Energy and nutrient density of foods in relation to their carbon footprint[1–5]

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ABSTRACT

Background: A carbon footprint is the sum of greenhouse gas emissions (GHGEs) associated with food production, processing, transporting, and retailing.

Objective: We examined the relation between the energy and nutrient content of foods and associated GHGEs as expressed as g CO_2 equivalents.

Design: GHGE values, which were calculated and provided by a French supermarket chain, were merged with the Composition Nutritionnelle des Aliments (French food-composition table) nutrient-composition data for 483 foods and beverages from the French Agency for Food, Environmental and Occupational Health and Safety. Foods were aggregated into 34 food categories and 5 major food groups as follows: meat and meat products, milk and dairy products, frozen and processed fruit and vegetables, grains, and sweets. Energy density was expressed as kcal/100 g. Nutrient density was determined by using 2 alternative nutrient-density scores, each based on the sum of the percentage of daily values for 6 or 15 nutrients, respectively. The energy and nutrient densities of foods were linked to log-transformed GHGE values expressed per 100 g or 100 kcal.

Results: Grains and sweets had lowest GHGEs (per 100 g and 100 kcal) but had high energy density and a low nutrient content. The more–nutrient-dense animal products, including meat and dairy, had higher GHGE values per 100 g but much lower values per 100 kcal. In general, a higher nutrient density of foods was associated with higher GHGEs per 100 kcal, although the slopes of fitted lines varied for meat and dairy compared with fats and sweets.

Conclusions: Considerations of the environmental impact of foods need to be linked to concerns about nutrient density and health. The point at which the higher carbon footprint of some nutrient-dense foods is offset by their higher nutritional value is a priority area for additional research. *Am J Clin Nutr* 2015;101:184–91.

Keywords carbon footprint, energy density, greenhouse gas emissions (GHGEs), nutrient density, diet, France, greenhouse effect

INTRODUCTION

The challenge of ensuring sustainable nutrition security in the face of climate change has led to renewed concerns about the future of the current Western diet (1). Sustainable diets are defined by the FAO as those that are nutritionally adequate, affordable, safe, and culturally acceptable while sparing of natural and human resources (2, 3). The many measures of environmental sustainability include the use of land, water, and energy resources as well as biodiversity and the protection of ecosystems (2). One measure of the environmental impact of food production is the life-cycle assessment (LCA)[6] of the carbon footprint of foods (4) estimated as greenhouse gas emissions (GHGEs).

Analyses of GHGEs associated with the production of animal foods have influenced agricultural and farm policies, particularly in the European Union (5, 6). The major sources of food-associated GHGEs are agricultural production, food processing, transport, distribution, and storage as well as food preparation, waste, and disposal. The contribution of the agriculture and food industries to total global GHGEs has been reported to range from 15% to 30% (7, 8).

One common belief is that plant-based diets are more environmentally friendly than are diets that contain foods of animal origin (9, 10). Studies have noted that Mediterranean-style diets were both healthier and more protective of natural resources than was the typical Western diet (11, 12). However, recent analyses of diet-associated GHGEs have produced some unexpected results

(13, 14). In a French study (15), nutrient-dense diets with more meat, vegetables, and fruit were associated with higher rather than lower GHGEs (15). The replacement of red meat with equicaloric amounts of vegetables and fruit led to a net increase in modeled GHGEs (8). By contrast, among foods with lowest GHGEs were grains and sweets of high energy content but low nutritional value (8). Indeed, some analyses have suggested that the plant food associated with lowest GHGEs is sugar (8, 16, 17).

Researchers in the European Union have begun to explore the relation between the nutrient density (ND) of foods and their environmental impact (13, 14), ranging from the carbon footprint to sustainability of existing fisheries (18). New food patterns may be able to balance good nutrition with greater sustainability (14, 19, 20). With the use of linear programming, Macdiarmid et al. (14) showed that reduced-GHGE but nutritious diets could be achieved without a net increase in cost and without eliminating meat or dairy products, which are considered to be important sources of key nutrients in the British diet (21).

The current study examined the relation between the carbon footprint of foods and their energy and nutrient contents. Nutrient-profiling methods (22–24) were applied to a large database of GHGE values for foods and beverages developed and provided by the Casino Group, which is one of the world's largest food retailers. The question was whether higher GHGEs associated with meat and dairy production in France would be offset in part by their higher energy contents and/or greater nutritional values (25).

METHODS

Data development

GHGE values for 661 foods and beverages were developed and provided by the Casino Group in 2012. The Casino Group has >12,000 retail outlets in France operating the brands Hyper Géant Casino, Casino Supermarché, Monoprix, Franprix, and Leader Price. Casino is the largest food retailer in Latin America and Brazil.

The 661 foods included fresh and processed meats and dairy products, grains, fats, and sweets. Data for fresh produce were not available, and vegetables and fruit were either frozen or processed. Calculations were based on an attributional LCA following the International Organization for Standardization 14040–44 (26, 27) and the French regulation BP X 30–323 (28) guidelines. On the basis of current practices, the attributional LCA used a range of life-cycle inventory databases (29, 30) to estimate GHGE values associated with current agricultural production methods, processing, packaging, distribution to the store, and in-store storage (26, 27, 31). GHGE data were expressed as the g CO_2 equivalent/100 g or g CO_2 equivalent/100 kcal.

An attributional LCA does not address indirect effects such as land-use change or other potential changes in the food systems. Current GHGE values were for food products as purchased in the store and did not include transportation by consumers from a retail center to the home, home preparation, home disposal, or waste. Estimates of consumer-specific GHGEs indicated that transport to home, storage at home, preparation, and disposal may represent 16% of total food-related emissions and 2.7% of all GHGEs (32).

Of 661 foods, several foods were available in different package sizes. Their GHGE values varied, but nutrient compositions were the same (e.g., cola beverages, smoked salmon, potato chips, ham, eggs, rice, and yogurt were all available in numerous package sizes). For these foods, median GHGEs were based on available package sizes. Sales data that would have permitted the differential weighting of package sizes were not available. Water and diet beverages (<5 kcal/100 g) were excluded from analyses as were nonreconstituted ingredients such as oils, ground coffee, syrups, flour, and pastry mixes. After median values were derived and exclusions were applied, 483 foods and beverages were available for analysis.

For those foods, GHGE values were merged with the publicly available Composition Nutritionnelle des Aliments (French food composition table) (CIQUAL) database (33) provided by the French Agency for Food, Environmental, Occupational and Health and Safety. Study staff manually matched foods from the Casino database with the nutrient-composition data from the CIQUAL. Individual foods in the Casino database were aggregated into 34 categories following a modified CIQUAL grouping scheme. The CIQUAL database, which has been used to calculate energy and nutrient intakes in dietary surveys in France, is intended to reflect the French food supply. The number of foods in the Casino database within each CIQUAL category ranged from 2 to 69 foods, and the median number of foods per category was 11 (IQR: 6–17). The largest categories were meats and products (n = 69), sweet biscuits (n = 33), yogurts (n = 28), cakes and pastries (n = 27), and pasta (n = 25). CIQUAL nutrient-composition data were used to derive the energy density and ND metrics for foods, food categories, and food groups.

ND profiles

Two alternative nutrient-profile models (22, 23) were used to assess the ND of foods. All ND calculations used reference values described in **Table 1**. Reference values were derived from the French Apports Nutritionnels Conseillés (French Reference Dietary Intakes) (ANC) (34). The average of the recommended

TABLE 1
Reference values for nutrients used to construct ND-6 and ND-15 nutrient-profiling models[1]

Nutrients	Reference values
Protein,[2] g	50
Potassium,[2] mg	2840
Dietary fiber, mg	25
Magnesium,[2] mg	390
Vitamin A, μg	700
Vitamin C, mg	110
Vitamin E, mg	12
Iron, mg	16
Calcium,[2] mg	900
Phosphorus,[2] mg	750
Vitamin D,[2] μg	5
Thiamin, mg	1.25
Riboflavin, mg	1.55
Niacin, mg	12.5
Folate, μg	315

[1] All nutrients were included in the ND-15 score. ND, nutrient density.
[2] Included in the ND-6 score.

amount for men and women was used when ANC values differed by sex. When ANC values were lacking, alternative standards were used, notably those from the United States Institute of Medicine (35). In general, the 2 sets of reference values were comparable.

Two alternative ND profiles were constructed. Most ND models assess the ratio of nutrients to calories (22). Each ND measure was the sum of percentage daily values for *n* nutrients, calculated per a 100-kcal reference amount. Higher ND scores represented higher nutrient densities. The ND-6 model was based on protein, vitamin D, calcium, phosphorus, potassium, and magnesium (23). The ND-15 model, which was based on the previously published Naturally Nutrient Rich score (36), was based on the sum percentage of daily values for protein, fiber, vitamins A, C, D, and E, thiamin, riboflavin, niacin, folate, calcium, iron, phosphorus, potassium, and magnesium. The calculations truncated the daily value for each nutrient at 100% to avoid extreme values for a single nutrient from influencing the total score.

Analytic approach

We analyzed the relation between GHGEs and energy density by 34 food categories sorted into 5 major food groups as follows: meat and meat products, milk and dairy products, frozen and processed fruit and vegetables, grains, and sweets. These analyses accounted for the number of individual foods within each category so that categories with more foods had greater weight. To ensure that results were not affected by aggregating food groups, correlation analyses were repeated at the individual food level.

For each ND measure, quantitative analyses were also conducted at the individual food level. Quintiles for each ND score were estimated. In linear regression models with the log-transformed GHGE per 100 kcal as the outcome, the geometric mean GHGE per 100 kcal was estimated at each quintile of ND. This approach was conducted for all foods ($n = 483$) and for the 5 major food groups. Trends were evaluated with a trend test whereby the midpoint of each quintile was entered into a linear regression model as a continuous variable. All analyses were conducted with Stata 12.0 software (StataCorp LP). $P < 0.05$ was considered significant.

RESULTS

GHGE components by major food group

Figure 1A provides the breakdown of GHGE values per 100-g edible portion for the 5 major food groups by agricultural production, processing, transportation, packaging, and in-store components. Consistent with past reports (8), meat and meat products, followed by dairy, were associated with highest GHGEs per 100 g product. By contrast, grains, sweets, and frozen and processed fruit and vegetables were associated with lower GHGEs.

Figure 1B shows corresponding GHGE values expressed per 100 kcal. Overall, 58% of emissions were from agriculture, and an estimated 15% of emissions were from transportation and in-store storage. Although meat products were associated with highest GHGEs from agriculture, frozen and processed fruit and vegetables had higher associated GHGEs for transport and storage. GHGEs were calculated per 100 kcal food product. Corresponding GHGE values calculated per 100 g and 100 kcal expressed as medians and interquartile intervals are provided in **Supplemental Table 1**.

Figure 2 shows that the estimated carbon cost of different foods can vary depending on whether GHGE values are expressed per kg or kcal food. Shown in Figure 2A are geometric means of GHGE values for the 34 CIQUAL food categories/100 g. The sizes of circles denote numbers of foods within each of the 34 food categories. On a per-weight basis (100 g), processed meats, meat dishes, cheeses, and processed fish were associated with higher GHGE values. Lowest GHGEs per 100 g were obtained for sugar, sweet rolls, flatbreads, milk, and grain snacks and chips.

In general, more–energy-dense food categories were associated with higher geometric mean GHGEs per 100 g. The strength of the association differed substantially across meat, dairy, processed and frozen fruit and vegetables, and other products. Although the weighted group-level correlation coefficient between the geometric mean energy density and GHGE per 100 g was only 0.10 overall, it was much stronger within specific food groups. Values were $r = 0.92$ for dairy, $r = 0.77$ for meat, $r = 0.32$ for processed and frozen fruit and vegetables, and $r = 0.77$ for sweets ($P < 0.01$). The coefficient for grains was negative ($r = -0.31$) indicating that grains supplied energy at a much lower carbon cost than did other food groups.

The expression of GHGEs per 100 kcal altered the nature of this relation. Figure 2B shows that food groups of lower energy density, such as processed and frozen vegetables, were associated with higher GHGEs per 100 kcal. Lowest GHGEs per 100 kcal were obtained for sugar, sweet rolls, grain snacks and chips, biscuits, and chocolate.

This negative relation was also observed within food groups as follows: dairy ($r = -0.35$, $P = 0.003$), meat ($r = -0.33$, $P < 0.001$), grains and other foods ($r = -0.78$, $P < 0.001$), processed and frozen fruit and vegetables ($r = -0.72$, $P < 0.001$), and sweets ($r = -0.87$, $P < 0.001$). Individual-level correlation coefficients were similar, and all had P values < 0.001.

These analyses suggested that sweets, chocolate, sweet rolls, snacks and chips, and candy and cakes had the lowest carbon costs per calorie and per gram. The higher carbon cost per 100 g processed meats and dairy was reduced after conversion to calories. In contrast, lower GHGEs for low–energy-density foods calculated per 100 g were increased after conversion to 100 kcal.

GHGE values and ND of foods

The ND-6 nutrient-profile model was based on the sum percentage of daily values for 6 index nutrients per reference amount (100 kcal). **Figure 3**A shows the association between the geometric mean of ND 6 and geometric mean of GHGEs both expressed per 100 kcal. Data are shown for 34 food categories. Consistent with past results on nutrient profiling (22), processed vegetables, milk, yogurts, eggs, poultry and fish, and fortified breakfast cereals were the most–nutrient-dense food categories (37). With the exception of breakfast cereals and fresh fish, these foods tended to have higher GHGE values than did grains and sweets. There was a positive association between ND-6 scores and higher GHGEs.
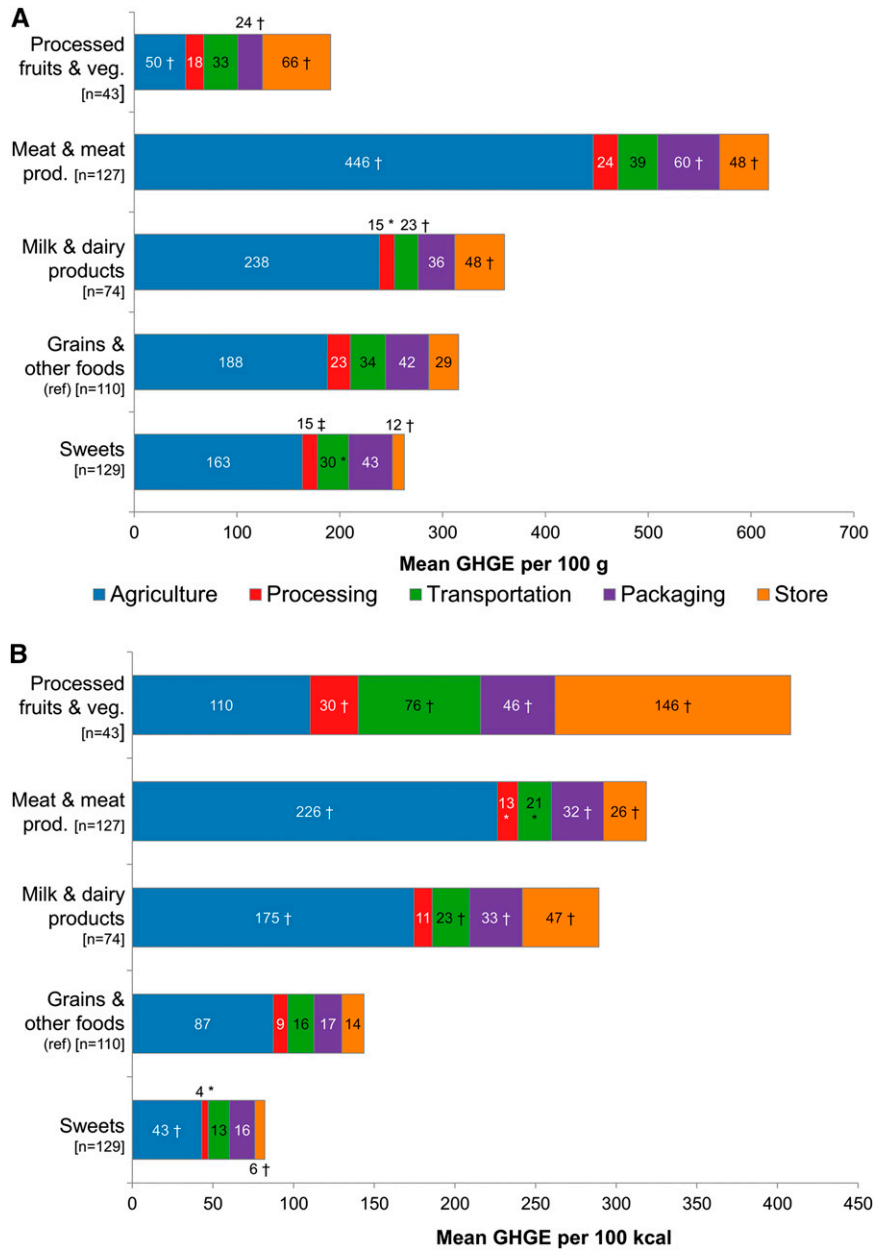
FIGURE 1 Mean GHGEs for broad food groups by GHGE origin. GHGE values are expressed per 100 g (A) and 100 kcal (B). The reference group for comparisons was the grains and other foods category. This broad food category was used as the reference group because it had a large sample size and intermediate GHGE compared with the other broad food groups on both the per 100-g and per 100-kcal scales. $^{†}P < 0.001$, $^{‡}0.001 < P < 0.01$, $^{*}0.01 < P < 0.05$. GHGE, greenhouse gas emission; prod., products; veg., vegetables.

Figure 3B shows the association between the geometric mean of ND 15 and geometric mean of GHGEs both expressed per 100 kcal. Processed fruit and vegetables, eggs, fish, and breakfast cereals and bars were the food categories with the highest ND-15 scores followed by for yogurts and white cheese. Again, there was a positive association between ND-15 scores and higher GHGEs.

DISCUSSION

By building on previous research on the carbon footprint of foods in France (8, 15), the current study merged nutrient-composition data for a large number of supermarket foods with their GHGE value, as calculated by a major supermarket chain.

To our knowledge, this is the first analysis of GHGEs associated with 483 unique foods and beverages in 34 product categories as sold in France. Analyses showed that grains and sweets, including sweetened beverages, were associated with lower GHGEs, whereas meat and dairy products were associated with higher GHGEs when calculated per 100 g of product. Grains and sweets continued to be associated with lower GHGEs when GHGEs were expressed per 100 kcal.

Although frozen and processed fruit and vegetables were associated with very-low GHGEs when calculated per 100 g, their low energy densities raised the carbon footprint when GHGEs were expressed per 100 kcal. These data support previous results (8) that were based on 73 foods; in both cases, the choice
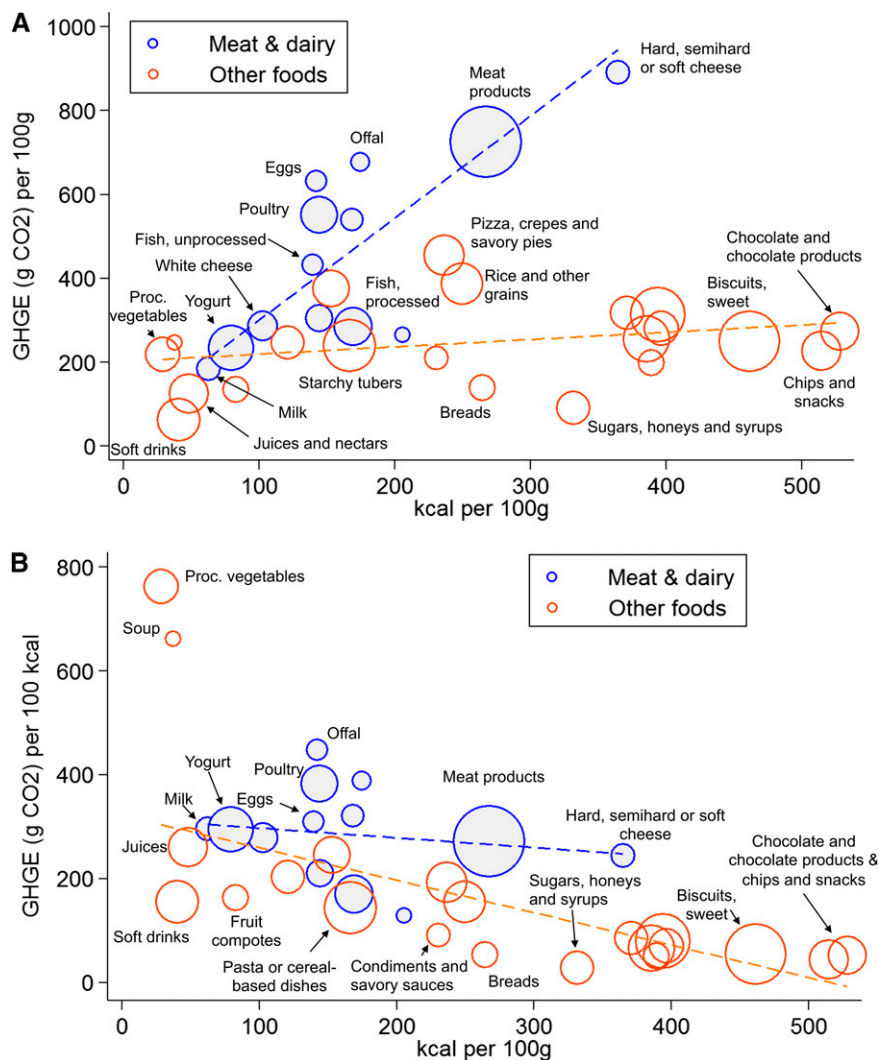
FIGURE 2 Association between geometric mean energy density for 34 food categories and GHGE values per 100 g (A) and 100 kcal (B). Sizes of circles indicate numbers of individual foods within each food category. GHGE, greenhouse gas emission; Proc., processed.

of the functional unit (100 g or 100 kcal) dramatically influenced the results. It is important to note that the sustainability of alternative diets, matched for energy and nutrient adequacy, can only be made on the basis of calories and nutrient contents and not per gram of weight (19).

The carbon footprint, estimated through GHGEs, has become an important criterion for assessing the environmental sustainability of alternative diets. In the current analyses, sweets, syrups, and soft drinks were associated with lowest GHGEs whether expressed per calories or per grams. However, even though sugar and sweets may have a low environmental impact, they cannot be viewed as the most-sustainable foods because the FAO definition of sustainable diets makes a direct reference to population well-being and health (2). The current results were consistent with earlier observations that some nutrient-dense foods did not have the lowest carbon footprint and vice versa (13, 14). In this study also, more nutrient-dense foods, including meats and poultry, milk and dairy products, and frozen and processed fruit and vegetables were associated with higher GHGEs expressed per 100 kcal.

The question whether the healthiest diets were also the most environmentally sustainable has been raised previously (8, 14, 15).

Consistent with other data from the United Kingdom and France (13, 15), the current analyses showed that some of the lowest GHGEs were associated with foods of low nutritional value, including sweets. In past analyses, sugar appeared to have a lower carbon footprint than that of many other foods (13, 32), and the lowest GHGE food patterns had one-third more added sugars than did healthier alternatives. The modeled high-sugar diets were also the cheapest (13, 32).

Contrary to some assumptions, the most–nutrient-dense foods did not have the lowest carbon footprint (13, 14). Some tradeoffs in balancing nutrition with the environmental impact and cost of diets may need to be made (17, 38). The identification of foods and diets that provide optimal amounts of nutrients at low monetary and carbon costs is one research priority (19, 20). Future analyses will examine the relative carbon cost of providing a 15% daily value of selected nutrients by major food groups. The higher GHGE cost of some meat and dairy products may be compensated for, to some extent, by their higher nutritional value.

The study had a number of strengths. GHGE values for 483 foods and beverages were linked to nutrient-composition data and
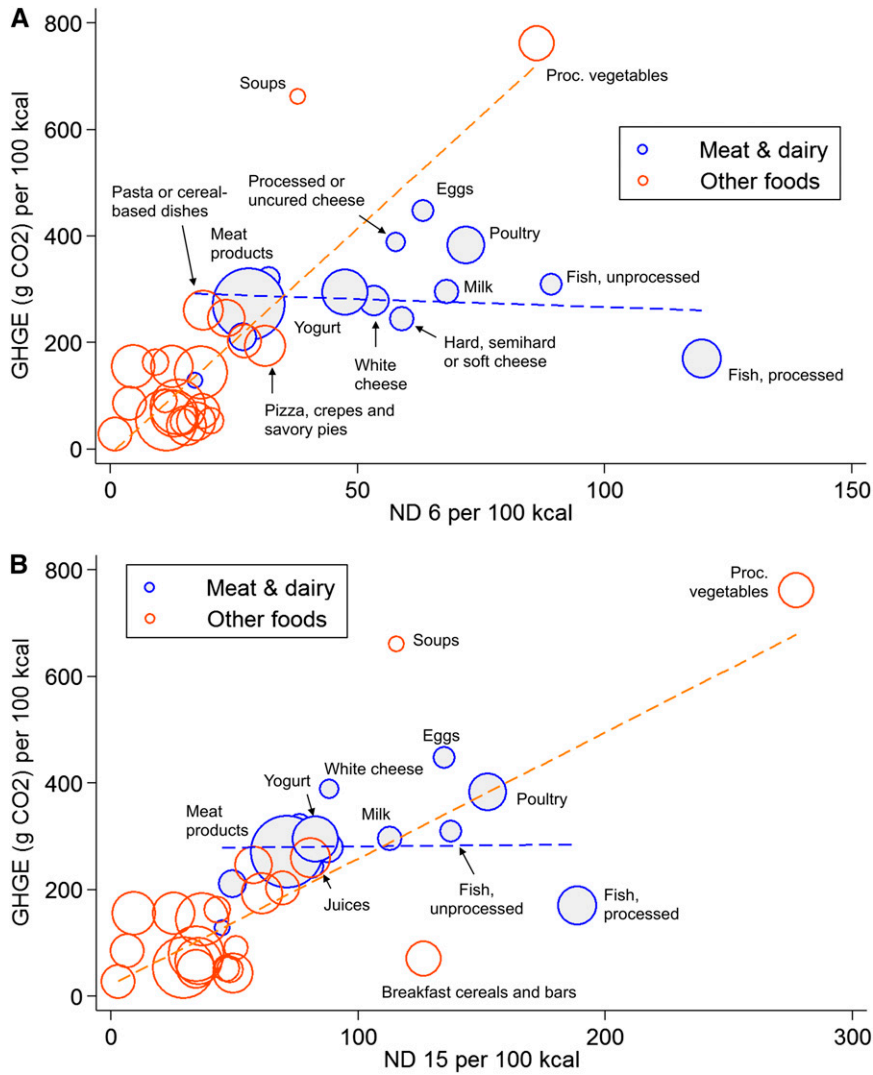
FIGURE 3 Association between ND-6 score (A) and ND-15 score (B) and geometric mean GHGE per 100 kcal for 34 food categories. Sizes of circles indicate numbers of individual foods within each group. GHGE, greenhouse gas emission; ND, nutrient density; Proc., processed.

aggregated into 34 food categories and 5 major food groups. To our knowledge, this is the largest number of foods available in the literature to date (15). Published studies used from 7 to 391 foods to evaluate the carbon cost of individual foods and total diets (8, 10, 13–15).

This study also had a number of important limitations. First, the foods available in the Casino and CIQUAL databases were not necessarily representative of eating habits or food patterns in France. This database included a high number of processed meats, but it lacked fresh produce. Fruit and vegetable products, including juices, were processed or frozen. However, the conclusions of this report would be influenced only if the foods excluded systematically differed in their relation between ND and GHGE values.

Second, the current measures of ND measures were subsets of previously published nutrient-profiling models, focusing on nutrient adequacy and on foods' contents of protein, fiber, vitamins, and minerals. More-extensive nutrient profiling needs to be conducted to assess the relation between composite ND scores and GHGEs associated with beverages and foods. The data used in the current study did not account for protein quality

or bioavailability measures for calcium and iron. Third, the current GHGE calculations expressed in g CO_2 equivalents accounted for food production, transportation to the market, and in-store storage but did not account for transport to the home, storage, cooking, and waste, which would have result in a modest underestimate of the GHGEs for foods that required refrigeration or cooking. Finally, analyses of the association between ND and GHGE values for individual foods may not reflect the carbon footprint of different-type diets.

Efforts to decrease global GHGEs while maintaining nutritionally adequate, affordable, and acceptable diets need to be guided by considerations of the ND and environmental impact of different foods and food groups. In a series of recent studies, the principal sustainability measure was carbon cost expressed in terms of GHGEs (8, 14, 15). Testing the relation between nutrient profile of foods and their carbon footprint can help identify those food groups that provide both calories and optimal nutrition at a low carbon cost. Of course, the carbon cost is only one of many metrics that can be used to assess the environmental impact of food production (20). Other metrics, in varying stages of development, include the use of water resources by agrofood

industries (39, 40) and the global impact of land-use change (41). As these new metrics are integrated with GHGE emissions, our views on the relation between the ND of foods and their environmental impact will most likely evolve.

However, the carbon cost is by no means the only measure of sustainable agriculture. Because of concerns regarding the impact of agricultural production on global climate change, it is important to develop additional metrics (42) to assess crop biodiversity and the use of water resources and land-use change (34).

In conclusion, analyses of ND and GHGEs for a large number of foods and beverages revealed that many foods with low GHGEs also had relatively low nutritional values. In particular, some of the lowest GHGE values were observed not for processed fruit and vegetables but for sugar and sweets. By contrast, higher GHGEs associated with meat and dairy products were linked to their higher ND. More studies are needed to determine the relation between the nutrient adequacy of individual foods and total diets in relation to multiple sustainability measures including carbon costs. One question is whether the higher GHGE cost of some foods can be offset by their higher nutritional value.

REFERENCES

1. Friel S, Dangour AD, Garnett T, Lock K, Chalabi Z, Roberts I, Butler A, Butler CD, Waage J, McMichael AJ, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. Lancet 2009;374:2016–25.
2. FAO. Definition of sustainable diets. International scientific symposium: biodiversity and sustainable diets united against hunger. Rome (Italy): Food and Agriculture Organization of the United Nations; 2010.
3. Leaver JD. Global food supply: a challenge for sustainable agriculture. Nutrition Bulletin 2011;36:416–21.
4. Kling M, Hough I. The American carbon footprint: understanding your food's impact on climate change. Brighter Planet Inc; 2010 [cited June 2014]. Available from: http://climateactionbrookline.org/pdfs/Brighter_Planet_carbon_foodprint_wp.pdf.
5. Corson MS, van der Werf HMG, editors. Proceedings of the 8th international conference on life cycle assessment in the agri-food sector (LCA Food 2012). Saint Malo (France): INRA, Rennes, France; 2012.
6. Macdiarmid J, Kyle J, Horgan G, Loe J, Fyfe C, Johnstone A, McNeill G. Livewell: a balance of healthy and sustainable food choices. Godalming (United Kingdom): WWF-UK and the Rowett Institute, 2011.
7. Kim B, Neff R. Measurement and communication of greenhouse gas emissions from US food consumption via carbon calculators. Ecol Econ 2009;69:186–96.
8. Vieux F, Darmon N, Touazi D, Soler LG. Greenhouse gas emissions of self-selected individual diets in France: changing the diet structure or consuming less? Ecol Econ 2012;75:91–101.
9. Reijnders L, Soret S. Quantification of the environmental impact of different dietary protein choices. Am J Clin Nutr 2003;78:664S–8S.
10. Carlsson-Kanyama A, Gonzalez AD. Potential contributions of food consumption patterns to climate change. Am J Clin Nutr 2009;89:1704S–9S.
11. de Boer J, Helms M, Aiking H. Protein consumption and sustainability: Diet diversity in EU-15. Ecol Econ 2006;59:267–74.
12. Duchin F. Sustainable consumption of food: A framework for analyzing scenarios about changes in diets. J Ind Ecol 2005;9:99–114.
13. Macdiarmid JI. Is a healthy diet an environmentally sustainable diet? Proc Nutr Soc 2013;72:13–20.
14. Macdiarmid JI, Kyle J, Horgan GW, Loe J, Fyfe C, Johnstone A, McNeill G. Sustainable diets for the future: Can we contribute to reducing greenhouse gas emissions by eating a healthy diet? Am J Clin Nutr 2012;96:632–9.
15. Vieux F, Soler LG, Touazi D, Darmon N. High nutritional quality is not associated with low greenhouse gas emissions in self-selected diets of French adults. Am J Clin Nutr 2013;97:569–83.
16. Audsley E, Brander M, Chatterton J, Murphy-Bokern E, Webster C, Williams A. How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope for reducing them by 2050. 2010 [cited 30 Aug 2014]. Available from: http://assets.wwf.org.uk/downloads/how_low_can_we_go.pdf.
17. Edjabou LD, Smed S. The effect of using consumption taxes on foods to promote climate friendly diets – the case of Denmark. Food Policy 2013;39:84–96.
18. Mitchell M. Increasing fish consumption for better health - are we being advised to eat more of an inherently unsustainable protein? Nutrition Bulletin 2011;36:438–42.
19. Masset G, Vieux F, Verger EO, Soler LG, Touazi D, Darmon N. Reducing energy intake and energy density for a sustainable diet: a study based on self-selected diets in French adults. Am J Clin Nutr 2014;99:1460–9.
20. Saxe H. The New Nordic Diet is an effective tool in environmental protection: it reduces the associated socioeconomic cost of diets. Am J Clin Nutr 2014;99:1117–25.
21. Riley H, Buttriss JL. A UK public health perspective: what is a healthy sustainable diet? Nutrition Bulletin 2011;36:426–31.
22. Drewnowski A, Fulgoni V 3rd. Nutrient profiling of foods: creating a nutrient-rich food index. Nutr Rev 2008;66:23–39.
23. Drewnowski A, Maillot M, Darmon N. Testing nutrient profile models in relation to energy density and energy cost. Eur J Clin Nutr 2009;63:674–83.
24. Drewnowski A. The cost of US foods as related to their nutritive value. Am J Clin Nutr 2010;92:1181–8.
25. Smedman A, Lindmark-Mansson H, Drewnowski A, Edman AK. Nutrient density of beverages in relation to climate impact. Food Nutr Res 2010:54.
26. International Organization for Standardization (ISO). 14040:2006 environmental management - life cycle assessment - principles and framework. Geneva (Switzerland): International Organisation for Standardization; 2006.
27. International Organization for Standardization (ISO). 14044:2006 environmental management - life cycle assessment - Requirements and guidelines. Geneva (Switzerland): International Organisation for Standardization; 2006.
28. AFNOR. BP X30-323—principes généraux pour l'affichage environnemental des produits de grande consommation. [General principles for environmental labeling of consumer products.] La Plaine Saint-Denis (France): AFNOR; 2011 (In French).
29. INSEE National Institute of Statistics and Economic Studies. Statistical operations:sSurvey on industrial energy consumption/EACEI [cited 30 Aug 2014]. Available from: http://www.insee.fr/en/methodes/default.asp?page=sources/ope-enq-conso-energie-industrie-eacei.htm.
30. Frischknecht R, Jungbluth N, editors. Ecoinvent data v2.0. Overview and methodology. 2007 [cited 30 Aug 2014]. Available from: http://www.ecoinvent.org/fileadmin/documents/en/01_OverviewAndMethodology.pdf.
31. Reijnders L. Life cycle assessment of greenhouse gas emissions. In: Chen W-Y, Seiner J, Suzuki T, Lackner M, editors. Handbook of climate change mitigation. New York: Springer; 2012. p. 13–41.

32. Garnett T. Cooking up a storm: food, greenhouse gas emissions and our changing climate. Surrey (United Kingdom): Food Climate Research Network. University of Surrey, Centre for Environmental Strategy; 2008.

33. ANSES. Table de Composition Nutritionnelle des Aliments Ciqual 2012/French Food Composition Table-CIQUAL 2012. French Agency for Food, Environmental and Occupational Health & Safety [cited 20 Aug 2014]. Available from: http://www.ansespro.fr/tableciqual.

34. Martin A. The "apports nutritionnels conseilles (ANC)" for the French population. Reprod Nutr Dev 2001;41:119–28.

35. Institute of Medicine. Dietary Reference Intakes tables and applications. Updated 30 Nov 2010 [cited 2 Sep 2014]. Available from: http://www.iom.edu/Activities/Nutrition/SummaryDRIs/DRI-Tables.aspx .

36. Drewnowski A. Concept of a nutritious food: toward a nutrient density score. Am J Clin Nutr 2005;82:721–32.

37. Maillot M, Darmon N, Darmon M, Lafay L, Drewnowski A. Nutrient-dense food groups have high energy costs: an econometric approach to nutrient profiling. J Nutr 2007;137:1815–20.

38. Schulz M, Kroke A, Liese AD, Hoffmann K, Bergmann MM, Boeing H. Food groups as predictors for short-term weight changes in men and women of the EPIC-Potsdam cohort. J Nutr 2002;132:1335–40.

39. Ruini L, Marino M, Pignatelli S, Laio F, Ridolfi L. Water footprint of a large-sized food company: The case of Barilla pasta production. Water Resources and Industry 2013;1-2:7–24.

40. Gerbers-Leenes PW, Mekonnen MM, Hoekstra AY. The water footprint of poultry, pork, and beed: A comparative study in different countries and production systems. Water Resources and Industry 2013;1-2: 25–36.

41. Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, Tokgoz S, Hayes D, Yu TH. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 2008;319:1238–40.

42. FAO. Sustainable diets and biodiversity: directions and solutions for policy, research and action. Rome (Italy): Food and Agriculture Organization of the United Nations, 2010.