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ORIGINAL ARTICLE

Greenhouse gas emissions of realistic dietary choices in Denmark: the carbon footprint and nutritional value of dairy products

Louise Bruun Werner[1]*, Anna Flysjö[2] and Tine Tholstrup[1]

[1]Department of Nutrition, Exercise and Sports, Faculty of Sciences, University of Copenhagen, Copenhagen, Denmark;
[2]Arla Foods, Viby J, Denmark

Abstract

Background: Dairy products are important in a healthy diet due to their high nutritional value; they are, however, associated with relatively large greenhouse gas emissions (GHGE) per kg product. When discussing the need to reduce the GHGE caused by the food system, it is crucial to consider the nutritional value of alternative food choices.

Objective: The objective of this study was to elucidate the role of dairy products in overall nutrition and to clarify the effects of dietary choices on GHGE, and to combine nutritional value and GHGE data.

Methods: We created eight dietary scenarios with different quantity of dairy products using data from the Danish National Dietary Survey (1995–2006). Nutrient composition and GHGE data for 71 highly consumed foods were used to estimate GHGE and nutritional status for each dietary scenario. An index was used to estimate nutrient density in relation to nutritional recommendation and climate impact for solid food items; high index values were those with the highest nutrient density scores in relation to the GHGE.

Results: The high-dairy scenario resulted in 27% higher protein, 13% higher vitamin D; 55% higher calcium; 48% higher riboflavin; and 18% higher selenium than the non-dairy scenario. There was a significant correlation between changes in calcium and changes in vitamin D, selenium, and riboflavin content ($P = 0.0001$) throughout all of the diets. The estimated GHGE for the dietary scenario with average-dairy consumption was 4,631 g CO_2e/day.

Conclusions: When optimizing a diet with regard to sustainability, it is crucial to account for the nutritional value and not solely focus on impact per kg product. Excluding dairy products from the diet does not necessarily mitigate climate change but in contrast may have nutritional consequences.

Keywords: *sustainable diet*; *dairy products*; *nutrient density*; *nutrient recommendations*; *greenhouse gas emission*

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During the next decades, this planet will have to be able to feed and sustain 9 billion people. This will put significant pressure on the food production system. It is therefore essential that our resources are used efficiently and that the negative environmental impacts from production are reduced. One of the great challenges is to reduce the greenhouse gas emissions (GHGE). At the same time, it is equally critical that we produce and provide nutritious food. Hence, sustainable diets must be based on nutritional value and not only on energy content. Public health messages for recommended dietary intakes have focused on the impact on health outcomes while all the wider issues relating to sustainability still remain relatively unexplored. However, the concept of a sustainable diet is neither new nor simple (1, 2), rather a complex issue including environmental, economic, and social aspects (3).

Animal-based products are generally associated with relatively large GHGE on a per kg basis. There has been a belief that consumers can make a positive contribution to reduce the environmental impact by replacing animal-based products, especially meat and dairy products, with vegetarian products (4, 5). However, a recent study estimating the GHGE from self-selected diets of a sample of adults in France showed that several scenarios related to the reduction of both caloric intakes and meat consumption are not necessarily the best approach to decreasing diet-related GHGE (6). In addition, some researchers have concluded that reducing GHGE by changing food production processes result in more profound changes (7, 8).

Reducing or excluding animal-based products, which make the greatest contribution to GHGE in the diets (4, 6, 8), is an inevitable policy option. However, reducing or excluding these products from the diet, which are unique sources of specific and essential nutrients, raises many nutritional challenges (9). In addition, when optimizing a diet with regard to sustainability, it is crucial to account

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for the nutritional value and not solely focus on impacts per kg products, because any dietary recommendations to reduce GHGE must also meet dietary requirements. Models that track the environmental impact of foods in the context of the nutritional benefits they offer are being developed. Recently, an index was proposed which explores nutrient density of beverages related to climate impact – it showed that milk performed better than other beverages (10). Moreover, two studies have demonstrated that a sustainable diet that meets the dietary requirements for heath combined with lower GHGE can be achieved without eliminating meat or dairy products (11, 12).

Dairy products are part of dietary recommendations in many countries (13–15). The dietary guidelines of United States Department of Agriculture (USDA) recommend three daily servings of low-fat dairy products for adults, corresponding to 720 ml (15). Dairy products contribute with high-quality protein as well as calcium and several other essential nutrients. On the contrary, dairy fat is very rich in saturated fatty acids (SFA) known to raise cholesterol levels. However, the health effects of dairy products are controversial (16–20), and the majority of observational studies have failed to find an association or even an inverse association between the intake of dairy products and risk of cardiovascular diseases (21, 22).

In this study, we created different dietary scenarios with realistic quantities of dairy products included in order to elucidate the role of dairy products in overall nutrition and, further, to clarify the effect of dietary choices on GHGE. This was evaluated based on national intake data and carbon footprint (CF) data of 71 widely consumed food items, which were selected as representative of the Danish diet and assigned to one of the main food types in the same proportion as eaten by adults (23). The quantities of each food group were according to Danish Dietary Guidelines (DDG) (24). If not quantified by the DDG, we made assumptions based on the available literature. This study only includes natural foodstuffs and supplements and fortified foodstuffs were excluded as they are not part of the recommendations. Although this is a theoretical study, based on dietary data and associated GHGE, the results contribute with new knowledge to how dairy products can contribute to a healthy and sustainable diet.

Materials and methods

Food consumption and GHGE data

This study relies on nutrient composition data of 71 widely consumed food items, which are representative for the diet of the Danish population, as well as the associated GHGE of each food item.

Food consumption data

We used dietary data for women ($n = 3{,}165$) collected from the Danish National Dietary Survey (DNDS) conducted from 1995 to 2006, including the average intake (in grams per day) of a majority of food items (25).

GHGE data

The GHGE estimates, also referred to as the CF, for each of the 71 food items are taken from the literature. GHGE associated with food production primarily consist of nitrous oxide (N_2O), methane (CH_4), and fossil carbon dioxide (CO_2), where the first two gases are related to primary production. Although biogenic CO_2 emissions from land use and land use change (LULUC) can also be significant for food production (26, 27), the present paper does not include emissions from LULUC due both to large uncertainties in data (as it is difficult to estimate carbon stocks and measure carbon fluxes) and the lack of agreed methodology on how to account for these emissions. To assess the total GHGE from primary production (including production of all inputs) to final consumption, the method life cycle assessment (LCA) is used (28, 29). The total amount of GHGE is expressed as CO_2 equivalents (CO_2e) assuming a 100-year perspective, where 1 kg CO_2 equals 1 kg CO_2e, 1 kg CH_4 equals 25 kg CO_2e, and 1 kg N_2O equals 298 kg CO_2e (30). It is acknowledged that there can be substantial variation in CF numbers due to methodological choices (e.g. 'consequential' or 'attributional' modeling[1]) (31, 32) or system boundaries (e.g. whether the consumer stage is included or not) (33, 34). These aspects have been considered. The CF data used in the present study are selected to be representative for Denmark. Data are also gathered to the largest possible extent from studies using the same methodology (attributional modeling, recommended by, for example, BSI, 2011). In addition, the CF numbers are verified by comparing different sources when possible. In many CF studies, the consumer stage is not included. To harmonize the system boundaries, the latter stage of the life cycle is added in the studies where this is not accounted for (transport from retail to consumer and, if relevant, preparation of the food). Data on home transport is estimated as 0.1 kg CO_2e per kg food (35, 36) and preparation of food is taken from Carlsson-Kanyama and Boström-Carlsson (37). There is great variation both within and between different food types. The CF per kg of edible food is about 0.2–4 kg CO_2e for fruit and vegetables; 0.6–5 kg CO_2e for potato, rice, and pasta; 0.9–2 kg CO_2e for bread and cereals; around 1 kg CO_2e for milk and yoghurt; 1–10 kg CO_2e for 'leeway' (e.g. candy, cakes, pizza); 3–10 kg CO_2e for cheese; and 5–30 kg CO_2e for meat (poultry, pork, and beef) (10, 26, 34, 38–61). A summary of the CF data on foods used in the present

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[1] Attributional modeling uses average data and distributes emissions between co-products by allocation, opposed to consequential modeling that uses marginal data and so-called system expansion (to avoid allocation by expanding the system to include the additional functions related to co-products).

Table 1. Greenhouse gas emission excluding and including waste at consumer level (kg CO_2e per kg) for each food item used in the study

	Representative	Consumer level	
Food types	Food items	Excluding waste	Including waste
Vegetables	Carrot	0.22	0.27
	Cabbage (white)	0.29	0.36
	Red cabbage	0.29	0.36
	Brussels sprouts	0.29	0.36
	Cauliflower	0.61	0.76
	Broccoli	1.67	2.06
	Pear	0.59	0.73
	Onion	0.48	0.60
	Lettuce (iceberg)	0.45	0.56
	Tomato	2.60	3.21
	Cucumber	3.00	3.70
Fruits	Apple	0.60	0.74
	Orange	0.80	0.99
	Banana	1.22	1.51
	Pear	0.60	0.74
Juice	Apple juice	0.71	0.71
Meat and meat products	Beef	27.99	31.45
	Pork	5.57	6.25
	Chicken	5.21	5.85
Bread and cereals	Wheat bread, coarse	1.10	1.47
	Wheat bread, fine	1.50	2.00
	Rye bread	0.90	1.20
	Oatmeal	0.90	1.20
Potatoes, pasta, rice	Potatoes	0.57	0.69
	Pasta	1.93	2.57
	Rice	3.74	4.99
Fish	Cod	4.47	5.02
	Herring	1.47	1.65
Eggs	Eggs	2.10	2.21
Fats	Olive oil	2.20	2.29
	Corn oil	2.20	2.29
	Margarine, 60% fat	1.66	1.75
Milk and milk products	Mini milk, 0.5% fat	1.09	1.17
	Skim milk, 0.3% fat	1.09	1.17
	Butter milk, 0.5% fat	1.24	1.33
	Yoghurt, 0.5% fat	1.24	1.33
Cheese products	Cheese 20+, 17% fat	8.47	9.11
	Cheese 30+, 31% fat	9.23	9.93
	Cheese, smoked	6.05	6.50
	Cheese, cottage 20+, 4% fat	3.44	3.70
Marmalade	Marmalade	1.60	1.60
Soft drinks	Mineral water, added sugar	1.00	1.00
	Mineral water, unsweetened	1.00	1.00
	Lemonade, added sugar	1.00	1.00
	Lemonade, unsweetened	1.00	1.00
Beverages	Water	0.10	0.10
	Tea	0.33	0.33
	Coffee	0.33	0.33
Vegetable drink	Soy drink	0.40	0.43
Beans	Beans, brown	1.24	1.29
	Beans, white	1.24	1.29
	Beans, soy	1.24	1.29
Alcoholic drinks	Beer	1.10	1.10
	Wine	2.20	2.20
Leeway	Dark chocolate, including marzipan	1.00	1.00
	Licorice	2.60	2.60
	Sweets	2.60	2.60
	Chewing gum	2.60	2.60
	Pastry	2.50	2.50
	Tebirkes	2.50	2.50
	Croissant	4.00	4.00
	Cream cake	2.50	2.50
	Chocolate cake	2.50	2.50
	Biscuit	2.50	2.50
	Ice cream	2.80	2.80
	Lollies	2.60	2.60
	Burger	10.00	10.00
	Hot dog	2.50	2.50
	Pita	2.50	2.50
	Pizza	2.50	2.50

study is found in Table 1 (10, 26, 34, 38–61). Food waste, especially at the consumer level, has been gaining attention over the past few years (62, 63). It is estimated that around one third of all food produced is not consumed, and the largest share in industrialized countries of this food waste occurs at consumer level (62). Table 1 shows CF numbers both excluding and including waste at the consumer level. When CF data has only been available for primary production, food waste has been estimated for the rest of the value chain based on a study from the Food and Agriculture Organization of the United Nations, FAO (62). In the present study, CF numbers including food waste at the consumer level are used to calculate total GHGE as well as their absolute and relative contribution. However, we have also analyzed the GHGE excluding food waste in this study.

Creating different dietary scenarios

Creating a 'base' diet

We created a realistic and healthy 'base' diet representing the dietary requirements of an adult woman (9.2 MJ) with a sedentary lifestyle and who undertakes limited physical activity in her leisure time (PAL, Physical Activity Level = 1.6) in the age range 31–60 (64). The age group for women was chosen based on the prevailing health and nutritional problems. It has been recognized that the pregnant and lactating women form one of the most nutritionally vulnerable segments of the population. For example, women in this age group have higher iron requirement than men. The first step was to create the diet in agreement with the DDG (24). The DDG mainly aim to communicate the concept of a healthy diet in order to increase the population's intake of fruit and vegetables, fish, potatoes, rice or pasta, as well as whole meal bread, to limit the intake of added sugar from sugar-containing soft drinks, cake and candy, and to limit the intake of fat, especially animal fat (24). In order to create a whole diet, we categorized the 71 food items into different main food types (e.g. fruit, vegetables, meat, and fish).

Table 2 shows the main food types used to create the different dietary scenarios, the recommended intake according to the DDG, and the quantities used in the diets as well as any specifications. The DDG quantify the intake of fruit, vegetables, fish, bread, cereals, potatoes, pasta and rice, but not the intake of meat, milk, cheese, and eggs, or the intake of sugar, sugary foods, fat, or fatty foods (24). If not quantified by the DDG, we made assumptions based on the available literature, as discussed below (Table 2). The next step was to create the composition of the main food types using data for DNDS. The most widely consumed food items in each food type were selected as representative of Danish diets. For example, according to national intake data, we consume 164 g fruit per day including 10 different fruits. Of the 164 g of fruit, 128 g represent apple (58 g), pear (20 g), orange (21 g), and banana (29 g), and the last 36 g are divided into kiwi, grapes, melon, peach, pineapple, and berries (23). As the intake of apple, pear, orange, and banana were much higher compared to the six other fruits, these food items were selected as representative of this food type. Moreover, the compositions of each food type are composed in the same proportion as eaten. For example, 100 g of fruit include 45.3 g apple, 15.6 g pear, 16.4 g orange, and 22.7 g banana. In this way, each food type was based on actual food choices and composed in the same proportion as eaten by adults. The consumption of some food items in DNDS was deficient. In this case, we made assumptions based on the literature as mentioned below (Table 2).

According to the DDG, 600 g fruits and vegetables are recommended, corresponding to three fruits and three vegetables of around 100 g per piece (65). This recommendation is based on the minimum amount at which

Table 2. Danish Dietary Guidelines 2005 and food intake patterns for women, by food types, quantities, and specifications

Food types	DDG 2005 recommended intake	Food intake pattern used to create dietary scenarios	
		Amounts	Specifications
Vegetables	600 g per day	300 g per day	Half of the vegetables are coarse*
Fruits		250 g per day	Fresh fruit
Juice		50 g per day	A glass of juice counts as one of the recommended Six units of fruit and vegetables
Bread and cereals	500 g per day	250 g per day	Half of the bread and cereals are fiber-rich§ Predominantly bread and moderate amount of cereals
Potatoes, pasta, rice		250 g per day	Predominantly potatoes
Fish	200–300 g per week	300 g per week/42 g per day	Half oily fish and half lean fish
Meat and meat products	Not specified	100 g per day	Including beef, pork and chicken Maximum 10 g fat per 100 g
Fats	Not specified	30 g per day	Half margarine and half oils
Eggs	Not specified	25 g per day	Whole eggs
Milk and milk products	Not specified	Various amounts	Low fat milk and milk products ($\leq$0.5 g fat per 100 g), predominantly milk
Cheese products	Not specified	Various amounts	Low fat cheese products ($\leq$18 g fat per 100 g)
Marmalade	Not specified	Various amounts	Strawberry jam
Water, tea and coffee	1–1.5 L per day	1 L per day	Predominantly water and moderate amount of coffee and tea
Alcoholic drinks	Not specified	Various amounts	Beer and wine
Soy drink	Not specified	Various amounts	Unfortified
Soft drinks	Not specified	Various amounts	Soft drinks and lemonade with added sugar and unsweetened
Leeway	Not specified	9 E%	Soft drinks, candy, cake, ice cream, fast food
Beans	Not specified	Various amounts	Brown, white and soy beans

DDG 2005: Danish Dietary Guidelines 2005; E%. Percentage of energy. *Coarse vegetables are vegetables with a dietary fiber content over 2 g per 100 g. §High fiber-rich bread and cereals contains over 6 g per 100 g.

beneficial effects on cardiovascular disease and obesity have been observed in epidemiological studies (65). According to DDG, we decided to divide the 600 g per day into 300 g vegetables, 250 g fruits, and 50 g juice (65). Half of the vegetables (150 g/day) should be high-fiber type (i.e. containing over 2 g of dietary fiber per 100 g) (Table 2). The DDG recommend 500 g per day of potatoes, rice, pasta, bread, and cereals. Half of this food type should be potatoes, rice and pasta, and half bread and cereals whereas half of the bread and cereals should be rich in fiber (i.e. containing over 6 g fiber per 100 g) (Table 2). The DDG recommended eating at least two portions of fish a week corresponding to 200–300 g per week (half of the fish should be lean and half oily). These values are based on an evaluation balancing the positive nutritional aspects against the potential toxicological aspects. We decided to use 42 g fish per day corresponding to 300 g per week. The type of fish in the DNDS was not specified further so we decided that half of the fish should be cod and half should be herring representing lean and oily fish, respectively (Table 2).

We made assumptions about the approximate quantities of the remaining food types (e.g. meat, eggs, fat, beverages, milk, cheese, and sugary and fatty foods), which are mentioned below. Regarding meat and meat products, the amounts were estimated to be 100 g per day to cover the major nutrients that they supply (66). The composition of this food type includes beef, pork, and chicken which represented the most widely consumed meat types according to the DNDS (Table 2). The consumption of eggs is recommended in the context of a healthy balanced diet and no restriction of dietary eggs intake is available (67). However, individuals who have familial hypercholesterolemia, an inherited susceptibility to high blood cholesterol levels associated with a greatly increased risk of premature development of coronary heart diseases, may be particularly sensitive to dietary cholesterol intake and are advised to restrict egg consumption to two to three per week (67, 68). In addition, we decided to use three eggs per week. A medium egg weighs around 50–60 g which corresponds to 25 g per day. Regarding fat, the amount of fat used for cooking and consumed on bread was estimated to be 30 g per day (68). According to the Nordic Nutrition Recommendation (NNR) 2004, most dietary fat intake should be in the form of monosaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) such as vegetarian oils (64). In addition, it is necessary to use vegetable oils and soft plant margarines in daily cooking. We therefore included half margarine and half oils. The types of oils were unspecified in DNDS (69). We decided to use PUFA-rich oil (corn oil) and MUFA-rich oil (olive oil), which are both good for salads and for cooking, respectively (Table 2). The DDG recommended 1–1.5 L of beverages per day for adults. However, this amount may vary depending on factors such as age, size, physical activity, and climate (24). The total amounts of non-alcoholic drinks in the diet are estimated to about 1.6 L per day. As for dairy products, we used the average Danish consumption of dairy products, corresponding to 322 g milk and milk products and 27.5 g cheese products (69). The DDG recommend low fat dairy products so we used milk and milk products with ≤ 0.5 g fat per 100 g and cheese products with ≤ 18 g fat per 100 g (Table 2). The food type called 'soft drinks' includes sugar-sweetened beverages such as soft drinks and lemonade both with sugar added and unsweetened. We estimated the water, tea, and coffee group to 1 L per day to reach a total daily intake of around 1.5 L as recommended (23). Moreover, this was comprised predominantly of water according to DNDS (69) (Table 2). Regarding alcohol, we decided to include alcohol to make the diets realistic because alcohol is part of Danish drinking habits. The energy contribution from alcohol should not exceed 5 percentage of energy (E%) (64). Therefore, we decided to include 200 g alcoholic drinks corresponding to one unit of alcohol (12 g alcohol), which corresponded to a maximum of 4 E%. The majority of women's alcohol intake is in the form of wine and beer, which are consumed in almost similar amounts (23). In addition, we decided to use half beer and half wine. Realistic diets should also include nutritionally less desirable foods, referred as leeway, including energy-dense food items with high sugar and/or fat content (e.g. candy, cake, ice cream, fast food). This food type can be eaten in moderation as part of a healthy diet, contributing to approximately 10% of the energy when the total energy level is 10 MJ (25). In addition, the leeway contributes with 9 E% in this study, which is in good agreement with 10 E%. Data on natural foodstuffs were used to minimize error and to enhance generalizability; supplements and fortified products were excluded. Very few products on the Danish market are fortified. Whereas there is no legislative requirement for fortification, Danish legislation calls for the iodine fortification of salt. Moreover, the impact of fortification on climate impact is uncertain.

Alternative dietary scenarios

In order to elucidate the role of dairy products in overall nutrition and, further, to clarify the effect of dietary choices on GHGE, we modeled on the 'base' diet (*scenario 1*). In total, we looked at eight dietary scenarios, six omnivorous, one vegetarian, and one vegan, with different quantities of dairy products in each. All scenarios were adjusted to have the same energy content.

Table 3 shows the dietary scenarios with different quantities of dairy products for women with an energy level of 9.2 MJ.

*Scenario 1 (**Average-dairy**)*: 332 g milk and milk products and 27.5 g cheese products were included corresponding to the Danish average consumption.

Table 3. Food intake patterns for dietary scenarios (gram per day) with different quantities of dairy products included for women with a recommended energy intake of 9.2 MJ

Food types	Average dairy	High dairy	Milk products	Cheese products	Non-dairy	Soy drink[§]	Vegetarian	Vegan
Vegetables	300	300	300	300	300	300	300	300
Fruits	250	250	250	250	250	250	250	250
Juice	50	50	50	50	50	50	50	50
Bread and cereals	250	250	250	250	250	250	250	250
Potatoes, pasta, rice	250	250	250	250	250	250	250	250
Fish	42	42	42	42	42	42	42	0
Meat and meat products	100	100	100	100	100	100	0	0
Fats	30	30	30	30	30	30	30	30
Eggs	25	25	25	25	25	25	25	0
Milk and milk products	322	500	500	0	0	0	500	0
Cheese products	27.5	25	0	25	0	0	0	0
Marmalade	0	0	25	0	25	25	25	0
Water, tea and coffee	1000	1000	1000	1000	1000	1000	1000	1000
Alcoholic drinks	200	200	200	200	200	0	200	200
Soy drink	0	0	0	0	0	500	0	300
Soft drinks	300	0	0	900	900	0	0	0
Leeway	115	115	115	115	115	115	115	115
Beans	0	0	0	0	0	0	45	90

The quantities of the food types in the shaded boxes vary throughout the dietary scenarios and the quantities of the other food types are constant.

[§] Unfortified soy drink.

*Scenario 2 (**High-dairy**)*: 500 g milk and milk products and 25 g cheese products were included corresponding to a high consumption of dairy products.

*Scenario 3 (**Milk-products**)*: 500 g milk and milk products were included and cheese products were excluded. Cheese products were substituted with the same amount (kJ) of marmalade (a realistic choice in a Scandinavian breakfast) to elucidate the role of milk products in overall nutrition (70).

*Scenario 4 (**Cheese-products**)*: 25 g cheese products were included and milk and milk products were substituted with the same amount (kJ) of soft drinks to elucidate the role of cheese products in overall nutrition. Soft drinks, such lemonade and coca cola, are used as alternatives to milk products, and both national and international studies have found an inverse association between intake of milk and sugar-containing soft drinks (i.e. sugar-containing soft drinks replacing milk in the diet (25, 71, 72)). Moreover, there is a high consumption of lemonade in the population (25).

*Scenario 5 (**Non-dairy**)*: All dairy products were excluded. Milk and milk products were substituted with soft drinks and cheese products were substituted with marmalade in the same amount (kJ). We wanted to assess the role of dairy products in overall health as well as their contribution to nutritional status for the major nutrients that they supply.

*Scenario 6 (**Soy drink**)*: 500 g milk and milk products were substituted with 500 g unfortified soy drinks. This diet was included because of the new trend among the younger generation to consume non-dairy drinks (e.g. soy drink) as an alternative to milk (70). Alcoholic drinks were excluded to adjust for the same energy level.

*Scenario 7 (**Vegetarian**)*: All meat and meat products were substituted with beans (healthy alternatives to meat) in the same amount (kJ). Dairy consumption was 500 g milk and milk products.

*Scenario 8 (**Vegan**)*: All foods of animal origin (i.e. meat, fish, eggs, and dairy products) were excluded. To maintain the energy level, these products were substituted with soy drinks and beans. The vegan diet is oversimplified regard to nutrition. However, we include the vegan diet manly due to the fact that it is relevant when considering sustainable issues.

Calculating percentages of energy and nutrients in dietary scenarios

To create and prepare the dietary scenarios from the main food types, we calculated the nutrient composition for 100 g of each food type using Dankost 3,000 dietary assessment software (Dankost, Copenhagen, Denmark). This gave us the opportunity to create dietary scenarios composed of the most consumed food items, taking current food consumption patterns into account. The 21 nutrients included in the present study were the ones specified by the NNR 2004 (protein, carbohydrates, fat, vitamin A, vitamin D, vitamin E, vitamin C, vitamin B12, niacin, thiamin, riboflavin, vitamin B6, folate, magnesium, iron, zinc, phosphorus, potassium, calcium, selenium, iodine) (see tables 4 and 5) (64). The nutritional value for the food intake patterns were compared with the NNR for women aged 31–60 (64).

Calculating GHGEs of dietary scenarios

Besides estimating the total GHGE for each dietary scenario, the absolute (g CO_2e per day) as well as the relative (% of total g CO_2e per day) contribution and the contribution from each food type to total diet weight were also calculated for *scenario 1* with average-dairy consumption. This was included to analyze the effects of the various food types in terms of GHGE.

Calculation of nutrition density in relation to GHGE

The Nutrient Density of Climate Impact (NDCI) index, which takes into account the fact that foods contribute differently with respect to energy and nutrients, was used to estimate the nutrient density of different solid food items in relation to nutrition recommendations and climate impact (10). We included 15 different solid food items, which were representative for all food types. Nutrient density of a food item was calculated by summarizing the proportions of the recommended daily intake of each nutrient provided by 100 g of the food item multiplied by the proportion of nutrients contributing to more than 15% NNR. The cut-off level for a significant contribution was set according to the Codex Alimentarius Commission's health claim definition of solid food items: source of nutrients for 15% of recommended intake of a nutrient (73). The same 21 nutrients used to calculate the nutritional value from the dietary scenarios were used.

$$\text{Nutrient density of food item Y} = \sum_{21\text{nutr}} \left(100 \times \frac{\text{Amount of nutrient X in 100 g of Y}}{\text{Recommended intake of nutrient X}}\right) \times \left(\frac{\text{Number of nutrients in Y} \geq 15\% \text{ of rec.intake}}{21}\right)$$

$$\text{NDCI index} = \left(\frac{\text{Nutrient density of Y}}{\text{CO}_2\text{ e for 100 g of Y}}\right)$$

The NDCI was calculated for the selected solid food items by dividing the nutrient density of the food with its CF (g CO_2e per 100 g food item).

Although many of the solid food items contained a broad range of nutrients, the amounts present contributed to $<15\%$ of the daily dietary recommendation. Nutrient density was calculated for 15 different solid food items including the following: beef, pork, chicken, cheese, cod, eggs, brown and polished rice, pasta, oatmeal, broccoli, carrots, brown beans, potatoes, and bananas. The selected food items were representative for the whole diet. The nutrient contents of the food items included were taken from the Danish Food Composition database – version 7 (National Food Institute, Technical University of Denmark) (74). Data on raw food items were used in order to minimize error and to enhance generalizability. The CF data included in the calculation of the index excluded waste at the consumer level because data on raw food items were used in the calculation of nutrient density. Food items with the highest NDCI index values are those with the highest nutrient density scores in relation to the GHGE.

Cut-off value

If the NDCI index is calculated as the nutrient density divided by the CO_2e for 100 g of food items without including a cut-off value, the index only takes into account the amount of nutrients in a given food item. However, including a cut-off value in the model takes into account both the nutrient amount and the nutrient balance. In addition, the NDCI index is dependent on the choice of cut-off value.

Statistical analysis

Linear regression was used to assess the significance of changes in vitamin D, selenium, and riboflavin as a function of calcium content in all dietary scenarios except the vegan diet. The vegan patterns were excluded in the linear regression, because the nutritional value of vitamin D and selenium were very different from the other diets representing the different dietary compositions, that is, not including fish which has a high value of vitamin D and selenium. P-values were evaluated at a 5% significance level. The analyses were carried out using PROC GLM procedure in Statistical Analysis System (SAS), version 9.1 (SAS Institute, Cary, NC).

Results

Dietary scenarios and nutrient content

Energy and macronutrients

Table 4 shows the energy percentage of macronutrients for the dietary scenarios for women (aged 31–60). All of the created dietary scenarios, except vegetarian and vegan diet, were compliant with NNR regarding the contribution of daily-recommended intake of macronutrients (Table 4).

The percentage of energy (E%) from protein was between 12E and 17E% in all dietary scenarios compared to the NNR of 10E to 20E% with the highest value in the high-dairy and the lowest in the non-dairy and vegan diets. The low protein content (66 g) in the non-dairy and vegan diets is above the recommended value. The high-dairy diet resulted in 27% (24 g per day) higher protein than the non-dairy diet (Table 4).

Carbohydrates contributed with 53E to 60 E% in all dietary scenarios compared to the recommended level of 52E to 60 E% with the highest amount in non-dairy,

Table 4. Energy percent of macronutrients for the dietary scenarios

Macronutrients	NNR	Average dairy	High dairy	Milk products	Cheese products	Non dairy	Soy drink§	Vegetarian	Vegan
Protein E%	10–20	16	17	16	14	12	14	14	12
Carbohydrate E%	50–60	54	53	55	57	59	58	59	60
Added sugar E%	max 10	5	2	5	10	**12****	**13****	5	7
Fat E%	25–30	26	27	26	26	25	28	**23***	**24***
Saturated fat E%	max 10	8	8	7	7	6	7	6	5
Monounsaturated E%	10–15	**9***	**9***	**9***	**9***	**9***	**9***	**8***	**8***
Polyunsaturated E%	5 to 10	6	6	6	6	6	7	6	7
Alcohol E%	max 5	4	4	4	4	4	0	4	4

E%. percentage of energy; NNR: Nordic Nutrition Recommendations 2004 for women with a sedentary lifestyle with limited physical activity in the age range 31–60. The food composition of each diet corresponds to the quantities (gram per day) represented in Table 3. All dietary scenarios were adjusted to same energy level (9.2 MJ). *Values below the recommended NNR level. **Values over the recommended NNR level. §Unfortified soy drink. The shaded columns are values below and values over the recommended NNR level.

vegetarian, and vegan diets and the lowest amount in high-dairy diets. According to NNR, the proportion of pure refined sugar types should not make up more than 10 E%. In addition, the energy from added sugar reached the maximum in non-dairy and soy drinks, which mainly comes from soft drinks and soy drinks, respectively (Table 4).

The percentage of energy from fat should provide 25E to 30E% according to NNR levels. The E% from fat was between 23 E and 28 E% with the lowest amount in the vegetarian and vegan diets and the highest amount in the soy drinks. All dietary scenarios were below the maximum level of SFA, which should be restricted to at most 10E%. Dairy products provided 15% of the overall SFA in the average-dairy diet. The monounsaturated fatty acid (MUFA) content of all dietary scenarios were below or in the lower level of the recommended level of 10E to 15E%, and the polyunsaturated fatty acid (PUFA) content was 6E or 7E% compared to the NNR level of 5E to 10E% (Table 4).

Micronutrients

Table 5 shows the content of micronutrients for the dietary scenarios for women (aged 31–60). The created dietary scenario, that is, average-dairy, high-dairy, milk products, and vegetarian diet were the ones most compliant with NNR 2004 regarding the contribution of daily recommended intake of micronutrients (Table 5).

All dietary scenarios meet the nutritional recommendations for vitamin A, vitamin E, vitamin C, vitamin B12, niacin, thiamine, vitamin B6, folate, magnesium, zinc, phosphorus, and potassium (Table 5). The variation in calcium was significantly ($P = 0.0001$) correlated with the amount of dairy products in the dietary scenarios with the highest amount found in the high-dairy diet. The calcium content was below the recommended level of 800 mg per day in the diets with a low amount or without dairy products (i.e. cheese-products, non-dairy, soy drinks and the vegan diet) (Table 5). The iron content in most dietary scenarios was slightly below the recommended NNR level of 15 mg per day except for the vegan diet. The large source of iron in the vegan diet came from beans. The non-dairy diet resulted in 3% (0.43 mg per day) higher iron than the high-dairy diet (Table 5). The vitamin D content in all dietary scenarios was below the recommended level of 7.5 μg day per day with the highest content in the high-dairy diet (Table 5). In the vegan diet, the vitamin D, selenium, iodine, and vitamin B12 content was below the recommended level, mainly because of the lack of animal-based products. The iodine content in the diet that included soy drink was just below the recommended level (Table 5). The selenium and riboflavin content in the diets with low or no dairy products (i.e. cheese-products, non-dairy, soy drink, and vegan diet) were below the recommended NNR level of 40 μg/day and 1.1 mg/day, respectively. The high-dairy diet had the highest content of selenium and riboflavin (Table 5).

The high-dairy diet resulted in 13% (0.44 μg per day) higher vitamin D; 55% (645 mg per day) higher calcium; 48% (0.92 mg per day) higher riboflavin, and 18% (8.35 μg per day) higher selenium than the non-dairy diet. There was a significant correlation between changes in calcium and changes in vitamin D content ($P = 0.0001$), selenium ($P = 0.0001$), and riboflavin ($P = 0.0001$) throughout all the diets.

Dietary GHGE

Table 6 shows the total estimated GHGE (in g CO_2 e per day and kg CO_2 e per year) and the absolute (g CO_2 e per day) contributions of food categories for the dietary scenarios including waste at the consumer level.

The estimated GHGE for the average-dairy, high-dairy, milk-products, cheese-products, and non-dairy diets ranged from 4,340 to 4,826 g CO_2e per day with the highest GHGE in cheese-products and lowest GHGE in milk-products (Table 6). For soy drink, the estimated

Table 5. Nordic Nutrition Recommendations 2004 for women, and the nutritional content of the dietary scenarios

Nutrients	NNR	Average dairy	High dairy	Milk products	Cheese products	Non-dairy	Soy drink§	Vegetarian	Vegan
Dietary fiber (g/day)	25–35	31.4	31.41	31.41	31.41	31.41	31.41	39.31	47.22
Vitamin A (RE/day)	700	1052.7	1056.1	1030.7	1039	1013.6	1023.6	1028.3	962.7
Vitamin D (µg/day)	7.5	**3.20**	**3.34**	**3.31**	**2.94**	**2.90**	**2.90**	**2.87**	**0.1**
Vitamin E (α-TE/day)	8	11.27	11.16	11.13	11.47	11.44	11.23	11.15	10.56
Vitamin C (mg/day)	75	168.1	168.5	169.7	167.7	168.9	163.5	163.2	156.1
B12-vitamin (µg/day)	2	5.65	6.49	6.13	4.03	3.67	3.67	5.07	**0.1**
Niacin eug. (NE/day)	15	32.6	33.9	32.4	29.7	28.1	29.7	26.9	24.1
B1-Thiamin (mg/day)	1.1	1.52	1.59	1.57	1.39	1.38	1.57	1.47	1.66
B2-Riboflavin (mg/day)	1.3	1.61	1.90	1.83	**1.05**	**0.98**	**1.02**	1.75	**0.88**
B6-vitamin (mg/day)	1.2	2.05	2.11	2.10	1.89	1.88	2.07	1.95	1.91
Folate (µg/day)	400	479.3	486.2	474.7	463.5	451.9	586.5	563.4	706.1
Magnesium (mg/day)	280	369	384	378	341	335	386	436	493
Iron (mg/day)	15	**13.39**	**13.27**	**13.34**	**13.62**	**13.7**	**14.09**	**14.86**	17.91
Zinc (mg/day)	7	11.39	12.0	11.09	10.04	9.13	9.91	9.11	7.87
Phosphorus (mg/day)	600	1541	1696	1570	1227	1102	1258	1583	1276
Potassium (mg/day)	3100	4081	4315	4306	3662	3654	3685	4656	4540
Calcium (mg/day)	800	1011	1173	1021	**681**	**528**	**470**	1068	**525**
Iodine (µ/day)	150	231.4	258.4	255.3	182.6	179.5	**145**	255	**97.8**
Selenium (µg/day)	40	44.19	46.18	44.04	**39.97**	**37.83**	**39.83**	40.81	**22.89**

NNR: Nordic Nutrition Recommendations 2004 for women with a sedentary lifestyle with limited physical activity in the age range 31–60. The food composition of each diet corresponds to the quantities (gram per day) represented in Table 3. All dietary scenarios were adjusted to same energy level (9.2 MJ). The shaded columns are values below the recommended NNR level. §Unfortified soy drink.

Table 6. The total estimated greenhouse gas emission (in g CO_2e per day) and the absolute contributions of food types for the dietary scenarios including waste at consumer level

Food types	Average dairy	High dairy	Milk products	Cheese products	Non-dairy	Soy drink§	Vegetarian	Vegan
Vegetables	343	343	343	343	343	343	343	343
Fruits	239	239	239	239	239	239	239	239
Juice	36	36	36	36	36	36	36	36
Bread and cereals	355	355	355	355	355	355	355	355
Potatoes, pasta, rice	356	356	356	356	356	356	356	356
Fish	146	146	146	146	146	146	146	0
Meat and meat products	1335	1335	1335	1335	1335	1335	0	0
Fats	61	61	61	61	61	61	61	61
Eggs	55	55	55	55	55	55	55	0
Milk and milk products	383	595	595	0	0	0	595	0
Cheese products	243	221	0	221	0	0	0	0
Marmalade	0	0	40	0	40	40	40	0
Water, tea and coffee	202	202	202	202	202	202	202	202
Alcoholic drinks	340	340	340	340	340	0	340	340
Soy drink	0	0	0	0	0	215	0	129
Soft drinks	300	0	0	900	900	0	0	0
Leeway	237	237	237	237	237	237	237	237
Beans	0	0	0	0	0	0	58	116
Sum (g CO_2e per day)	4631	4521	4340	4826	4645	3620	3063	2414

The estimated greenhouse gas emission for the dietary scenarios corresponding to the quantities (gram per day) represented in Table 2. The shaded boxes indicate the food types where the quantities vary throughout the dietary scenarios. §Unfortified soy drink.

values were 3,620 g CO_2e per day. For the vegetarian and vegan diets, the estimated GHGE were 3,063 and 2,414 g CO_2e per day, respectively. The average dairy diet resulted in 48% (2,217 g CO_2e per day) higher GHGE compared to the vegan diet and 34% higher GHGE (1,568 g CO_2e per day) compared to the vegetarian diet (Table 6).

Figure 1 shows the contribution of each food type in the average-dairy diet to total diet quantity (% of total gram per day) and to total GHGE (% of total g CO_2e per day) including waste at the consumer level. The contribution of total dairy products including milk products and cheese to diet quantity (11%) was very close to their relative contribution to total GHGE (13%) (Figure 1). Similarly, the contribution for vegetables, fruits, and juice to diet quantity (19%) and the contribution of bread, cereals, potatoes, pasta, and rice to diet quantity (16%) was closer to their relative contribution to total GHGE (13 and 16%, respectively) (Figure 1). However, the relative contribution of meat and meat products was the strongest contributor to total GHGE (29%) whereas the contribution to diet quantity was one of the smallest (3%). Similarly, the relative contribution of cheese to total GHGE (5%) was also high compared with its weight contribution (1%) (Figure 1).

Nutrition density in relation to GHGE

Table 7 shows the NDCI index for the 15 solid food items and the values used in the calculation where cheese has the highest nutrient density, brown beans the highest number of nutrients over 15% of NNR, and beef the highest GHGE compared to the other food items. Figure 2a and b shows the CF per kg food and the NDCI index when 15% was used as the cut-off level for nutrients with a significant contribution.

The CF ranged from 0.22 to 28 kg CO_2e per kg food items with the highest values for meat products, cheese, and cod and the lowest values for plant-based products such as carrots, potatoes, oatmeal, bananas, and brown beans (Figure 2a). When combining nutritional value and climate impact using the NDCI index, the ranking of food items changes and values for animal-based and plant-based products are more similar (Figure 2b). The index values for cod, pork, cheese, chicken, brown rice, pasta, and potatoes were quite similar (between 0.19 and 0.35) despite very different nutrient density values, reflecting different GHGE values. Cheese has the highest nutrient density value compared to all the other food items included in the study, which can be explained with regard to both the number of nutrients and their amount relative to recommendations. Beef, polished rice, and bananas have the lowest index NDCI values (0.06, 0.07 and 0.09, respectively). The nutrient density of beef was higher than that of bananas, but the GHGE was also higher, resulting in an almost similar index value (Table 7). The index value was highest for beans, oatmeal, and eggs (2.17, 1.49 and 1.10, respectively). The nutrient density of eggs was close to brown beans, but the GHGE was higher, resulting in a lower index value. The nutrient density for oatmeal was much lower than that of eggs, but the GHGE were also much lower, resulting in a higher index value than eggs (Table 7). Broccoli and carrots have similar index values (0.40) despite a very low GHGE for carrots. This can be explained by a very low nutrient density value for carrots, reflecting the low amount of many nutrients relative to the dietary recommendations (Table 7).

Discussion

This study shows that excluding dairy products from our diet does not necessarily mitigate climate change; however, it may have nutritional consequences. A healthy diet

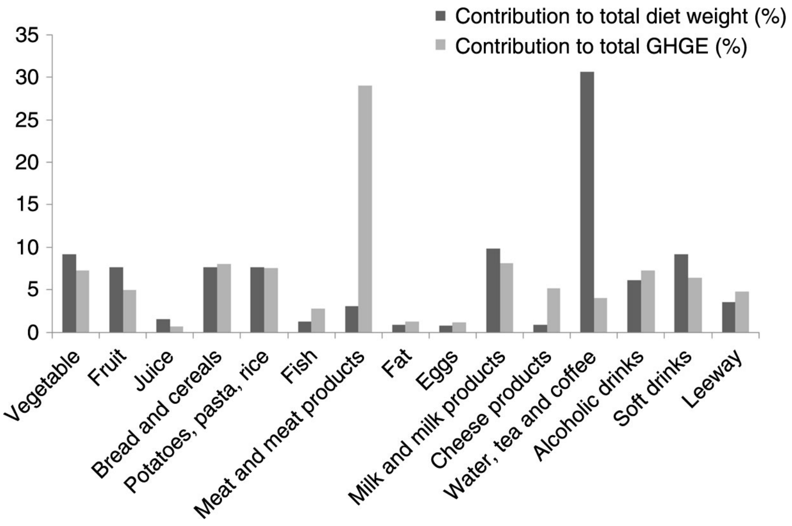

Fig. 1. The contributions of each food type in the average-dairy scenario to total diet weight (% of total gram per day) and to total greenhouse gas emission (GHGE) (% of total g CO_2e per day). Total diet weight: 3262 g per day; Total GHGE: 4631 g CO_2e per day.

Table 7. Nutrient density in relation to climate impact for solid food items

Solid food items	Number of nutrients ≥15% NNR	% of NNR in 100 g food	Nutrient density	GHGE	NDCI Index
Beef	9	389	166.8	2799	0.06
Rice, polished	3	175	25.0	374	0.07
Bananas	2	115	10.9	122	0.09
Chicken	7	297	98.8	521	0.19
Potatoes	2	138	13.2	57	0.23
Pasta	5	187	44.5	193	0.23
Rice, brown	6	326	93.1	374	0.25
Cheese	11	545	285.5	923	0.31
Pork	10	387	184.4	557	0.33
Fish, Cod	7	465	155.0	447	0.35
Broccoli	4	351	66.8	167	0.40
Carrot	1	187	8.9	22	0.40
Eggs	11	440	230.2	210	1.10
Oatmeal	8	352	134.1	90	1.49
Beans, brown	12	471	269.4	124	2.17

NNR: Nordic Nutrition Recommendations; NDCI index: nutrient density to climate impact index (NDCI = nutrient density/ GHGE); nutrient density = percentage of NNR in 100 g of product × number of nutrients ≥15% NNR/ 21; GHGE: greenhouse gas emission (gram CO_2e per 100 g food items) excluded waste at consumer level.

can be achieved through various food combinations, which are associated with different environmental impacts (e.g. GHGE). Current dietary guidelines are based on nutrient recommendations for health and do not account for the environmental aspects of the diet. The present study highlights the importance of examining these two aspects together when considering future dietary recommendations for a sustainable diet. If the main focus is solely on a reduction in diet-related GHGE, then reductions in animal-based food, which make the greatest contribution to GHGE in our diet, may result in a lower diet related GHGE (4, 6, 8). This is in agreement with new research from the United States, where a study shows a lower GHGE when comparing vegetarian and vegan diets with animal-based diets (75). Not all of these diets meet the dietary recommendations of a healthy population (75). However, some studies have shown that it is possible to decrease GHGE without health consequences (11, 12). This study shows that reducing consumption of food items with high or relative high GHGE is not necessarily the best approach to decreasing diet-related GHGE. Where substituting a product in an isocaloric approach, the resulting variations in diet-related GHGE depend both on the GHGE per kg of the substituted product and also its energy density. If a product is replaced by food with lower energy density, the quantity needed to compensate for the caloric loss is greater than the quantity removed. This may result in a higher diet-related GHGE despite the lower GHGE per kg of the substituted product. This is in agreement with a French study showing that the isocaloric substitution of meat with fruit and vegetables results in either no reduction or even an increase in GHGE, because the required amounts of fruit and vegetables to maintain the caloric content of the diet were relatively high (6). However, the relatively high variability of diet-related GHGEs within the high-nutritional quality class suggests that some individuals have diets with both high energy density and low GHGEs (76). More research is therefore needed to evaluate the feasibility of adopting sustainable dietary patterns in everyday life.

On a per kg basis, dairy products have a relatively high CF, but at the same time they have a high nutritional value. This study confirms that it could be difficult to fulfill the recommended daily intake of, in particular, calcium if dairy products are excluded from our diet. For example, according to own calculations, 1,300 g of the vegetable food type or 700 g of broccoli should be included in the non-dairy diet in order to reach the recommended intake of calcium (data not shown). The created dietary scenarios, that is, average-dairy, high-dairy, milk-products, and vegetarian (including dairy products) diet were the ones most compliant with NNR. A reduction in the intake of dairy products may be considered in the context of the whole diet to ensure that substitutions made in the diet are appropriate with respect to health. The bioavailability of some minerals (e.g. calcium) is an importance aspect to be considered. Plant-based products containing compounds, for example, phytates and oxalates, can inhibit the absorption of some minerals (e.g. calcium) (77), and there are only a few green vegetables and dried fruits that are good sources of calcium (78). Another aspect to take into account when comparing protein with animal sources and vegetable protein is the quality of the protein. All of the dietary scenarios in this study have adequate protein

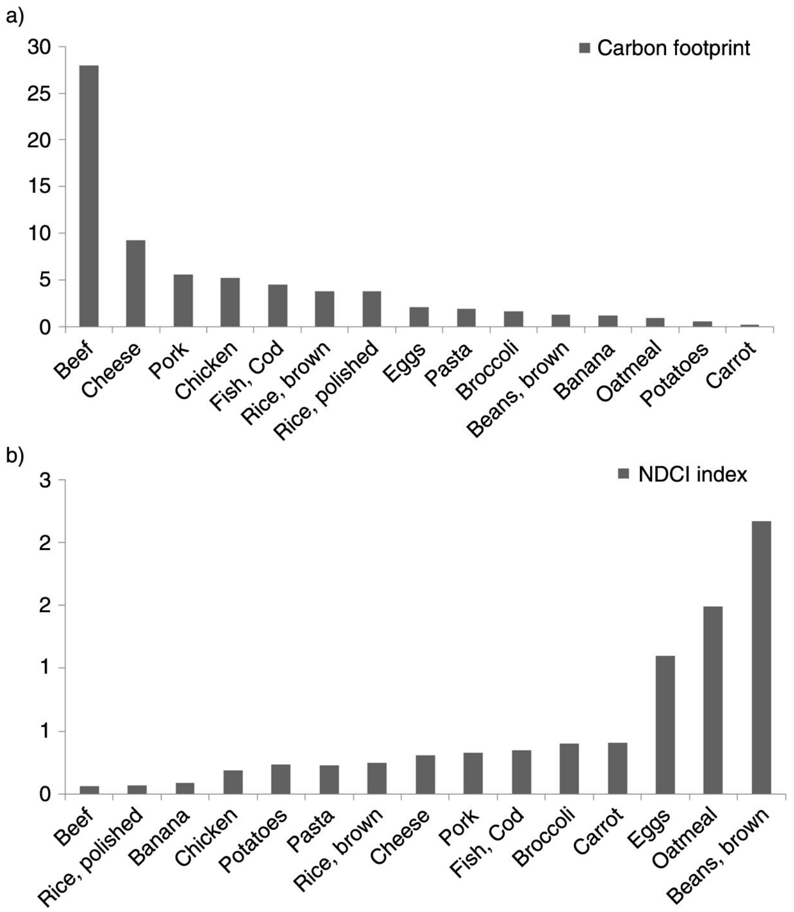

Fig. 2. NNR: Nordic Nutrition Recommendations; (a) Carbon footprint (kg CO_2e per kg solid food item) excluding waste at consumer level. (b) NDCI index: nutrient density to climate impact index (NDCI = nutrient density/GHGE); nutrient density = percentage of NNR in 100 g of product × number of nutrients ≥15% NNR/ 21; GHGE: greenhouse gas emission (gram CO_2e per 100 g food item) excluding waste at consumer level.

content. However, dairy products are sources of high-quality protein together with eggs, meat, and fish. Dairy proteins are mostly composed of casein, which is well known for high nutritional value and physiological properties (79, 80). The high level of lysine makes casein and total milk protein an important complement for many plant proteins that normally have limited amounts of lysine (81). When planning a vegan diet, the minimum requirement of protein should be higher compared to an animal-based diet to account for decreased protein bioavailability in vegetarian foods (82, 83). However, preparation of some plant foods and cooking reduces the amount of antinutrition (trypsin inhibitors, etc.), thus increasing the bioavailability of protein (84). Although dairy products are low in vitamin D, a recent study from Canada revealed that people who consume milk more than once a day show a higher level of vitamin D than those who do so less than once a day (85). On the contrary, dairy fat accounted for about 30% of the total SFA intake in Denmark in 2003 (23). However, this study indicates that there is room for low-fat dairy products in a healthy diet.

Models to integrate the environmental impact with their inherent nutritional value are being developed. The NDCI index is one such example. The aim of the index is to identify desirable food items that are both sustainable and also have maximum nutritional value. Calculations of nutrient density are based on nutrient density models described by Drewnowski (86). The intention is to distinguish food items that are energy dense from those that are rich in nutrients. There have been several attempts to formally define what is meant by nutrient-rich food and some of these considerations have been accounted for and incorporated into the NDCI index. In 1974, the Federal Trade Commission (FTC) proposed to limit the use of the term 'nutritious' for food that provides ≥10% of the US recommended dietary allowances (RDA) for protein and three other nutrients per 100 kcal (87). However, only one vegetable and one milk product, out of a total of 135 different foods, met those criteria (88). Another study suggested that the designated food ought to provide 50% of the US RDA for one nutrient, 20% for two nutrients, 15% for three nutrients, 10% for four nutrients, and 6% for five nutrients (89). However, these criteria were also so strict that very few food items could fulfill these requirements. Similarly, one author proposed an index ranging from 0 to 100 points, where each nutrient was rated according to a 5-point scale: food items containing >20% of daily value (DV) were assigned 100 points, those containing 17–19% of DV got 75 points, those containing 14–16% got 50 points, those containing 10–13% got 25 points, and those containing <10% got 0 points (90).

When considering the CF in relation to various food products' nutrient density, meat from monogastric animal (e.g. pork, chicken) and cheese, which generally have the highest CF per kg product, were more similar to plant-based products. It is worth remembering that the index has some limitations, for example, due to the selection of nutrients, considerations of protein quality, bioavailability of nutrients, and the choice of criteria for setting the threshold values. However, introduction of the index contributes with new knowledge within the field of combining nutritional value and climate impact. Countries that have started to produce guidelines that combine dietary recommendations for health with a reduction in environmental impact focus on broad food groups (91, 92). Although, this is an important step forward, the next step is to consider what the whole diet might look like. A well-balanced diet is important when reducing GHGE and meeting dietary recommendations for health, and can be achieved without eliminating meat or dairy products (11, 12). However, these products must be consumed in smaller quantities (11, 12).

The dietary scenarios in the present study were created in a realistic and objective way by including the most frequently consumed food items in the diet of the Danish population in the same proportion as they are currently eaten. However, the vegan diet was oversimplified, which may have influenced the nutritional value of the diet. Furthermore, alcohol was excluded in the soy drink diet to match the total energy (9.2 MJ), which was a limitation. We made assumptions about the approximate quantities and composition of some food types if the information available was inadequate. The quantities of dairy products included in this study were realistic according to the USDA's dietary guidelines and the Danish average consumption. A further increase of these products is not necessary to meet dietary recommendations. Finally, generalizability of the results is limited when only women in a certain age group are included.

Comparing CF values for different studies is complex due to, among other things, methodological choices, uncertainties in data, and various assumptions behind the calculated CF values (choice of data sources, how are system boundaries defined, etc.). However, we have considered thoroughly all of these issues and accounted for to the greatest possible extent in the present study.

For example, in many CF studies the consumer stage is not included. To harmonize the system boundaries, the latter stage of the life cycle (transport from retail to consumer and, if relevant, preparation of the food) was added in our study. For some food items, GHGE data were not available in the literature and in those cases assumptions had to be made. The values calculated in our study seem to be compatible with the findings of other studies (6, 7).

Combining nutritional value and sustainability aspects – in the present paper limited to GHGE – is one step toward finding a more accurate way to address sustainable food consumption. However, future studies of sustainable food consumption need to focus further on dietary recommendations for health, as well as on a broader range of environmental impact categories. Accordingly, aspects such as protein quality, water use, land use change, eutrophication, and impact on biodiversity need further investigation. In addition, the role of livestock in sustainable food production requires more exploration, as there can be both positive as well as negative impacts associated with animal production. One of the greatest challenges to supply the growing population with nutritious food in the future is the competition of the limited land resource. Here, cattle have the ability to convert grass to valuable food products such as milk and meat and make use of land areas (rangelands) less suitable for direct food crops. Cattle might thereby play an important role also in our future food system, in order to use our resources as efficiently as possible.

In conclusion, this study shows that excluding dairy products from our diet does not necessary mitigate climate change but in contrast may have diametrical nutritional consequences. In addition, when optimizing a diet with regard to sustainability it is crucial to account for the nutritional value and not solely focus on impacts per kg products.

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Conflicts of interest and funding

There is no conflict of interest.

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*Louise Bruun Werner
Department of Nutrition, Exercise and Sports
Faculty of Sciences
University of Copenhagen
DK-1165 Copenhagen, Denmark
Email: lbw@life.ku.dk