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Differences in Environmental Impact between Plant-Based Alternatives to Dairy and Dairy Products: A Systematic Literature Review

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Abstract: A large body of research suggests a more plant-based diet, including a switch to plant-based alternatives to dairy, is needed for lowering human-induced climate change as well as land and water use. With the help of a systematic literature review, we analyzed data from 21 peer-reviewed articles about the differences in emissions and resources used between various plant-based alternatives to dairy and dairy products. Emissions included were greenhouse gases, acidifying, eutrophicating, and ozone-depleting substances, and resource use included water, energy, and land. The results are presented as the quotients of the ratios of plant-based alternatives to dairy and dairy products. The comparison shows that the plant-based dairy alternatives have lower, or much lower, impacts in almost all cases, with two exceptions: water use for almond drinks (several studies) and emissions of ozone-depleting substances for margarine (one study). There is a lack of data concerning impacts other than greenhouse gas emissions for plant-based cheese alternatives; and in general, emissions of greenhouse gases are more highly covered than other impacts. In the quest for a swift transition to a low carbon economy, however, there is already enough evidence to proceed with a dietary change involving switching dairy products to plant-based alternatives.

Keywords: systematic literature review; plant-based dairy alternatives; milk; environmental impacts; greenhouse gas emissions; land use; water use

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1. Introduction and Purpose

Limiting climate change is one of the great challenges of our time, and the United Nations [1] calls on all different types of actors to take measures to reduce greenhouse gas emissions [1]. Clark et al. [2] emphasize the importance of changing the food sector if the global average temperature increase is to be kept below 2 °C. The change needs to be radical [2]. Today's food systems account for a third of manmade greenhouse gas emissions [3], 32% of acidification, and 78% of eutrophication, which together means a major impact on species and ecosystems [4]. The same systems also use about 40% of the global land area that is not covered by ice or desert [4].

In the past 20 years, many scientific studies have drawn attention to the fact that a diet changed towards a more plant-based one could have large positive effects on ecosystems [4–6]. These effects can be created by freeing up large areas of land, as fewer animals must be provided with feed, which gives more space for other organisms. The same dietary change would also lead to reduced greenhouse gas emissions and improved health [7,8]. The UN Climate Panel states in its report from 2019 that a diet with little or no elements of meat and dairy products can lead to large reductions in greenhouse gas emissions and land use [9].

An aid for understanding the environmental impact of food in detail is to calculate emissions such as greenhouse gases, as well as resource use such as energy, land, and water during the lifecycle of products. For food, this usually starts by calculating the environmental impact from the production of inputs in agriculture, after which emissions and resource use during rearing of animals (if applicable), processing, packaging, transport, sales and, in some cases, cooking and waste management are included. Such studies may be called life cycle assessments [10], and are examples of system studies. Over the years, many such studies have been carried out that have shown that animal products, such as red meat, often have a much greater environmental impact than those made from plants, such as a bean burger [4]. Nijdam et al. [11] also state that some animal products, such as chicken, eggs, and certain fish products, have relatively low greenhouse gas emissions and land use. In light of such findings, some authors [12] argue for the possibility of including a certain amount of meat in sustainable diets.

Recent research of food systems assessing the environmental impacts of existing diets show that they could be improved both from an environmental and a health perspective. Hallström et al. [13], who reviewed results from many such studies, found that they showed great potential for reducing greenhouse gas emissions and land use by up to 50%. Springman et al. [14] stated that we cannot stay within the planetary boundaries without changing to more plant-based diets. The same conclusion was drawn by Gonzáles-Garcia et al. [15], who also drew attention to the fact that diet in Northern and Western Europe has a major environmental impact, which is partly due to the high consumption of dairy products. Regarding dairy products, Heller et al. [16] and Chapa et al. [17] state that dairy products contribute to a large proportion of greenhouse gas emissions and energy use in various diets. Concerning health impacts, several analyses of the health impacts of plant-based diets shows that there may be substantial benefits [18–20]. However, White and Hall [21] found that diets from plants only could increase nutrient deficiency. Their results were questioned on the grounds that the assumptions behind their scenario were unrealistic [22].

Insights that a decrease in the consumption of animal products may lower greenhouse gas emissions have led to the development of tools for menu planning. Colombo et al. [23] created and tested an optimization program for school meals to reduce environmental impact and found that greenhouse gas emissions could fall by 28% without increasing cost, decreasing nutritional content, or the students wasting food. The reduction in greenhouse gas emissions was achieved by, for example, reducing the amount of red meat and dairy products.

Over the past decade, a range of new foods that can replace dairy products have entered the market. These are products based on plants such as oats, soybeans, peas, almonds, coconut, rapeseed, and various nuts. The products are sold both as beverages that can replace, for example, milk or cream and as solid products that can replace items such as butter or cheese. The market for these plant-based (PB) alternatives to dairy has accelerated, and dairy is currently "under siege in key markets", most significantly in western countries [24]. Dairy products are defined as "kinds of foods that are obtained primarily from or contain milk of mammals such as cattle, goats, sheep, etc." [25]. Research on how PB alternatives to dairy products are marketed and received by consumers has been published [26–28] and the benefits of PB alternatives are discussed in the media [29,30]. However, as far as we know, there is no summary of the state of research regarding the differences in environmental effects between PB alternatives to dairy and dairy products. Such a compilation could help raise the level of the debate about the environmental impact of food and inform meal planners and politicians about the potential impacts of lowering dairy consumption.

Considering the situation above, this study aims to contribute to increased knowledge about the environmental differences between plant-based dairy alternatives and dairy products, and hence the research question is:

What does the research say about how plant-based dairy alternatives and dairy products differ in terms of environmental effects?

2. Method and Materials

To answer the research question, we performed a systematic review of current research. We followed a well-established guideline for conducting systematic reviews, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review protocol below was developed by the authors, and it is based on the PRISMA checklist [31]. The structure below (Sections 2.1–2.6) follows the PRISMA guidelines that were applicable to our study. We have also chosen to include outcomes from the steps in this section, rather than reporting them separately in the results section, since it makes the results section easier to read.

2.1. Eligibility Criteria

We applied the following inclusion and exclusion criteria to the studies identified in the database search:

Inclusion criteria:

- Peer-reviewed papers published in journals
- Studies describing the environmental impact of PB dairy alternatives
- Any population
- Studies published in the year 2000 or later
- Papers written in English

Exclusion criteria:

- Studies reusing data sets from other studies
- Studies without quantitative results
- Studies where the environmental impact was not compared to corresponding dairy products

2.2. Information Sources

Together with an information specialist librarian, we chose three databases to perform our searches. The databases were:

- Web of Science and Scopus, the two biggest commercial multidisciplinary databases
- GreenFILE, since it has a focus on sustainability

The databases were searched between 16 December and 21 December 2020. After removing duplicates and applying the inclusion and exclusion criteria, we then used backward snowballing to search the references in the included papers for other relevant titles, and then forward snowballing to search for possible relevant papers referencing the included papers, as per the guidelines supplied by Wohlin [32]. The same inclusion and exclusion criteria were applied. Backward snowballing was thus not limited to a specific database, whereas forward snowballing used Scopus and Web of Science. Forward snowballing was carried out on 10 February 2021.

2.3. Search Strategy

The search string was developed iteratively, where the two main criteria were that included papers should cover one or more aspects of ecological sustainability such as "greenhouse gas", "eutrophication" or "acidification", and that the object evaluated should be some kind of PB dairy product such as "soy milk", "oat yoghurt", and "rice milk". The first iteration of the search string was constructed by listing search terms based on our own prior knowledge within the area, and then we performed an initial search. We found several relevant papers and from these extracted more search terms. Using this new set of search terms, we conducted a Scopus search for papers including at least one term from both categories of words (see search question 1 in the Supplementary Material 1). This resulted in 525 papers. From these, all author keywords and journal keywords were extracted, which resulted in 5834 unique keywords. These were sorted according to frequency, and all 1163 keywords appearing at least three times were assessed for relevance by the research group. This resulted in a new set of search terms.

The terms for PB dairy alternatives found were then complemented by generating possible product terms by combining all product types (such as "yoghurt" and "spread") with synonyms for non-dairy (such as "soy" and "plant based") into new terms ("soy yoghurt", "soy spread", "plant-based yoghurt", "plant-based spread". The PB dairy alternatives terms were also complemented by a list of companies known to produce PB dairy alternatives. Based on this, the second iteration of the search string was constructed. After performing the search based on the second iteration of the search string, we limited the search to relevant subject areas by removing irrelevant ones such as astronomy or mathematics, and also limiting the search to publications published in the year 2000 or later, resulting in the final search string.

The search string (see also Supplementary Material 1) was then adapted to all three databases, and after conducting the three searches, duplicates were removed. This resulted in 4044 papers, to which the inclusion and exclusion criteria were applied. After scanning titles, 130 remained, and after reading abstracts, 27 remained, which were downloaded and read.

To find papers the search might have missed, we then, after completing the selection process (see next section), complemented the search by selecting all references found in the selected papers (backward snowballing) and by searching Scopus for all papers referring to the selected papers (forward snowballing) and then applying the selection process to these papers as well. We completed one round of backward and forward snowballing. The backward snowballing reviewed the 1720 references in the 26 papers found in the initial search. After screening titles, 28 papers remained, and after screening abstracts, 11 papers remained that were downloaded. The forward snowballing of the 26 papers identified 1593 papers referring to these papers. After removing duplicates and screening titles, 60 remained, and after screening abstracts, 25 papers remained that were downloaded. The snowballing procedure used is described by Wohlin (2014) [32]. The full search is presented in the Supplementary Materials using a PRISMA flow diagram (Supplementary Material 2).

2.4. Selection Process

The papers found in the database searches and in the snowballing process were first screened by applying the inclusion criteria to the title of the paper with a generous interpretation. For the papers remaining, the same process was applied to the abstract. For the papers remaining after the screening of the abstracts, the full papers were downloaded and read, and the inclusion/exclusion criteria were once again applied, resulting in our final corpus. When Supplementary Materials were presented, these were also downloaded. All these steps were conducted by the first author of this paper.

2.5. Data Collection Process

A data extraction form was developed, using Microsoft Excel, in which the results from each included study were recorded. The extraction form was informed by the standard data extraction strategies in the Cochrane Handbook of Systematic Reviews [33].

Data Items

For each study, the following data were collected:

- Basic information: Authors, Year
- Products compared: For example, "milk, soy drink, almond drink. Eight values for soy drink and four for almond drink"
- Functional unit: For example, "1 kg of product, energy, nutrition, and satiety"
- System boundary: For example, "Cradle to regional distribution center" or "cradle to retailer"

- Country where the products are sold
- Country where the products are produced

Then, for each product found, the following data were recorded:

- Greenhouse gas emissions, kg CO_2 eq./kg or kg CO_2 eq./L.
- Energy use, MJ/kg or MJ/L.
- Eutrophication potential, kg PO_4 eq./kg or kg PO_4 eq./L.
- Acidification potential, kg SO_2 eq./kg or kg SO_2 eq./L.
- Photochemical ozone depletion potential, kg C_2 H_4 eq./kg or C_2 H_4 eq./kg L.
- Land use, m^2/kg or m^2/L.
- Water use, m^3/kg or m^3/kg L.

Although we had included search terms such as "biodiversity" and "carbon storage" (Supplementary Materials 1) we found no studies comparing these parameters.

2.6. Effect Measures and Synthesis Methods

As an effect measure, we used the quotient of the ratio of the environmental impact of the PB dairy product divided by the corresponding environmental impact of the milk-based dairy product, resulting in a dimensionless quotient for each study. For example, if the greenhouse gas emissions for milk are 0.99 kg CO_2 e/kg product and the emissions for oat drink are 0.21 kg CO_2 e/kg product, the quotient is 0.21 (0.21/0.99). Another way of expressing this result is that oat drinks emit 21% of the greenhouse gases that milk does. When several values for PB dairy alternatives to dairy and dairy products were available in a study, averages for the respective product were used to calculate the quotient.

The reason for choosing a quotient instead of absolute values was that different studies often have different system boundaries. This may, for example, mean that a study has only included the environmental impact from milk and soy drinks until they leave the dairy/factory, while another study for the same purpose has gone further in the analysis and also included the sales stage. Both approaches are correct, but it is not correct to compare the results with each other. In the studies, there may also be a difference in how to measure, for example, water use (groundwater/rainwater/both) and how/if to measure carbon dioxide emissions from soil. Different methods for co-allocation of environmental impacts may also have been used. We assumed that the authors of the various articles had ensured that their environmental values for the various products studied were comparable, and that a quotient would therefore be the best way of comparing PB alternatives to dairy and dairy products from the different studies. We recorded all results of environmental impacts that were presented in tables but we did not attempt to estimate such a number from graphs only.

At the end of the analysis, we also calculated a weighted average for all PB alternatives compared with the dairy products for each environmental impact. This was obtained by weighting the quotients found for each study with the number of products studied in that study. This was performed to account for the large variations in the number of products studied in the different publications where several studies only had one product (e.g., soy drink), while other studies had up to 47 products. An example of how this was conducted is given for weighted average for water use of PB alternatives to cream versus cream, as shown below, see also Supplementary Material 3, sheet called weighted averages.

$$(16 \times 0.67 + 1 \times 0.14)/17 = 0.64 \tag{1}$$

3. Results

3.1. All Studies

We found 21 studies with comparative quantitative results regarding different types of environmental impacts from PB alternatives to dairy and dairy products. The overall result of the comparison is that the PB alternatives, with a few exceptions, have a lower environmental impact than the dairy products.

The studies deal, albeit to varying degrees, with PB alternatives to the dairy products available on the market today: milk, cream, yoghurt, cheese, and butter/spreads. In all 21 studies, there were data on environmental impact per unit weight (kg) or per volume (liters) for the different products. Supplementary Material 3 contains the quantities of emissions and resource use found in each study for each product as well as an explanation of the system boundaries, the products compared, the countries of consumption and production, the number of values, and the type of water included in the studies. A summary of the studies is presented in Table 1.

Table 1. List of the 21 publications with comparative environmental data about PB alternatives to dairy products and dairy products found in the systematic literature review. Authors, year of publication, journal, and products compared.

Authors	Year	Journal	Products Compared
Wallén et al. [34]	2004	Environmental Science and Policy	Margarine versus butter
Nilsson et al. [35]	2010	International Journal of Life Cycle Assessment	Margarine versus butter
Smedman et al. [36]	2010	Food and Nutrition Research	Soy and oat drinks versus milk
Ercin et al. [37]	2012	Ecological Indicators	Soy drink versus milk
Meier and Christen [38]	2012	International Journal of Life Cycle Assessment	Margarine versus butter
Werner et al. [39]	2014	Food and Nutrition Research	Soy drink versus milk
Clune et al. [40]	2017	Journal of Cleaner Production	Soy and almond drink versus milk
Grant and Hicks [41]	2018	Environmental Engineering Science	Soy and almond drink versus milk
Heller et al. [16]	2018	Environmental Research Letters	Soy drink versus milk
Yokessa and Marette [42]	2019	Sustainability	Soy drink versus milk
Beckerman et al. [43]	2019	American Journal of Public Health	Soy drink versus milk
Poor and Nemecek [4]	2019	Science	Soy drink versus milk
De Laurentiis et al. [44]	2019	International Journal of Life Cycle Assessment,	Margarine versus butter
Corrado et al. [45]	2019	Science of the Total Environment	Margarine versus butter
Smetana et al. [46]	2020	Journal of Cleaner Production	Margarine versus butter
Liao et al. [47]	2020	International Journal of Life Cycle Assessment	PB spreads, PB cream versus dairy products
Winans et al. [48]	2020	International Journal of Life Cycle Assessment	Almond drink versus milk
Kolbe [49]	2020	Advances in Climate Change Research	PB drink, PB cheese, PB cream and PB spreads versus dairy products
Mogensen et al. [50]	2020	Journal of Cleaner Production,	Oat yoghurt versus yoghurt
Chapa et al. [17]	2020	Science of the Total Environment	Soy drink versus milk
Scheelbeek et al. [51]	2021	BMJ Open	PB drink, PB cream, PB cheese and PB spreads versus dairy products

Table 1 shows that 57% of the studies were published from 2019 onwards. The most common journal for publication was the International Journal of Life Cycle Assessment (four publications), followed by the Journal of Cleaner Production (three publications).

3.2. PB Beverages Compared to Milk

Data on environmentally impacting emissions and resource use from PB drinks versus milk was found in 13 studies. The system boundaries in these studies varied from cradle to processing [16,17,37,48], cradle to retailer/wholesaler [36,40], and cradle to consumer [4,39,41–43,49]. In two studies, there was no explanation of the system boundaries [42,51]. Scheelbeck et al. [51] who calculated both nutrition, GHG emissions, the blue water footprint (ground and surface water) for a range of foods and diets referred to a large number of individual studies of greenhouse gas emissions from various foods as well as data from the Water Footprint Network (WFN) for water use. Yokessa et al., [42] who studied the effect on taxes in the milk market and compared milk with soy drink, state that the data on GHG emissions were collected using a lifecycle analysis but provided no detail of the system boundaries.

Co-allocation procedures were explained in four studies only. Allocation procedures differed: Winans et al. [48] used economic allocation for co-products and Clune et al. [40] mentions that economic allocation was used for some products in their systematic review of greenhouse gas emissions for different fresh food categories. Grant and Hicks [41] mention that co-product allocation was avoided, while Poor and Nemecek [4] used economic allocation.

The differences in environmental impacts from the studies above are summarized below.

3.2.1. Greenhouse Gas Emissions

Table 2 shows the results from the 12 studies regarding differences in greenhouse gas emissions between oat, soy, and almond drinks compared to milk. Only one study (Grant and Hicks [41] showed that the two PB alternatives had higher emissions than milk. Among the 11 studies that showed that PB beverages have lower greenhouse gas emissions than milk, the range was large. In these studies, the PB alternatives give rise to 21–67% of the emissions that occur during milk production.

Table 2. Greenhouse gas emissions that occur when PB beverages are produced in relation to the same emissions for milk. The number of values shows how many results for each PB product category were available in the different studies. The data on emissions of CO_2 equivalents refer to the quotient between emissions from PB drinks and milk.

Authors	Year	Country of Sale	Number of Values	Emissions of CO_2 Equivalents		
				Oat Drink versus Milk	Soy Drink versus Milk	Almond Drink versus Milk
Smedman et al. [36]	2010	Sweden	1 and 1	0.21	0.30	-
Werner et al. [39]	2014	Denmark	1	-	0.37	-
Clune et al. [40]	2017	World	8 and 4	-	0.67	0.32
Grant et. al. [41]	2018	USA	1 and 1	-	1.19	1.40
Heller et al. [16]	2018	USA	1	-	0.20	-
Yokessa et al. [42]	2019	Not explained	1	-	0.08	-
Beckerman et al. [43]	2019	USA	1	-	0.27	-
Poor and Nemecek [4]	2019	World	47	-	0.27	-
Winans et al. [48]	2020	USA	1	-	-	0.22
Kolbe [49]	2020	Germany	1.1 and 1	0.37	0.47	0.47
Chapa et al. [17]	2020	USA	1	-	0.31	-
Scheelbeek et al. [51]	2021	UK	1 and 1	-	0.58	0.65

The outlier regarding greenhouse gas emissions in the table above is Grant and Hicks [41] who found that both soy and almond drinks have higher emissions of GHG than milk. The soybeans were produced in the USA, as were the almonds. Grant and Hicks comment on their result and refer to other studies where results showed lower GHG emissions for milk as well as soy and almond drinks. They (ibid) mention factors such as system boundaries, allocation, and FU (functional unit) as reasons for these differences but do not provide further details.

3.2.2. Land, Water, and Energy Use

Only one study [4] with 47 values for soy drink compares land use between milk and soy drinks. The result was that the soy drink used 8% of the land required to produce the same amount of milk. The variation in land use was large in this study: 0.7–242.1 m^2/L for milk and 0.3–1.7 m^2/L for soy drink (see also Supplementary Material 3). Similarly, we found only one study [16], with one value, that compared energy use between milk and soy drinks. The comparison showed that the soy drink used 24% of the energy used to produce milk. In this study (ibid), the aim was to calculate GHG emissions and energy use from diets and the authors calculated the environmental impacts from a large range of foods.

Water use was compared in five different studies (see Table 3). Most distinctively, some studies show that the production of almond drinks can lead to much higher water use than when producing milk. It is the irrigation of almond trees (in California) that is responsible for the large water use. However, Winans et al. [48] also assumed that the almonds used in almond drink were grown in California with irrigation but nevertheless found that the water use for almond drink was lower than for milk. For soy drinks, all studies showed that water use was less than in milk production; soy drinks use between 4 and 64% of the water consumed in milk production. Scheelbeek et al. [51] calculated the health impacts and environmental footprints of diets that meet the Eatwell Guide in the UK and used a list of 173 foods to accomplish that. We did not find any data on water use for oat drinks.

Table 3. Water use that occurs when PB beverages are produced in relation to the same emissions for milk. The number of values shows how many results for each PB product category were available in the different studies. Data on water use refer to the quotient between water use from PB alternatives and milk.

Author	Year	Country of Sale	Number of Values	Water Use		
				Oat Drink versus Milk	Soy Drink versus Milk	Almond Drink versus Milk
Ercin et al. [37]	2012	No information	7	-	0.28	-
Grant et al. [41]	2018	USA	1	-	0.64	93.42
Poor and Nemecek [4]	2019	World	47	-	0.04	-
Winans et al. [48]	2020	USA	1	-	-	0.56
Scheelbeek et al. [51]	2021	UK	1	-	0.08	2.99

3.2.3. Other Environmental Impacts

Poor and Nemecek [4] reported data on emissions of eutrophication and acidifying substances for soy drinks and milk. The results were that soy drinks emit only 6% of the eutrophication substances that occur during milk production (23 values). For acidifying substances, the corresponding figure was 13% (41 values).

3.3. PB Alternatives to Cream and Yoghurt Compared to Corresponding Dairy Products

We found four studies that quantified the environmental impact of PB alternatives to cream and yoghurt and compared them with the corresponding dairy products. Only one study of alternatives to yoghurt showed what the plant-based raw material was, namely oats [50].

Three of the studies had more or less the same system boundaries, cradle to consumer including waste [47,49,50]. In one study, there was no explanation of the system boundaries [51]. Liao et al. [47] used economic allocation of co-products. Kolbe [49] did not mention co-allocation procedures and neither did Scheelbeck et al. [51] and Mogensen et al. [50].

Table 4 shows how greenhouse gas emissions from PB alternatives to cream and yoghurt relate to the emissions from the corresponding dairy products. All PB alternatives gave rise to lower emissions than the dairy products. Mogensen et al. [50], who investigated the potential to reduce GHG emissions and land use by substituting animal-based proteins by foods containing oat protein concentrate concluded that such a substitute has a considerable potential to mitigate climate change and reduce land use.

Table 4. Greenhouse gas emissions arising from the production of PB alternatives to cream and yoghurt in relation to the same emissions for the corresponding dairy products. The number of values shows how many results for each PB product category were available in the different studies. Data on emissions of CO_2 equivalents refer to the quotient between greenhouse gas emissions from PB products and dairy.

Author	Year	Country of Sale	Number of Values	Emissions of CO_2 Equivalents	
				PB Alternatives to Cream versus Cream	PB Alternatives to Yoghurt versus Yoghurt
Liao et al. [47]	2020	21 countries in Europe and North America	16	0.50	-
Scheelbek et al. [51]	2021	UK	1	0.54	-
Kolbe [49]	2020	Germany	2	0.18	-
Mogensen et al. [50]	2020	Denmark	1	-	0.69

Differences in land use were reported in two of the studies, Liao et al. [47], 16 values, and Mogensen et al. [50], one value. The analysis showed that PB alternatives to cream used 58% of the land needed to produce cream. PB alternatives to yoghurt used 42% of the land compared to yoghurt. Liao et al. [47], 16 values, and Scheelbek et al. [51], one value, also calculated the water use for PB alternatives to cream versus cream. The comparison showed that PB alternatives uses either 14% or 67% of the water needed to produce the same amount of dairy product. Liao et al. [47] calculated both water consumption and water depletion. In this study, the figures for water consumption were used.

3.4. PB Spreads Compared to Milk-Based Spreads

Spreads is a term for products that can be spread on a sandwich, such as butter or margarine. Today, however, there is a large selection of other types of spreads that can be both plant or milk-based. Butter is defined as a product that is made from churning milk or cream [52], while margarine is "made usually from vegetable oils churned with ripened skim milk" [53]. Margarines can also be made from vegetable oils only [54]. In the section below, we have divided the spreads into two categories: those that are only milk-based (butter) and those that are wholly or partly plant-based (PB spreads). In the nine studies we found regarding the environmental impacts of PB and milk-based spreads, the contents of the products were not always accounted for and, thus, we cannot differentiate between those with or without a milk component.

The system boundaries in these studies varied from cradle to processing [34,46], cradle to retailer/wholesaler [35,38], and cradle to consumer [44,45,47,49]. Liao et al. [47] used economic allocation of co-products as did Nilsson et al. [35]. Meier et al. [38] applied various allocation methods. In the six other studies the co-allocation procedures were not mentioned.

3.4.1. Greenhouse Gas Emissions

Table 5 contains comparisons between nine different studies regarding greenhouse gas emissions for PB spreads compared with milk-based ones. In all but one study [34], the PB alternatives had lower emissions compared with the milk-based ones. The range in these eight studies was between 12% and 47%.

Table 5. Greenhouse gas emissions that occur when PB spreads are produced in relation to the same emissions for milk-based spreads. The number of values shows how many results for each PB product were found in the different studies. Data on emissions of CO_2 equivalents refer to the quotient between greenhouse gas emissions from PB spreads and milk-based ones.

Author	Year	Country of Sale	Number of Values	Emissions of CO_2 Equivalents
				PB Spreads versus Milk-Based Ones
Wallén et al. [34]	2004	Sweden	1	2.16
Nilsson et al. [35]	2010	UK, Germany, and France	3	0.16
Meier et al. [38]	2012	Germany	1	0.14
De Laurentiis et al. [44]	2019	UK	6	0.15
Corrado et al. [45]	2019	Italy	1	0.21
Smetana et al. [46]	2020	Not indicated	2	0.17
Liao et al. [47]	2020	21 countries in Europe and North America	212	0.27
Kolbe [49]	2020	Germany	1	0.12
Scheelbeek et al. [51]	2021	UK	1	0.47

The study from Liao et al. [47] is exceptional as they studied 212 PB spreads and 21 milk-based spreads that included butter. The results from this study are therefore much more reliable than the results from most other studies where significantly fewer products were studied. In the study by Wallén et al. [34], there was no explanation for why margarine had higher emissions than butter. Several of the studies mentioned above aimed at calculating the GHG emissions from various diets and subsequently calculated GHG emission for a range of foods [34,38,44,45,49,51]. Smetana et al. [46] compared insect margarine with other margarine and butter, Liao et al. [47] compared PB spreads with milk-based ones, and Nilsson et al. [35] compared butter with different types of margarine.

3.4.2. Land, Water, and Energy Use

In three studies, there was information on energy use: Smetana et al. [46], two values; Nilsson et al. [35], three values; and Wallén et al. [34], one value. The first two studies show that the energy used to make PB spreads was 61% of the energy use required to make milk-based spreads. In both these studies, all examples of margarine used less energy than butter. Wallén et al. [34], on the other hand, showed higher energy use for PB spread with a ratio of 1.94. The authors (ibid) did not comment upon the result in their study.

Land use was calculated in four studies and is reported in Table 6. The results in all studies showed that the PB spreads used less land than the milk-based ones, from 15–43% of the land used for spreads made from milk.

Table 6. Land uses that occur when PB spreads are produced in relation to the same emissions for milk-based spreads. The number of values shows how many results for each PB product were found in the different studies. Land use data refer to the quotient between land use from PB products and milk-based products.

Authors	Year	Country of Sale	Number of Values	Land Use
				PB Spreads versus Milk-Based Ones
Smetana et al. [46]	2020	Not indicated	2	0.39
Liao et al. [47]	2020	21 countries in Europe and North America	212	0.3
Meier et al. [38]	2012	Germany	1	0.15
Nilsson et al. [35]	2010	UK, Germany, and France	3	0.43

Water use was calculated in three studies and is reported in Table 7. The results in all studies showed that the PB spreads used less water than the milk-based spreads, from 17–74% of the water used for spreads made on milk.

Table 7. Water use that occurs when PB spreads are produced in relation to the same emissions for milk-based spreads. The number of values shows how many results for each PB product were found in the different studies. Data on water use refer to the quotient between water use from PB products and milk-based products.

Authors	Year	Country of Sale	Number of Values	Water Use
				PB Spreads versus Milk-Based Ones
Liao et al. [47]	2020	21 countries in Europe and North America	212	0.38
Meier et al. [38]	2012	Germany	1	0.17
Scheelbeek et al. [51]	2021	UK	1	0.74

3.4.3. Other Environmental Impacts

Emissions of acidifying and eutrophicating substances were reported in two studies, Smetana et al. [46], two values, and Nilsson et al. [35], three values. According to the same studies, eutrophication from PB spreads was 20% and 30% of emissions from butter, respectively.

There was only information from one study, Nilsson et al. [35], three values, on emissions of ozone-depleting substances. That study showed that the production of PB spreads (margarine) emitted more ozone-depleting substances than the production of butter, which was explained by the fact that the substance hexane is used in margarine production [35].

3.5. PB Cheese Compared to Milk-Based Cheese

We found only two studies comparing plant-based cheese with milk-based cheese [49,51]. In both studies, greenhouse gas emissions were calculated and in Scheelbeek [51] water use was also calculated. Both studies were made with the intention to calculate environmental impacts from diets and thus presented a long list of food items. Kolbe [49] used the system boundary cradle to consumer while Scheelbeek et al. [49] did not explain their system boundaries. Neither of the two studies specified co-allocation procedures.

The comparison of greenhouse gases shows that the plant-based cheese caused 20% and 29% of greenhouse gas emissions, respectively, compared to the milk-based cheese. The water use of the PB cheese was 3% of water use from milk-based cheese. Both of these studies contained only one value of the PB cheese. In the study by Kolbe [49], the PB cheese was assumed to be made from soybeans while Scheelbeek et al. [51] did not reveal the ingredients of their PB cheese.

3.6. Weighted Averages of All Environmental Impacts

By weighing all quotients presented so far in the Results section with the respective number of values, the following weighted averages of all environmental values for all products were achieved (Table 8 and Supplementary Material 3). As can be seen, PB alternatives to dairy products are less polluting and resource demanding in all aspects apart from two: water use in almond production and emissions of ozone-depleting substances in the production of PB spreads (margarine).

Table 8. Weighted averages for all products and their respective environmental impacts. Numbers in bold indicate where PB dairy alternatives have larger environmental impacts than dairy products.

	GHG Emissions	Water Use	Land Use	Energy Use	Eutrophication Emissions	Acidification Emissions	Ozone-Depleting Emissions
Oat drink versus milk	0.29	-	-	-	-	-	-
Soy drink versus milk	0.34	0.13	0.08	0.24	0.06	0.13	-
Almond drink versus milk	0.50	**32.32**	-	-	-	-	-
PB alternative to cream versus cream	0.47	0.64	0.58	-	-	-	-
PB alternative to yoghurt versus yoghurt	0.69	-	0.42	-	-	-	-
PB spreads versus milk-based spreads	0.27	0.39	0.33	0.83	0.26	0.22	**4.55**
PB alternative to cheese versus cheese	0.24	0.03	-	-	-	-	-

4. Discussion and Conclusions

In this report, we have tried to answer the question of how PB alternatives to dairy products differ from dairy in terms of environmental impacts. The method has been a systematic literature review whose results have been translated into a measure of differences between PB alternatives and dairy products. We have recorded the following environmental parameters: greenhouse gas emissions, land, water, and energy use as well as emissions of acidifying, eutrophicating, and ozone-depleting substances. For some of these parameters, there are a lot of data (e.g., on greenhouse gas emissions), while the data on land and water use are lower, and the data on emissions of ozone-depleting substances only appear in one study. We did not find any studies that reported differences in carbon storage and contributions to biodiversity between PB alternatives to dairy and dairy products, although these concepts were included in our search.

The results from our study find that the differences, with a few exceptions, are to the advantage of the PB alternatives. The study also shows the need for more research on PB alternatives to cheese, environmental effects other than greenhouse gas emissions, and how PB alternatives can be optimized to achieve the least possible environmental impact. In a transition to a more plant-based diet, it is important that the substitutes for the animal-based alternatives take place with minimal environmental impact to thus contribute to maximum effect. We found examples of PB beverages that had between 21% and 67% of greenhouse gas emissions from milk. Of course, the type of alternative that will dominate makes a big difference to the climate impact of the food system. We also recommend that future studies of PB dairy alternatives versus dairy incorporate large number of various products such as was performed by Liao et al. [47]. Only then can the true environmental potential of PB alternatives be estimated and the most environmentally friendly ones be identified. Given that the transition to a low carbon society is urgent, so is this research.

Regarding the impacts on biodiversity, where comparative analyses on PB dairy versus dairy are missing according to this study, it is of utmost importance to ensure that PB dairy alternatives do not cause more harm to biodiversity than milk-based products do. An area for concern is the use of soybeans for producing PB drinks, etc., as it is known that the cultivation of soybeans partly takes place in areas recently covered by natural vegetation such as tropical forests and savanna woodlands located in South America [55].

IPBES [56] states that that around one million species already face extinction, many within decades. For terrestrial and freshwater ecosystems, land-use change has had the largest relative negative impact on nature since 1970 and agricultural expansion is the most widespread form of land-use change (ibid). Moreover, climate change itself is projected to become increasingly important as a direct driver of changes in nature. Approximately 25 per cent of the globe's greenhouse gas emissions come from land clearing, crop production and fertilization, with animal-based food contributing 75 per cent of that [56].

The current use of soybeans is mainly for animal feed, 77% [57]. PB dairy alternatives are made from numbers of different products including cereals, tubers, legumes, and nuts. It is crucial that the soybeans used in such products have not been farmed on land recently converted from species rich nature types such as savannas and forests, otherwise they may be as harmful to biodiversity as the animal husbandry using soybeans as fodder. In this study, we did not find any mention of the use of soybeans from countries in South America. However, many authors did not mention the origin of soybeans in their studies.

Another reason for concern about biodiversity when substituting dairy for PB alternatives may occur in some countries, such as Sweden, where grazing livestock are considered crucial for preserving species-rich pastures [58]. In Sweden, there are currently about 440,000 ha of semi-natural grazing land that should be grazed by ruminants for reasons of biodiversity conservation. In a scenario using pure suckler herds for grazing, the amount of beef produced was estimated at 40 g per week and person in Sweden. This assumed that the cows had a calf every year that was slaughtered and that no milk was produced [59]. This example shows that some animal husbandry may be needed to maintain biodiversity in selected areas.

In our study, we used data on the environmental impacts of various products on a per kg/liter basis. It is worth noting that there is a discussion taking place among researchers about how the environmental impact between different food products should be compared, whether this should be per kg or liter or in some other way. Some believe that the environmental impact should be set in relation to the nutrient content and suggest methods for it [36,60], while others claim that they can give a skewed picture for certain foods, e.g., vegetables [61]. Others emphasize that satiety should be a comparative measure [62]. Among the increasing number of studies assessing the environmental impact of different meals and diets, the initial value is the environmental impact per weight or unit of volume, as weight and volume are the data found in recipes and dietary surveys.

Alternative ways of assessing the environmental impact of the food sector have also begun to develop. Röös et al. [63] compared, for example, a farm where the business had the same goal: to produce a beverage with the same function as milk with a certain amount of protein, oil, and animal feed and to keep a certain area of pasture open. When the beverage was delivered as an oat beverage, the greenhouse gas emissions were much lower than when the beverage was delivered as cow's milk. From this, we conclude that alternative approaches to depicting the environmental impact of food are being developed, and they should be followed up and evaluated.

Results from our review, with a few exceptions, show that PB alternatives to dairy have a smaller negative impact on the environment compared to dairy products. This implies that the environmental impact of meals most probably could be decreased by replacing dairy with PB alternatives. On the surface, this seems like a straightforward task and an easily accomplished way to contribute to mitigating harmful effects for the environment. However, since somebody actually needs to perform the shift from dairy to PB products in meals, they need to become aware of and trust these results. Furthermore, research results published in scientific articles need to find their way to their application in relevant everyday contexts. Relevant target groups need to be identified as well as communication channels and adequate packaging of results.

The results presented in this article may be of use for a multitude of stakeholders, including professionals planning canteen meals or restaurants and even private households. Our review points at least to one example where the communication chain has been pursued. Through an optimization program for school meals, Colombo et al. [23] showed that in reducing the amount of red meat and dairy products—without reducing nutritional content—the greenhouse gas emissions could fall by 28%. This example illustrates that research results from the calculation of the environmental impact of ingredients constituting a meal could be transformed into algorithms for an optimization program and subsequently substantiated in the preparation of school meals. An uptake of similar practices for more schools has the potential for upscaling the positive effect of the research results for the environment. The packaging of research results as well as targeting relevant groups to put research into practice is a crucial bridge construction for results to have a real and beneficial effect on the environment. The research area of environmental communication [64] has a lot to contribute to guiding the communication process.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su132212599/s1, Supplementary material 1: Search terms, Supplementary material 2: Prisma 2009 flow diagram and Supplementary material 3: All results.

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