [11]. A primary goal of this plant-forward diet, where whole grains, fruits, vegetables, nuts, and legumes comprise a great proportion of foods consumed, is to attempt to reconcile the nutritional needs of the growing human population while minimizing the negative effects of anthropopressure related to food production. Creators of the above-mentioned concept stated the global implementation of a planetary health diet would be associated not only with a significant reduction in the environmental footprint of the global food system, but also with measurable health benefits [11].

The environmental impact of food production and consumption is multidimensional and primarily concerns greenhouse gas emissions, land use for agriculture as well as water resources consumption (water footprint). It is estimated approximately 26% of anthropogenic greenhouse gas emissions result from processes related to food production, processing, distribution, and consumption, of which agriculture-related emissions account for around 61% (81% when emissions related to the land-use change are included) [12]. As indicated by the Food and Agriculture Organization of the United Nations (FAO) [13], livestock production, globally, accounts for about 5% of anthropogenic CO<sub>2</sub> emissions, 44% of CH<sub>4</sub> emissions, and 53% of N<sub>2</sub>O emissions. Cattle farming accounts for approximately 65% of emissions from this sector, while small ruminant, pig, poultry, and buffalo farming represent 7% to 10% of these emissions. Of the animal-derived products, beef is the least efficient source of protein in terms of CO<sub>2</sub> eq. emissions generated. Obtaining 1 kg of beef protein generates on average more than 300 kg CO<sub>2</sub> eq. The main sources of greenhouse gas emissions from livestock include enteric fermentation of ruminants, cultivation, and production of feeds, land use change related to the expansion of pasture for grazing animals and cropland for growing feed crops, manure management, energy use in the production, and finally all emissions related to processing [14].

An important aspect of the environmental impact of food production is the use of land. According to FAO, in 2019 land area used by agriculture accounted for 4.8 billion hectares and about one-third of the global land area. Of this, about one-third was cropland, while the remaining two-thirds were covered by meadows and pastures used for livestock [15]. In addition, about one-third of the mentioned cropland was dedicated to forage crops [16]. Such a contribution of the livestock production to the land use is due to the fact that far more energy and protein needs to be provided to livestock compared to the amount of energy and nutrients that can be obtained from their products. The protein conversion factor for none of the animal-based products (except for edible insects) is higher than 30%, which means at least 70% of the protein consumed by livestock is then not available for human consumption. Beef has the lowest protein and energy conversion factor. On average, only 3.8% of the plant proteins supplied to beef cattle in feeds is then available for human consumption in the final product [7,17]. This is one of the main reasons why beef is the most disadvantageous product in terms of land use.

A third important indicator of the environmental impact of food production is water footprint. The term water footprint refers to the amount of water used to produce goods and services, and can refer either to a single process, product, company or to the water consumption generated by a country, population, or humanity as a whole [18]. Among all food products, beef is considered to generate the largest water footprint. For the same energy value, it has about 20 times the water footprint of cereal crops and more than three

times that of poultry. As with the land use rates, the differences in water footprint between various animal products are primarily caused by different feed conversion efficiencies (ECI), and consequently different feed requirements. Plant-based foods are generally characterized by significantly smaller water footprints per equal nutritional value than foods of animal origin [12,19].

Even though the environmental costs of many single animal-based foods have been in many cases proven to be higher than those of plant-based foods, the environmental sustainability of whole diets (i.e., more plant-based vs. meat-containing) has been studied so far to a limited extent, in many cases not taking into consideration various regional settings, which to a great extent determine actual meat- and other animal-based foods' substitutes used by vegetarians and vegans. In this study we aimed to estimate three environmental indicators (land use, carbon footprint, and water footprint) of vegan and vegetarian diet in a selected group of Polish consumers who provided data through a short questionnaire and a three-day food record. The study utilized the Poore and Nemecek's [12] methodology to estimate the environmental indicators of the compared diets, further standardized based on the dietary protein intake and diet energy value. Further details of the employed methodology are outlined in the following section. The hypothesis of the study is the environmental footprint of diets of vegetarians and vegans in Poland is significantly lower compared to the footprint of diet of regular 'meat-eaters'.

## 2. Materials and Methods

### 2.1. The Study Group and Research Tool

The pilot study group consisted of 24 young adult Polish women (aged 20–31 years). Data was collected with a short questionnaire followed by a three-day food record. The questionnaire covered aspects such as the type of diet followed, the length of time it has been followed, and the motivation for following certain diet. The study group included participants with higher education or studying, living in big cities (over 100,000 inhabitants) of central Poland (mainly Warsaw), characterized by average or above-average economic status, and following a vegan diet (8), vegetarian diet (8), or diet containing meat and other animal-derived foods ('traditional diet') (8). Such inclusion criteria allowed for high homogeneity of the study group, and thus for limitation of the confounding effects of the variation in socio-demographic characteristics on the estimated environmental indicators. It has also facilitated the group formation, since there are significantly more vegans and vegetarians among women than men, and among highly educated and young consumers living in cities [5]. The three-day food record protocol included detailed instructions in which the participants were asked to note the portion sizes of the products before heat treatment and after the removal of inedible parts, and to indicate the type of heat treatment if it was not possible to weigh the product before treatment. In addition, the instructions included guidance on the use of household measures and an indication that, in the case of processed products, the brand of the product should be recorded. The questionnaire and the food record protocol were developed and provided to the participants in the Microsoft Word document format. All data was collected in May–July 2020. The food records covered three consecutive days, including two weekdays and one weekend day.

### 2.2. Methodology for Estimating Environmental Indicators of Diet

Information on the environmental footprint of individual foodstuffs were based on the publication of Poore and Nemecek [12], in which the authors estimated the environmental impact of specific products based on data from approximately 38,700 farms in 119 countries. Three environmental indicators were considered: land use (m<sup>2</sup>), greenhouse gas emissions (kg CO<sub>2</sub> eq.), and fresh water use (liters). Product-specific averages, converted per kilogram of edible parts or per liter, were used for calculations. From this information, a database was developed (in Microsoft Excel) that allowed to estimate the environmental indicators of each participant's diet based on their reported consumption data.

Calculations included all products consumed by the participants, with the exception of dietary supplements, condiments, water, coffee, tea, and alcoholic beverages. Some simplifications were applied during the calculations, due to the limitations of the Poore and Nemecek database (limited number of products): (a) some products were recalculated as products with a similar nutritional value or similar production method (e.g., seeds and fruit stones recalculated as nuts; plant-based drinks (e.g., oat milk) recalculated as soya drinks); (b) some processed products were recalculated as the ingredients listed in their formulation or the raw materials/products from which the final product was made (e.g., sweets were recalculated as different amounts of palm oil, sugar, milk, cereal products, etc.; ketchup—tomatoes and sugar). Consequently, the environmental impacts of processing of certain products were omitted from the calculations.

### 2.3. Standardisation of Results

The study results were further standardized based on the energy value of the diet, ensuring the comparison was independent of energy consumption. Additionally, standardization with respect to dietary protein intake was also performed, since animal-derived food products belong to significant protein sources.

For this purpose, environmental indicators were calculated per 1000 kcal and 50 g of protein. The diet energy value and protein intake of the participants were estimated using the DietetykPro programme (based on products and dishes typical for the Polish population), then the mean values for 1 day of the menus (average of 3 days) were calculated. The final results were calculated according to the following formula:

$$SI = Im * \frac{1000 \text{ kcal}}{Em} \text{ and } SI = Im * \frac{50 \text{ g}}{Pm}$$

SI—standardized index, Im—mean index value (for 3 days), Em—mean energy value (for 3 days), Pm—mean protein intake (for 3 days).

### 2.4. Statistical Analyses

All statistical analyses were performed using the Statistica version 13 (Statsoft, Poland) software. The conformity of the distribution of each trait (each of the calculated environmental indicators) with the normal distribution for each of the study groups was examined using the Shapiro–Wilk W test. If the distribution of a given trait in each of the 3 groups followed a normal distribution, a one-way analysis of variance (ANOVA) with a post-hoc Tukey’s HSD test was used to compare the groups. If the distribution of a given trait deviated from normal for at least one of the study groups, the non-parametric Mann–Whitney U test was used for comparison, and groups were compared in pairs. Differences between groups were considered statistically significant at  $p < 0.05$ . Results were presented using mean values and standard deviations.

## 3. Results

### 3.1. Time and Motivations for Following Vegetarian or Vegan Diet

The vegetarians participating in the study had been following this diet for an average of 2.2 years, while vegan participants had been following such a diet for an average of 4.1 years. The shortest declared period of a vegan or vegetarian diet among the study participants was 0.5 year, while the longest was 10 years (Table 1).

In the question about motivations for following a vegan or vegetarian diet, the participants were asked to mark a maximum of two out of four answers: (1) ‘I do not want to contribute to animal suffering’ (‘Ethical motivation’), (2) ‘I believe that such a diet has a positive impact on my health’ (‘Health motivation’), (3) ‘I follow such a diet to reduce my negative impact on the environment’ (‘Environmental motivation’), (4) ‘Other’.

**Table 1.** Time and motivations for following a vegetarian or vegan diet by the study participants.

| Diet<br>(Study Group)      | Duration of Diet<br>(Years)<br>(Mean $\pm$ SD) | Motivations for Following the Diet |                     |                            |        |
|----------------------------|------------------------------------------------|------------------------------------|---------------------|----------------------------|--------|
|                            |                                                | Ethical <sup>1</sup>               | Health <sup>2</sup> | Environmental <sup>3</sup> | Other  |
| Vegetarian ( <i>n</i> = 8) | 2.2 $\pm$ 2.1                                  | 5 (62.5%) <sup>4</sup>             | 4 (50.0%)           | 5 (62.5%)                  | 0 (0%) |
| Vegan ( <i>n</i> = 8)      | 4.1 $\pm$ 3.1                                  | 8 (100.0%)                         | 2 (25.0%)           | 4 (50.0%)                  | 0 (0%) |
| TOTAL ( <i>n</i> = 16)     | 3.1 $\pm$ 2.7                                  | 13 (81.3%)                         | 6 (37.5%)           | 9 (56.3%)                  | 0 (0%) |

Explanatory notes: *n*—number of respondents; SD—standard deviation; <sup>1</sup> answer: ‘I do not want to contribute to animal suffering’; <sup>2</sup> answer ‘I believe that such a diet has a positive impact on my health’; <sup>3</sup> answer ‘I follow such a diet to reduce my negative impact on the environment’; <sup>4</sup> in brackets: percentage of respondents.

Animal welfare aspects (‘Ethical motivation’) was the most frequently reported reason to eliminate meat and/or other animal-derived foods from the diet. It was indicated by eight (100%) respondents on a vegan diet and five (62.5%) on a vegetarian diet. The willingness to reduce environmental impact (‘Environmental motivation’) was indicated by nine participants on vegetarian and vegan diet (56.3% of all respondents in this group). At the same time health aspects were amongst the most important motivations for six respondents (four vegetarians and two vegans) only. None of the study participants indicated other reasons/motivations to follow certain diets (Table 1).

### 3.2. Data on Intake and Nutritional Value of Diet

Table 2 presents the average daily energy value and protein intake of the different study groups. On average, the reported food records of participants following vegetarian and vegan diets were characterized by a higher energy value than those of participants on a meat-containing (‘traditional’) diet. On average, vegetarians and vegans consumed approximately 230 kcal/d and 430 kcal/d more, respectively, than participants who did not eliminate animal products from their diet. At the same time, the average protein supply was at a similar level in each group (66.3–72.5 g/d).

**Table 2.** Average daily energy value and protein intake in the diet of respondents in particular study groups.

| Group (Diet)                | Energy Value (kcal/d) |      |      | Protein Intake (g/d) |      |       |
|-----------------------------|-----------------------|------|------|----------------------|------|-------|
|                             | Mean $\pm$ SD         | Min. | Max. | Mean $\pm$ SD        | Min. | Max.  |
| Traditional ( <i>n</i> = 8) | 1528 $\pm$ 386        | 973  | 2005 | 72.5 $\pm$ 23.8      | 28.8 | 97.5  |
| Vegetarian ( <i>n</i> = 8)  | 1762 $\pm$ 490        | 1061 | 2610 | 66.3 $\pm$ 15.8      | 45.0 | 95.5  |
| Vegan ( <i>n</i> = 8)       | 1962 $\pm$ 366        | 1487 | 2436 | 72.3 $\pm$ 19.2      | 53.4 | 103.5 |
| TOTAL ( <i>n</i> = 24)      | 1751 $\pm$ 438        | 973  | 2610 | 70.4 $\pm$ 19.2      | 28.8 | 103.5 |

Explanatory notes: SD—standard deviation; Min.—minimum; Max.—maximum; d—day.

Tables 3 and 4 present data on the reported consumption of certain product groups by study participants following the particular diets. Study participants following vegetarian and vegan diets reported significantly higher consumption of tofu and legumes and, in addition, vegans consumed significantly more plant-based drinks compared to the participants following a traditional (meat-containing) diet. Moreover, vegans consumed on average 90% more fruit and 67% more cereal products (such as groats, pasta) than the participants not eliminating animal products from their diet. Some trends towards (a) higher bread and vegetables consumption in the group of vegans, (b) higher consumption of potatoes and sugar in the group of vegetarians, as well as (c) higher consumption of nuts and seeds and vegetable oils in both vegan and vegetarian groups compared to the meat-eating group were also noted.

**Table 3.** Estimated average daily consumption (g/d) of selected food products/groups of food products of plant origin in the study groups.

| Group (Diet)                | bd    | dcp   | pt   | tf     | dl      | sgr  | nss  | pbd     | vo   | vvp   | fp    |
|-----------------------------|-------|-------|------|--------|---------|------|------|---------|------|-------|-------|
| Traditional ( <i>n</i> = 8) | 114.8 | 68.8  | 62.5 | 0.0    | 12.0    | 5.6  | 16.8 | 15.8    | 11.5 | 326.5 | 122.1 |
| Vegetarian ( <i>n</i> = 8)  | 109.4 | 84.3  | 74.6 | 30.0 * | 45.8 *  | 13.4 | 22.0 | 28.1    | 15.2 | 319.0 | 164.0 |
| Vegan ( <i>n</i> = 8)       | 133.2 | 115.4 | 62.5 | 82.3 * | 123.0 * | 7.0  | 19.7 | 152.7 * | 19.0 | 360.2 | 232.9 |

Explanatory notes: \*—statistically significant differences ( $p < 0.05$ ) compared to the traditional diet; bd—bread; dcp—dry cereal products; pt—potatoes; tf—tofu; dl—dry legumes; sgr—sugar; nss—nuts and seeds; pbd—plant-based drinks; vo—vegetables oils; vvp—vegetables and vegetable preserves; fp—fruits and their preserves.

**Table 4.** Estimated average daily consumption (g/d) of selected food products/groups of food products of animal origin in the study groups.

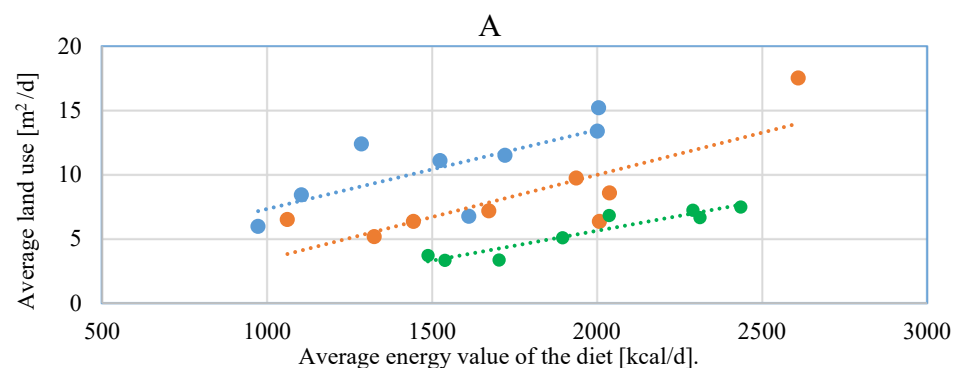
| Group (Diet)                | Beef | Pork | Poultry | Fish | Milk and Dairy Products (Except Cheese) | Cheese | Eggs |
|-----------------------------|------|------|---------|------|-----------------------------------------|--------|------|
| Traditional ( <i>n</i> = 8) | 32.1 | 32.1 | 60.0    | 19.0 | 296.0                                   | 31.0   | 35.4 |
| Vegetarian ( <i>n</i> = 8)  | -    | -    | -       | -    | 236.9                                   | 30.8   | 35.4 |
| Vegan ( <i>n</i> = 8)       | -    | -    | -       | -    | -                                       | -      | -    |

Study participants following a traditional, meat-containing diet consumed on average over 30 g/d of beef, over 30 g/d of pork, 60 g/d of poultry, and 19 g/d of fish. Consumption of eggs and cheese was reported at similar levels in the group of vegetarians and in the group of respondents following a traditional, meat-containing diet. At the same time a trend towards a lower milk and dairy (except cheese) consumption was noted in the group of vegetarians compared to the respondents following a meat-containing diet.

### 3.3. Environmental Indicators of the Studied Diets

This section presents the results on the environmental indicators of the studied diets, before standardization and after standardization in relation to the energy value of the diet and in relation to the protein content of the diet.

Figure 1 shows the estimated environmental indicators of the diets (Y axis) of each study participant in relation to the energy value of the diet (X axis) (results before standardization). The figure shows (1) the diets' environmental footprints are generally positively associated with energy intake and (2) environmental footprint indicators of vegetarian and vegan diets are in the majority of cases lower than those of a traditional (meat-containing) diet.

**Figure 1.** Cont.

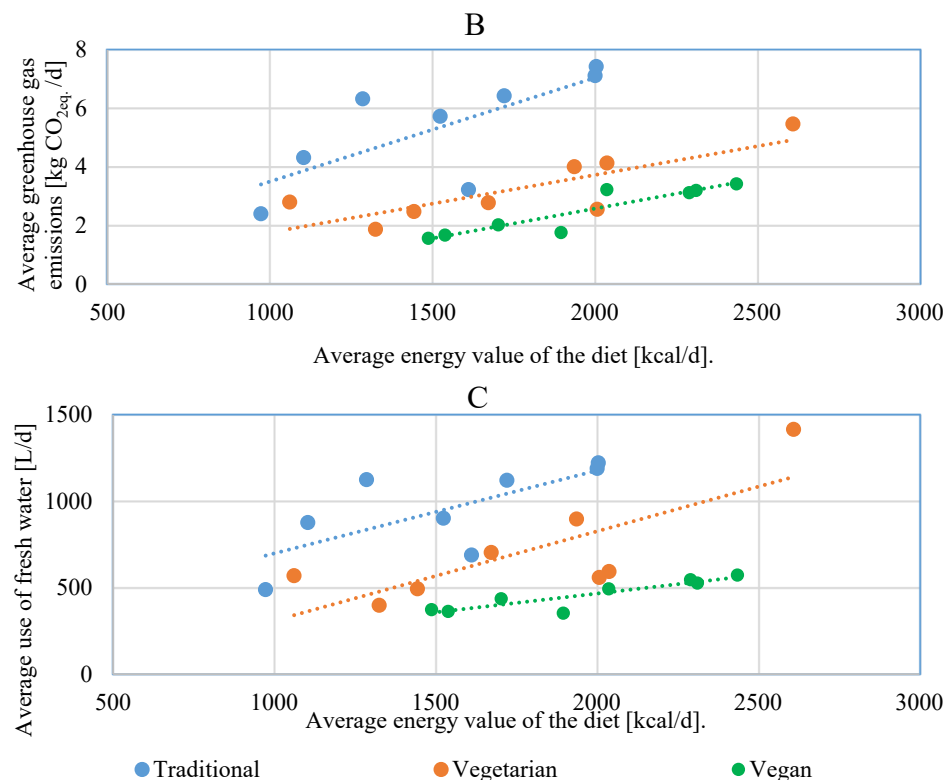


**Figure 1.** Estimated land use (A), greenhouse gas emission (B), and fresh water use (C) indicators (Y axis) in relation to the energy value of diet (one point—result for 1 person).

After standardization in relation to the energy value, the diets of vegans and vegetarians were characterized by significantly ( $p < 0.05$ ) lower mean values of all three environmental indicators compared to the traditional diet. In addition, the diet of the vegan group was characterized by lower average land and fresh water use compared to the diet of vegetarians. The mean values of environmental indicators of each diet, standardized in relation to the energy value of the diet, are presented in Figure 2A–C and in Table 5.

As shown in Table 5, the reported menus of vegetarians had significantly lower environmental indicators compared to the participants on meat-containing diet. They were related to 2.25 m<sup>2</sup> (32.2%) lower land use, 1.65 kg CO<sub>2</sub> eq. (47.0%) lower carbon footprint, and 37.1% (234 L) lower water footprint for every 1000 kcal of energy intake. At the same time, the reported menus of the vegan study participants were characterized by the lowest environmental indicators. On average, the vegan diet per 1000 kcal required over 2.5 times less land (2.72 compared to 6.98 m<sup>2</sup>), had an approximately 2.8-fold lower carbon footprint (1.25 compared to 3.51 kg CO<sub>2</sub> eq.) and used approximately 2.7 times less water (234.2 compared to 630.7 L) compared to the meat-containing diet. After standardizing the results in terms of protein intake, the values of all environmental indicators for the vegan diet were significantly ( $p < 0.05$ ) lower compared to the meat-containing diet. The vegan diet had a lower carbon footprint than the meat-containing diet. The values of land use and fresh water use indicators were significantly ( $p < 0.05$ ) lower for the vegan diet, compared to both the meat-containing and vegetarian diets. In contrast, they were not significantly different between vegetarian and meat-containing diets.

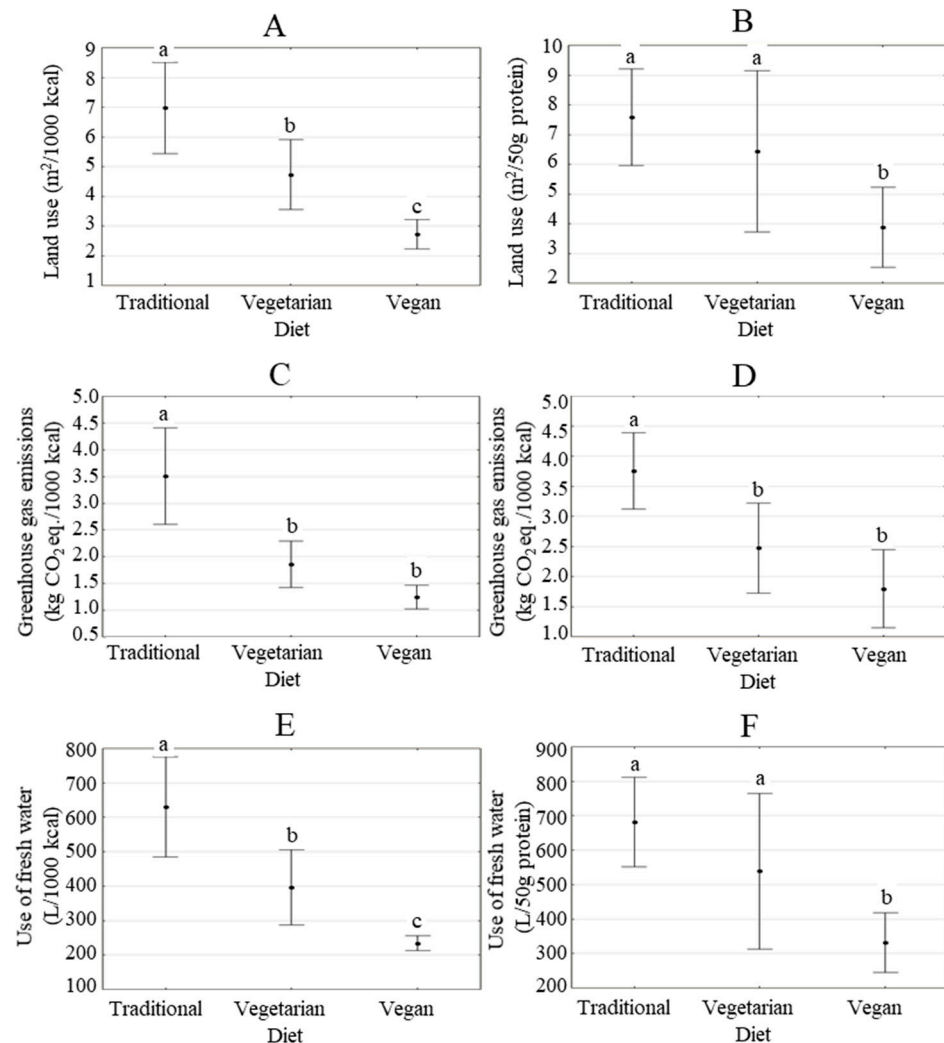


**Figure 2.** Environmental indicators (land use (A,B), greenhouse gas emissions (C,D), and fresh water use (E,F)) of the studied vegan, vegetarian, and traditional diets, standardized against the energy value of the diet (A,C,E) and the protein intake in the diet (B,D,F). Data expressed as mean  $\pm$  SD. Different lowercase letters (a, b, c) denote statistically significant differences between the compared diets ( $p < 0.05$ ).

**Table 5.** Environmental indicators of meat-containing, vegetarian, and vegan diets, standardized in relation to the energy value of the diet (mean  $\pm$  SD).

| Diet                       | Land Use<br>(m <sup>2</sup> /1000 kcal) | Greenhouse Gas<br>Emissions<br>(kg CO <sub>2</sub> eq./1000 kcal) | Use of Fresh Water<br>(L/1000 kcal) |
|----------------------------|-----------------------------------------|-------------------------------------------------------------------|-------------------------------------|
| Meat-containing<br>(n = 8) | 6.98 $\pm$ 1.54a                        | 3.51 $\pm$ 0.90a                                                  | 630.7 $\pm$ 145.4a                  |
| Vegetarian (n = 8)         | 4.73 $\pm$ 1.18b                        | 1.86 $\pm$ 0.44b                                                  | 396.7 $\pm$ 108.8b                  |
| Vegan (n = 8)              | 2.72 $\pm$ 0.49c                        | 1.25 $\pm$ 0.22b                                                  | 234.2 $\pm$ 21.5c                   |
| TOTAL (n = 24)             | 4.81 $\pm$ 2.09                         | 2.20 $\pm$ 1.13                                                   | 420.5 $\pm$ 194.4                   |

Explanatory notes: Different lowercase letters (a, b, c) within the same column denote statistically significant differences between the compared diets ( $p < 0.05$ ).

The mean values of environmental indicators, standardized in relation to the dietary protein intake, in each group are presented in Figure 2D–F and in Table 6.

**Table 6.** Environmental indicators of meat-containing, vegetarian, and vegan diets, standardized in relation to the protein intake (mean  $\pm$  SD).

| Diet                            | Land Use<br>(m <sup>2</sup> /50 g<br>Protein Intake) | Greenhouse Gas<br>Emissions<br>(kg CO <sub>2</sub> eq./50 g<br>Protein Intake) | Use of Fresh Water<br>(L/50 g<br>Protein Intake) |
|---------------------------------|------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------|
| Meat-containing ( <i>n</i> = 8) | 7.58 $\pm$ 1.62a                                     | 3.75 $\pm$ 0.63a                                                               | 681.6 $\pm$ 130.1a                               |
| Vegetarian ( <i>n</i> = 8)      | 6.43 $\pm$ 2.72a                                     | 2.47 $\pm$ 0.74b                                                               | 539.1 $\pm$ 226.2a                               |
| Vegan ( <i>n</i> = 8)           | 3.88 $\pm$ 1.35b                                     | 1.80 $\pm$ 0.65b                                                               | 332.0 $\pm$ 86.3b                                |
| TOTAL ( <i>n</i> = 24)          | 5.96 $\pm$ 2.47                                      | 2.67 $\pm$ 1.05                                                                | 517.6 $\pm$ 210.9                                |

Explanatory notes: Different lowercase letters (a, b) within the same column denote statistically significant differences between the compared diets ( $p < 0.05$ ).

The carbon footprint of the vegetarian diet was on average by about 1.28 kg CO<sub>2</sub> eq. (34.1%) lower for every 50 g of protein intake compared to the meat-containing diet. At the same time, environmental indicators for the vegan diet were lower by an average of 3.70 m<sup>2</sup> (48.8%) of land area used, 1.95 kg CO<sub>2</sub> eq. (52%) of carbon footprint and almost 350 L (51.3%) of fresh water compared to the meat-containing diet.

### 3.4. Environmental Impact of Consumption of Specific Product Groups

Figure 3 shows the estimated contribution of specific food groups to the environmental indicators of the three diets compared within the study.

In case of a traditional (meat-containing) diet, 79.6% of land use, 77.3% of carbon footprint, and 66.7% of fresh water consumption were estimated to be generated by the consumption of animal-derived foods. In case of a vegetarian diet, 59.9%, 50.6%, and 48.6% of each of the three environmental indicators, respectively, were estimated to be caused by the consumption of products of animal origin. The consumption of milk and dairy products was estimated to significantly contribute to the environmental indicators in the case of both the traditional and the vegetarian diet. Their consumption accounted for more than half of the value of the land use indicator (50.8% for the traditional diet and 57.3% for the vegetarian diet).

In addition, for the vegetarian diet, an average of 45.5% of the carbon footprint and 45.7% of the fresh water consumption was estimated to result from the consumption of dairy products. The consumption of meat and fish in the traditional diet group was, on average, estimated to be responsible for about 26.8% of the land use indicator value and 26.7% of the fresh water consumption indicator value and had the greatest impact on the carbon footprint indicator, accounting for 43.1% of its value on average.

In the vegan group, the land use indicator was found to be mainly influenced by the consumption of legumes and legume-based foods (42.2%), cereal products, potatoes and sugar (together 24.9%), and products containing cocoa and dark chocolate (15.3%). The estimated carbon footprint of the vegan diet was mostly influenced by the consumption of the products mentioned above (23.3%, 25.2% and 22.6%, respectively) and vegetables (16.9%). At the same time the consumption of cereal products, potatoes and sugar (together 40.4%), legumes and legume-based products (15.3%), nuts (15.7%) and vegetables (15.8%) were estimated to have the greatest impact on the fresh water consumption.

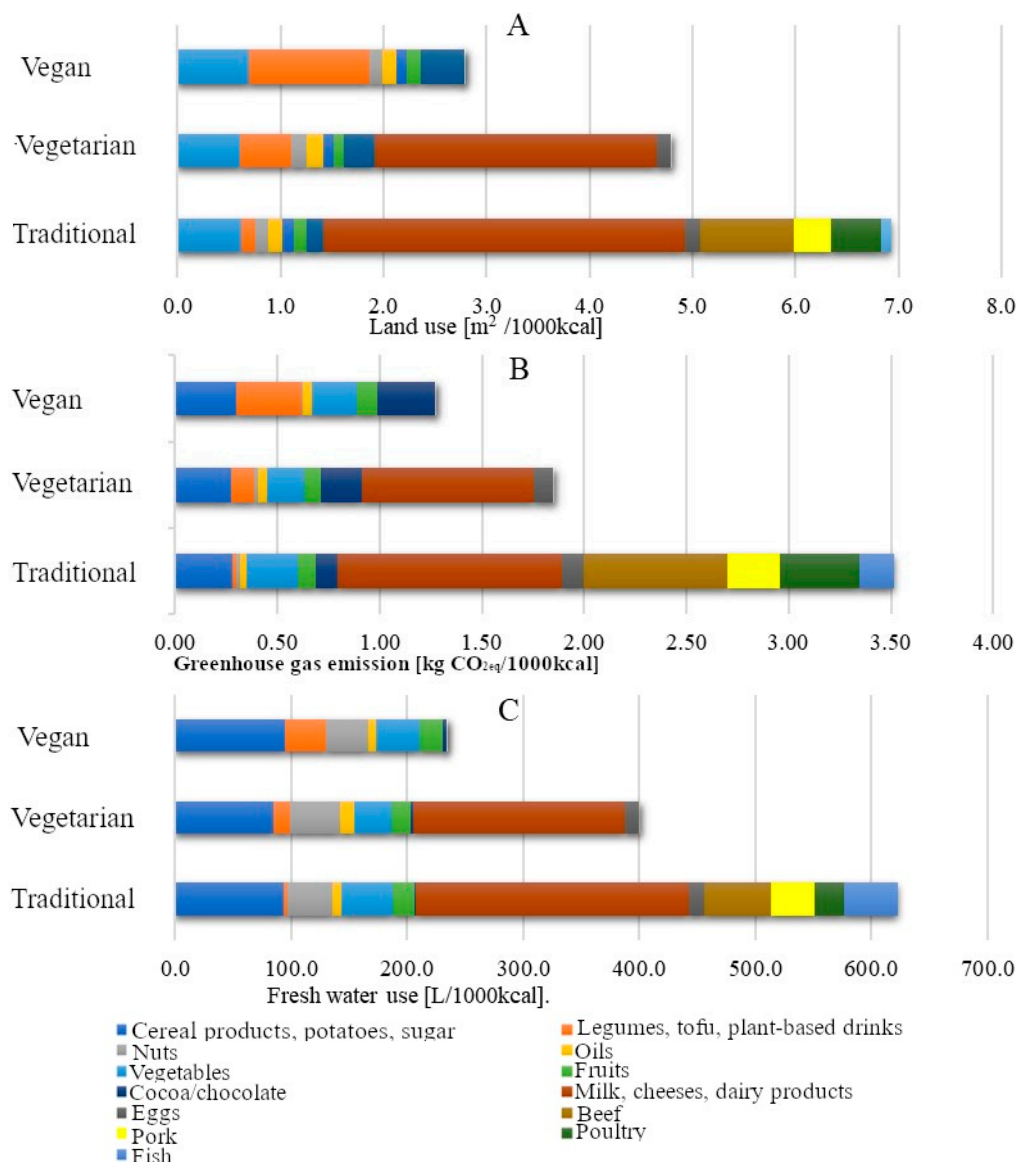


**Figure 3.** The estimated contribution of individual product groups included in the studied vegan, vegetarian, and traditional diets to the total values of the land use (A), carbon footprint (B) and water footprint (C) of the diets, standardized per 1000 kcal of the energy value.

#### 4. Discussion

The results of a pilot study presented here confirmed the lower environmental footprint of vegetarian diets compared to diets containing meat. Furthermore, vegan diet had significantly lower environmental footprint than the vegetarian diet.

Even though the study represented a pilot scale, one of its strengths was the homogeneity of the study groups. All participants were females, lived in large cities (over 100,000 inhabitants) and were of similar age (20–31 years). In addition, the results were standardized with respect to the energy value of the diet, so that the results presented did not depend on the amount of energy consumed. Results standardized in terms of dietary protein intake were also developed, as most products of animal origin are valuable sources of protein and the studied vegetarian and vegan diets assume partial or total elimination of these products.

On the other hand, the limitations of the study included: i.e., adoption of a number of simplifications when estimating the environmental indicators of the diets. As mentioned in the methodology section, this mainly concerned processed products. The environmental

cost of some products was assumed to be equivalent to the environmental cost of their ingredients, not taking into account the environmental impact of processing. Moreover, some products were recalculated as products with a similar nutritional value or similar production technology (e.g., plant-based drinks such as oat milk calculated as soya drinks). In this type of research, the adoption of certain simplifications is inevitable due to the fact that exact environmental impact of many products is not precisely known yet. However, future studies should employ the available, most recent and comprehensive data sources, to increase precision of the environmental footprint estimations.

When interpreting the results of the presented study, it is also important to remember the environmental indicators of the diets were calculated based on the average values of the environmental costs of individual foodstuffs. These were based on a paper by Poore and Nemecek [12], who analyzed significant amount of data from 38,700 farms and 1600 food processors from 119 countries. The authors noted, however, the environmental costs of certain products could significantly vary between different producers and production systems. Therefore, to determine the environmental indicators of certain diets more accurately, it would be necessary to develop a database containing estimated environmental costs for products specific i.e., to the Polish or European market, and take into consideration various production and processing systems, methods, and conditions.

One of the limitations of the study was also the fact that the reported food records came from one (spring-summer) season and thus did not take into consideration possible seasonal variation of the menus. At the same time, some significant differences in the diet composition between spring-summer and autumn-winter season could be expected [20]. Moreover, it needs to be taken into consideration that the three-day food record covering three consecutive days, including two weekdays and one weekend day, even though broadly used as one of the standard and reliable dietary assessment tools, has some limitations, e.g., it may not capture some foods consumed more occasionally or episodically [21]. Thus, to increase accurateness of the undertaken dietary estimations, in future similar studies, the food record could be supported by the food frequency questionnaire (FFQ) or/and other tools [22]. Other factors to be considered include consumption of left over meals, home gardening (availability of fresh foods), and restaurant meals. These could all impact the accuracy of undertaken dietary estimations.

Lower environmental footprint of diets involving reduced consumption of animal products compared to meat-containing diets was previously reported in the scientific literature. One of the reported advantages of plant-based diets in terms of environmental sustainability, in line with the presented study, was their lower carbon footprint. In the study by Springmann et al. [23] the authors have analyzed various scenarios assuming the entire global population would adopt different diets by 2050, and estimated consequences of such scenarios. The first scenario assumed the adoption of a diet in line with the World Health Organization (WHO) global recommendations for healthy eating, with energy value adequate to maintain the recommended body weight. The other two scenarios also assumed all people would consume the recommended amount of calories, but with a vegetarian or vegan diet. The reference scenario was the United Nations projection for 2050. The analysis showed the adoption of a vegetarian or vegan diet by the global population would result in a 63% and 70% reduction in greenhouse gas emissions associated with food production, respectively, by 2050. The reduction of emissions for a diet following the WHO recommendations would reach approximately 29%. Additionally, scenarios involving the adoption of a vegetarian or vegan diet were associated with a 6–10% reduction in global mortality. The study also presented how dietary change would affect emissions in different regions. It showed the adoption of an exclusively plant-based diet would have the greatest positive impact on the absolute value of the carbon footprint in developing countries (probably due to the size of their population), while on a per capita basis, the greatest benefits would be observed in developed countries.

White and Hall [24] analyzed how exclusion of animal production and basing US agriculture solely on plant products could impact national food security and greenhouse

gas emissions. According to the authors, if livestock farming was eliminated from American agriculture, i.e., allocating feed raw materials (e.g., corn, soybeans, etc.) to produce food for humans, the amount of available food would increase by approximately 23% and it could provide approximately doubled amount of energy and protein. According to the assumed scenario, greenhouse gas emissions from agriculture in the United States would be reduced by approximately 29%.

In a review by Aleksandrowicz et al. [25] the results of 63 publications examining the environmental impact of different diets were analyzed, taking into account environmental sustainability indicators such as greenhouse gas emissions, land use, and water consumption. The review focused on the differences in environmental indicator values between the studied diets and reference diets—consistent with the average intake in the studied populations. Only studies in which the difference in the energy value of the studied and reference diets was not greater than 5% were included in the review. Most of the analyzed diets considered different types of modifications to the intake of animal-derived foods. The diets characterized by the greatest reduction in the consumption of meat and animal-derived products, i.e., vegetarian and vegan, were found to be the most beneficial for the environment. The medians for the relative change in greenhouse gas emissions and land use indicators were −31% and −51% for the vegetarian diet and −45% and −55% for the vegan diet, respectively, compared to the reference diets. In terms of water use, the vegetarian diet was the most beneficial, with a median relative change of −37%.

In the work of Scarborough et al. [26] the carbon footprint of different diets, including vegetarian and vegan diet, was estimated using data from the EPIC-Oxford cohort study conducted in the UK. The study included food frequency questionnaires (FFQs) from 2041 vegans 15,751 vegetarians and 29,589 people on ‘omnivore’ diet. The carbon footprint was estimated for 2000 kcal for each diet, and adjustments for gender and age were made. With a daily calorie intake of 2000 kcal, the average carbon footprint was 2.89 kg CO<sub>2</sub> eq. for a vegan diet, 3.81 kg CO<sub>2</sub> eq. for a vegetarian diet, 4.67 kg CO<sub>2</sub> eq. for a diet including meat products in the amount of <50 g/d and 7.19 kg CO<sub>2</sub> eq. for a diet including meat products in the amount of >100 g/d.

In the previously mentioned study by Rosi et al. [27] environmental indicators of vegan, vegetarian, and traditional diets were compared, based on 7-day food records of 153 individuals (51 individuals in each group) in Italy. The average carbon footprint was 3.96 kg CO<sub>2</sub> eq./d for traditional diet, 2.60 kg CO<sub>2</sub> eq./d for vegetarian diet, and 2.34 kg CO<sub>2</sub> eq./d for vegan diet. The participants consumed an average 2300–2500 kcal/d. When converted to 2000 kcal, the average carbon footprint values calculated in our study were 7.02 kg CO<sub>2</sub> eq. for people on a traditional diet, 3.72 kg CO<sub>2</sub> eq. for vegetarians, and 2.50 kg CO<sub>2</sub> eq. for vegans. Among the scientific papers described above, the study by Rosi et al. [27] is, in terms of methodology, the most similar to our study. However, the calculated values of the average carbon footprint for each diet best match those presented by Scarborough et al. [26]. In comparison to the work by Rosi et al. [27], the greenhouse gas footprint values estimated in our study are higher for each diet, with the largest discrepancy for the traditional diet (7.02 kg CO<sub>2</sub> eq. for 2000 kcal vs. 3.96 kg CO<sub>2</sub> eq. for 2471 kcal). As meat has a high carbon footprint, differences in meat consumption in the study populations can significantly affect the obtained values of the carbon footprint of the diets. In our study, in the group of participants following the meat-containing diet, the average meat consumption reached 124.2 g/d, with an average dietary energy value of approximately 1528 kcal/d, while in the study by Rosi et al. [27] the intake of meat was estimated as 113.2 g/d with diet energy value of approximately 2471 kcal/d. In the publication by Scarborough et al. [26], people consuming more than 100 g/d of meat were defined as ‘high meat-eaters’. Consequently, the group of consumers on a ‘traditional diet’ in our study corresponded to the group of ‘high meat-eaters’ in the study by Scarborough et al. [26]. Thus, carbon footprint values calculated in both studies were largely in line, reaching respectively (for 2000 kcal): 7.02 and 7.19 (traditional diet), 3.72 and 3.81 (vegetarian diet), 2.50 and 2.89 (vegan diet) kg CO<sub>2</sub> eq.

Davis et al. [28] analyzed the environmental costs of a diet of an average Earth dweller, including CO<sub>2</sub> eq. emissions, water, nitrogen, and land area use. Food products of animal origin accounted for a significant amount of the calculated environmental costs, i.e., in the case of the land use indicator, for as much as 87% of its value. The results indicated beef consumption had the greatest contribution to the land area used. The authors concluded feeding a growing human population would require either agricultural intensification (to produce more food from the same land area) or changes in diets.

The relation between diet, land use, and the problem of sustainable feeding of the population is well shown in the study by Peters et al. [29], who estimated the size of the population that can be fed by local agriculture in the New York State, depending on the type of diet adopted. The study considered diets characterized with different levels of meat consumption (0–381 g) and percentage of energy from fat (20–45% E). The analysis showed, depending on the type of diet, the state's agriculture could nourish between 2.0 and 6.2 million people. This outcome demonstrated the enormous impact of diet on the ability to feed the population. As the meat content of the diet decreased, the potential to feed the population increased.

In the present study, the average land use indicators for the different diets, when estimated for 2000 kcal, were: 13.96 m<sup>2</sup>/d for the traditional diet, 9.46 m<sup>2</sup>/d for the vegetarian diet, and 5.44 m<sup>2</sup>/d for the vegan diet. In the previously discussed study by Rosi et al. [27] these indicators were (for approximately 2300–2500 kcal/d) estimated as 26.0 m<sup>2</sup>/d, 16.1 m<sup>2</sup>/d, and 14.5 m<sup>2</sup>/d, respectively. However, Rosi et al. [27] used data on food environmental footprints from the Barilla Center for Food and Nutrition [30], while in the present study we based the calculations on the publication by Poore and Nemecek [12]. Furthermore, when comparing the results of the present study with other work, it should be borne in mind in the present study the consumption of certain beverages (including alcohol) was not included in the calculations.

The last environmental indicator calculated in the present study was water consumption. According to the vast majority of studies, the water footprint of a vegetarian diet is lower than the water footprint of a meat-containing diet. In contrast, the impact of a vegan diet on water use is relatively poorly reported in the literature. The review by Fresán and Sabaté [31], which extensively discussed the environmental impact of vegetarian and vegan diets, included only four studies on the water footprint of vegan diets. In the work of Meier and Christen [32] a number of environmental indicators were calculated for different diets with an energy value of 2000 kcal. The reference point was consumption data for Germany in 2006. The vegan and vegetarian diets were characterized by lower greenhouse gas emissions, lower use of phosphorus and nitrogen, and a lower land use index, compared to the reference diet. However, the calculated water footprint was 85% higher for the vegetarian diet and 107% higher for the vegan diet, in comparison to the reference diet. Aleksandrowicz et al. [25] and Fresán and Sabaté [31] in their reviews excluded the results on water footprint of a vegetarian diet from the work of Meier and Christen [32], considering them as a significant outlier among the results of the majority of other available publications. At the same time, the results on the water footprint of a vegan diet were included in these reviews, probably due to the very limited number of studies on vegan diets that could provide a reference point. In the publication by Springmann et al. [33], which was based on data from 150 countries, and where the reference diet corresponded to current consumption in those countries, diets that assumed isocaloric substitution of animal-derived products with plant-based products were associated with an increase in the water footprint of the diet. In the scenario assuming 25% substitution of the products of animal origin with the products of plant origin, the increase in water footprint amounted to 4%, while total substitution of animal products with plant products was associated with a 16% increase in water footprint. Nevertheless, the above-described diets were characterized by positive effects on other environmental aspects, most notably by a significant reduction in greenhouse gas emissions (by up to 84%). In contrast, the vegetarian diet, in the same study, was characterized by a lower water footprint than the reference diet. The authors

suggested the complete elimination of animal products from a diet may be associated with an increase in the consumption of certain water-intensive crops. In addition, it should be noted products such as vegetables and fruit are mostly low-calorie products, and their water footprint may be low per unit weight but high per unit energy. Therefore, if the theoretically analyzed diet assumes isocaloric replacement of animal-derived products with plant products (including fruit and vegetables), its water footprint may be higher than the water footprint of the reference diet.

In the study by Rosi et al. [27] the average calculated water footprint of the traditional, vegetarian and vegan diets reached (for approximately 2300–2500 kcal) 3140.8 L/d, 2304.7 L/d, 2455.0 L/d, respectively. The differences between vegan versus traditional, and vegetarian versus traditional diets were statistically significant, while the differences between vegan and vegetarian diets were not statistically significant. In the study presented here, the average calculated water footprint values were lower compared to the work of Rosi et al. [27] and were estimated as (for 2000 kcal) 1261.4 L/d, 793.4 L/d, 468.4 L/d, respectively. Variances in the absolute values may be due to the differences in energy value, in consumption of individual products and due to the adopted simplifications. In our study, the water footprint of the vegan diet was significantly lower compared to both the traditional and vegetarian diets. Such a result contradicts with the studies quoted above.

Vanham et al. [34] quantified and compared the water footprint of current European diets with ‘healthy’ diets (based on regional dietary guidelines) and with vegetarian diets for four EU zones—west, north, south, and east. The water footprint of current diets differed considerably between the compared EU zones, due to different consumption behaviors, as well as different agricultural production methods and conditions. However, both the ‘healthy’ and vegetarian diets resulted—consistently in all zones—in substantial water footprint reductions. The largest reduction (27–41%) took place for the vegetarian diet.

The papers cited above show studies on the environmental impact of diets vary considerably in their methodology. Some studies are based on the analysis of consumption data collected directly from consumers following different diets. Other works took as their starting point data on average consumption in a country or region and, on this basis, analyzed how environmental costs would change if products of animal origin were (fully or partially) replaced by plant-based products. There are also studies analyzing potential impact of various scenarios to be adopted globally, in which the authors, on the basis of calculations, show, for example, how land use would change if all people on Earth followed a vegan diet. Regardless of the methodology adopted, the vast majority of available studies show switching from a traditional diet to a vegetarian or vegan diet can be considered as a step towards environmental sustainability.

According to Corrin and Papadopoulos [35], however, there is a number of barriers that discourage people from following diets that limit or eliminate animal-derived food products. These include the enjoyment of eating meat, a general reluctance to make changes to one’s diet and the fear that such diets may negatively affect one’s health. Although vegetarian diets are perceived increasingly positively by society, the vast majority of consumers do not follow them. This study focuses on vegetarian and vegan diets, but it is worth noting simply reducing the amount of meat in the diet, without eliminating it totally, can be associated with a significant limitation of negative environmental impacts. According to Bryngelsson et al. [36] limitation of the consumption of animal-derived foods is a necessary condition to prevent the Earth’s average temperature rise by 2 °C. Assuming technological advances would help to moderately reduce emissions associated with food production by 2050, global consumption of ruminant meat (i.e., beef, lamb, goat meat) should be reduced by 50% to meet climate targets. Another dietary modification that would clearly have a positive impact on the environment and food security would be to limit the amount of consumed food to maintain a healthy body weight. According to Tom et al. [37] limiting the average calorie consumption in the United States to the amount necessary to maintain a normal body weight would reduce the carbon and water footprint of the average American’s diet by 9%. Another important issue related to diet, environment and

food security is the problem of food waste. In a publication by Jalava et al. [38] it was estimated the reduction of global food waste by half, would allow to decrease the amount of water used for food production by 12%. Moreover, in a scenario involving an additional reduction in the consumption of animal-derived products, so that they would constitute a source of 25% of dietary protein, the water footprint of global food production would decrease by 23–28%. Under such a scenario, it would be possible to eliminate water scarcity in areas inhabited by around 600 million people.

The vast majority of studies looking into the amount of water, land, and CO<sub>2</sub> emissions embodied in plant-based versus animal-based diets, did not take into account an important aspect of spatial allocation of the impacts of the alternative diets. As shown by Laroche et al. [39], significant dietary shifts in Western countries can modify the way human-environment systems interact over long distances, primarily due to the existing trade flows in food products, with a risk of environmental degradation (i.e., increased impact on freshwater ecosystems) associated with production systems in the sourcing regions. Therefore, both global and local environmental impacts of meat and other animal-derived foods' substitutes should be taken into consideration and rigorously assessed, and insights from such assessments should be aligned with consumer preferences, to ensure the previously quoted global benefits of dietary changes would not be realized at the expense of local environmental contexts [39].

## 5. Conclusions

The study showed the elimination of meat and/or other animal-derived foods from a diet by the study respondents was predominantly caused by the concerns related to animal welfare issues, which appeared to be a stronger motivation than the willingness to reduce the diet's environmental footprint. At the same time the vegetarian and vegan diets studied within the presented pilot, were found to be characterized by, on average, 47.0% and 64.4% lower carbon footprint, 32.2% and 60.9% lower land use indicators, and 37.1% and 62.9% lower water footprints, respectively, compared to the meat-containing diet. These outcomes, being strongly in line with the studies published by other authors and targeting other populations, confirm moving towards more plant-based diets has a potential to significantly reduce the diet's and thus food systems' environmental footprint, and therefore could be considered as a step towards food system sustainability. Promoting a plant-forward diet, but also educating consumers about its contribution towards minimizing the negative effects of environmental anthropopressure related to food production, is therefore of great importance.

The present study gave also an insight into the contribution of specific food groups to the estimated environmental indicators of the studied diets. Animal-derived foods, including milk and dairy, appeared to be the main contributors to all three environmental footprint indicators of both the meat-containing and the vegetarian diets. In the vegan group, the environmental footprint was found to be mainly influenced by the consumption of legumes and legume-based foods, cereal products, potatoes, sugar, products containing cocoa and vegetables, with nuts showing especially significant contribution to the fresh water consumption. These outcomes could contribute to creating a 'roadmap' for consumers, to encourage them to plan diets responsibly, taking into consideration both the health and the environmental aspects.

The present pilot allowed us to draw some interesting preliminary conclusions, but also uncovered a number of significant research gaps that should be further elaborated and addressed, to increase precision of similar assessments in the future. Future studies on the impact of diets on the environment should thus be designed to look into dietary patterns of a greater population, taking into consideration various demographic factors (i.e., age, gender, education, economic status), diet seasonality, variation in environmental costs of products depending on the location, production and processing systems, methods and conditions, and finally the important aspect related to the spatial allocation of the impacts of the dietary changes. They should employ the available, most recent and comprehensive data sources,

to increase precision of the environmental footprint estimations. They could also look into a broader range of environmental/sustainability indicators, such as i.e., nitrogen fixation, eutrophication potential, and important biodiversity markers, e.g., pollinator abundance and diversity.

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