Carbon footprint of the Brazilian diet

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ABSTRACT

OBJECTIVE: To estimate the carbon footprint of the Brazilian diet and of sociodemographic strata of this population.

METHODS: Carbon footprint of the diet was estimated based on data from two 24-hour diet records, obtained in 2008 and 2009, from a probabilistic sample of the Brazilian population aged 10 years and over (n = 34,003) and on environmental impact coefficients of food and culinary preparations consumed in Brazil (gCO2e/kg). Means with 95% confidence intervals of food consumption (kcal/person/day) and the carbon footprint of the diet (gCO2e/person/day and in gCO2e/2,000kcal) were calculated for the population as a whole and for strata according to sex, age, income, education, macro-regions and Federative Unit. Linear regression models were used to identify significant differences (p < 0.05) in the dietary carbon footprint of different sociodemographic strata.

RESULTS: The average carbon footprint of the Brazilian diet was 4,489gCO2e/person/day. It was higher for males, for the age group from 20 to 49 years and for the North and Midwest regions, and tended to increase with income and education. The pattern of association of footprint with sociodemographic variables did not change substantially with adjustment for differences in the amount of food consumed, except for a reduction in the relative excess of the footprint among males and an increase in the relative excess of the footprint in the Midwest region.

CONCLUSION: The carbon footprint of the Brazilian diet exceeds by about 30% the footprint of the human diet, which could simultaneously meet the nutritional requirements of a healthy diet and the global goal of containing the increase in the planet’s average temperature. The pattern of association of this footprint with sociodemographic variables can help identify priority targets for public actions aimed at reducing the environmental impacts of food consumption in Brazil.

DESCRIPTORS: Carbon Footprint. Basic Diet. Socioeconomic factors. Brazil.
INTRODUCTION

The transition to a sustainable food system is a collective urgency, given the seriousness of global environmental changes and the impacts of food on ecological balance. Brazil has assumed multilateral commitments such as eliminating hunger and combating climate change, which requires the nutritional and environmental sciences to join forces to understand the multiple impacts of food and to build guidelines on adequate, healthy and sustainable diets under Brazilian conditions, clarifying the population and governments on how to protect nature.

Studies on the impacts or environmental footprints of food require the availability of representative data on the population’s food consumption and indicators that quantify the footprints of individual foods that make up the diet. These indicators, calculated using the product life cycle assessment methodology, account for the use of natural resources and the load of pollutants released into the environment per kilogram of food, such as the coefficient of the food’s carbon footprint, which quantifies the amount of atmospheric emissions of greenhouse gases. Based on studies of the environmental impact of food, dietary patterns such as the “Mediterranean diet” and the “vegetarian diet” are considered models for mitigating the negative effects of food on the environment.

Environmental impact assessments of diets that cover the general population, as well as specific sociodemographic strata, are relevant because they identify both the critical points to change in diet practices as the population groups public policies should focus on for substantial reductions in environmental impacts.

In this article, based on data collected in a national survey on food consumption in Brazil, we estimate the carbon footprint of the diet consumed by the Brazilian population and the diet of sociodemographic strata of this population.

METHODS

Source of Food Consumption Data

The data on food consumption analyzed in this study come from the personal food consumption assessment module of the Family Budget Survey (POF) carried out by the Brazilian Institute of Geography and Statistics (IBGE) between May 2008 and May 2009 (POF 2008–2009).

The 2008–2009 POF used a complex sampling plan, by clusters, with geographic and socioeconomic stratification of all census sectors in the country, followed by random drawings of sectors in a first stage and households in a second. The number of sectors drawn in each stratum was proportional to the number of households in it. The selection of households in each sector was carried out by simple random sampling without replacement. The sample covered 55,970 households and the module for assessment of personal food consumption was applied to a random sub-sample of 13,569 households (24.3% of the total number of households studied).

The interviews conducted by POF 2008–2009 in each stratum of the sample were evenly distributed over the 12 months of the survey. Residents aged ten years or over from all households drawn for assessment of personal food consumption (n = 34,003) completed two 24-hour food records, on non-consecutive days. In these records, people reported all the foods consumed, the type of preparation and the quantities consumed expressed in the form of household measures. Individual data on date of birth, gender, education, family income and number of people in the household were collected through questionnaires. The list of sociodemographic data includes the location of the household by Federative Unit (UF) and macro-region of Brazil.
In POF 2008–2009, the amounts of food reported in the form of household measures were converted to grams based on the Table of Referenced Measures for Foods Consumed in Brazil and then converted to energy based on the Table of Nutritional Composition of Foods Consumed in Brazil. For the purpose of this study, culinary preparations were broken down into food and culinary ingredients according to standardized recipes.

**Food Carbon Footprint Coefficients**

To estimate the carbon footprint of food consumption reported by the people studied in the POF 2008–2009, coefficients were used that quantify the atmospheric emissions of greenhouse gases, expressed in grams of carbon dioxide equivalent per amount of food consumed (gCO2e/kg).

Carbon footprint coefficients used in this study are those described in the publication “Footprints of food and culinary preparations consumed in Brazil.” This publication presents, for each food item reported by the people studied by the POF 2008–2009, average environmental impact coefficients calculated based on estimates by studies published in scientific articles or used in environmental product performance reports, and adopts food coefficients similar in the case of foods that did not have available estimates. In the case of culinary preparations, the coefficients consider all the ingredients included in the preparation. Coefficients also consider conversion factors and cooking indices that take into account, respectively, the removal of inedible parts and the incorporation or loss of water due to the cooking effect.

**Data Analysis**

The carbon footprint of the daily food consumption of each person studied by the POF 2008–2009 was calculated by adding the products of the amount consumed of each item by its respective carbon footprint coefficient, using the data reported in the two days of the 24-hour food record. Means with 95% confidence intervals of the carbon footprint of daily food consumption (gCO2e/kg/person/day) were calculated for the entire Brazilian population and for sociodemographic strata of this population. These strata were formed based on the location of the household (macro-region and FU) and on the following individual characteristics: gender (male/female), age (10 to 19 years old, 20 to 29, 30 to 39, 40 to 49, 50 to 59, and ≥ 60 years old), fifth of per capita family income and years of schooling (≤ 4, 5 to 8, 9 to 12, > 12).

To consider differences between sociodemographic strata regarding the amount of energy consumed, the total daily caloric consumption of each person and the carbon footprint of their diet were calculated at 2,000kcal (gCO2e/2,000kcal), and the same analysis made with respect to the carbon footprint was repeated below, without adjustment for the total calories.

Linear regression models were used to test differences between sociodemographic strata of the population in daily caloric intake and in the environmental footprint of the diet. Linear trend tests were used for ordinal categorical variables. For non-ordinal categorical variables or variables without significant linear trend, Bonferroni tests were applied.

All analyses were performed using the **survey** module of the Stata/SE software version 14.0, which considers the effects of complex sampling, allowing for the extrapolation of results to the Brazilian population. The identification of statistical significance was p-value ≤ 0.05.

**RESULTS**

Table 1 presents estimates of daily calorie intake for the Brazilian population aged 10 years and over and for sociodemographic strata of this population. An average caloric intake of...
1,900kcal/person/day was measured for the population as a whole. In addition, it was found that this average was higher among men than among women, tended to decrease with age and increase with income and education, and was higher in the North, intermediate in the Northeast, South and Southeast regions, and lower in the Midwest region.

Table 2 presents estimates of the Brazilian population’s dietary carbon footprint and sociodemographic strata of this population.

The average carbon footprint of the Brazilian diet, of 4,489gCO2e/person/day, was greater among men than among women; showed a curvilinear relationship with age, being maximum between 20 and 49 years; tended to increase with income and with schooling, and was higher in the North and Midwest regions than in other regions of the country. Adjusting for quantitative differences in food consumption, obtained by fixing consumption at 2,000kcal.

### Table 1. Daily food consumption according to sociodemographic variables. Brazilian population aged 10 and over, 2008 to 2009 (n = 34,003).

| Variables                     | Sample distribution (%) | Food consumption (Kcal/person/day) | CI95%     |
|-------------------------------|-------------------------|------------------------------------|-----------|
|                               |                         | Average                            | CI95%     |
| Sex                           |                         |                                    |           |
| Female                        | 52                      | 1,713 (1,696–1,731)                |           |
| Male                          | 48                      | 2,102 (2,062–2,143)*               |           |
| Age (years)                   |                         |                                    |           |
| 10 to 19                      | 22                      | 2,010 (1,974–2,046)                |           |
| 20 to 29                      | 21                      | 2,006 (1,973–2,039)                |           |
| 30 to 39                      | 18                      | 1,933 (1,899–1,967)                |           |
| 40 to 49                      | 16                      | 1,852 (1,813–1,890)                |           |
| 50 to 59                      | 12                      | 1,778 (1,723–1,832)                |           |
| ≥ 60                          | 13                      | 1,683 (1,570–1,796)*               |           |
| Family income per capita (R$) |                         |                                    |           |
| < 225.28                      | 20                      | 1,785 (1,747–1,823)                |           |
| 225.28–399.75                 | 20                      | 1,922 (1,875–1,970)                |           |
| 399.76–637.23                 | 20                      | 1,870 (1,830–1,911)                |           |
| 637.24–1,151.49               | 20                      | 1,936 (1,896–1,976)                |           |
| ≥ 1,151.50                    | 20                      | 1,988 (1,904–2,071)*               |           |
| Education (years of study)    |                         |                                    |           |
| ≤ 4 years                     | 33                      | 1,775 (1,746–1,804)                |           |
| 5 to 8 years                  | 27                      | 1,925 (1,895–1,957)                |           |
| 9 to 12 years                 | 30                      | 1,985 (1,956–2,015)                |           |
| > 12 years                    | 11                      | 1,990 (1,848–2,130)*               |           |
| Macro-region                  |                         |                                    |           |
| North                         | 8                       | 2,058 (2,006–2,110)*               |           |
| Northeast                     | 28                      | 1,944 (1,882–2,007)*              |           |
| Southeast                     | 43                      | 1,860 (1,826–1,894)*              |           |
| South                         | 15                      | 1,900 (1,851–1,949)*              |           |
| Midwest                       | 7                       | 1,806 (1,762–1,850)*               |           |
| **Total**                     | **100**                 | **1,900**                          | **(1,876–1,924)** |

CI95%: 95% Confidence Interval.

*p < 0.05 for dichotomous variables and p for linear trend < 0.05 in the case of ordinal variables.

*bc,de p < 0.05 in the Bonferroni test for two-by-two comparisons of macroregions and when macroregions do not share the same superscript letter.
per person, does not substantially change the relationship between sociodemographic variables and the dietary carbon footprint, except for a reduction in the relative excess footprint among men, which remains significant, and by the increase in the relative excess of the diet footprint in the Midwest region, which becomes the region with the largest carbon footprint, surpassing the North region.

The Figure depicts the spatial distribution of the carbon footprint of crude diets and diets adjusted for a fixed consumption of 2,000kcal per person, in the 27 Federative Units of Brazil. The smallest carbon footprints were found in Alagoas (3,522gCO\(_2\)e, gross footprint) and Rio Grande do Norte (4,056gCO\(_2\)e, footprint per 2,000kcal), while the largest were recorded in Tocantins (61,332gCO\(_2\)e, gross footprint; and 6,205gCO\(_2\)e, footprint per 2,000kcal), as shown in Table 4.

**Table 2.** Carbon footprint of food consumption according to sociodemographic variables. Brazilian population aged 10 and over, 2008 to 2009 (n = 34,003).

| Variables       | Carbon footprint (gCO\(_2\)e/person/day) | Average | CI95% | Carbon footprint (gCO\(_2\)e/2,000 kcal) | Average | CI95% |
|-----------------|----------------------------------------|---------|-------|----------------------------------------|---------|-------|
| **Sex**         |                                        |         |       |                                        |         |       |
| Female          | 3,934                                  | 3,859–4,009 | 4,641 | 4,567–4,716                            |         |       |
| Male            | 5,089                                  | 4,974–5,205\(^a\) | 4,899 | 4,812–4,986\(^a\)                       |         |       |
| **Age (years)** |                                        |         |       |                                        |         |       |
| 10 to 19        | 4,369                                  | 4,212–4,532 | 4,355 | 4,233–4,477                            |         |       |
| 20 to 29        | 4,787                                  | 4,651–4,923 | 4,802 | 4,687–4,917                            |         |       |
| 30 to 39        | 4,754                                  | 4,599–4,892 | 4,941 | 4,805–5,077                            |         |       |
| 40 to 49        | 4,627                                  | 4,441–4,813 | 4,981 | 4,842–5,120                            |         |       |
| 50 to 59        | 4,269                                  | 4,116–4,421 | 4,871 | 4,719–5,023                            |         |       |
| 60+             | 3,915                                  | 3,751–4,078 | 4,785 | 4,630–4,941                            |         |       |
| **Family income per capita (R$)** | |         |       |                                        |         |       |
| < 225.28        | 3,901                                  | 3,755–4,048 | 4,338 | 4,204–4,472                            |         |       |
| 225.28–399.75   | 4,431                                  | 4,228–4,634 | 4,650 | 4,493–4,807                            |         |       |
| 399.76–637.23   | 4,432                                  | 4,240–4,624 | 4,771 | 4,616–4,927                            |         |       |
| 637.24–1,151.49| 4,746                                  | 4,547–4,945 | 4,931 | 4,760–5,103                            |         |       |
| ≥ 1,151.50      | 4,933                                  | 4,767–5,100\(^a\) | 5,133 | 4,986–5,280\(^a\)                       |         |       |
| **Education (years of study)** | |         |       |                                        |         |       |
| ≤ 4 years       | 4,144                                  | 4,024–4,264 | 4,656 | 4,551–4,761                            |         |       |
| 5 to 8 years    | 4,439                                  | 4,308–4,569 | 4,652 | 4,542–4,763                            |         |       |
| 9 to 12 years   | 4,775                                  | 4,657–4,893 | 4,850 | 4,745–4,954                            |         |       |
| > 12 years      | 4,890                                  | 4,691–5,089\(^a\) | 5,145 | 4,962–5,328\(^a\)                       |         |       |
| **Macro-region**|                                        |         |       |                                        |         |       |
| North           | 5,245                                  | 5,051–5,439\(^e\) | 5,173 | 5,023–5,324                            |         |       |
| Northeast       | 4,435                                  | 4,297–4,573\(^b\) | 4,646 | 4,537–4,755\(^b\)                       |         |       |
| Southeast       | 4,281                                  | 4,130–4,431\(^h\) | 4,623 | 4,489–4,758\(^b\)                       |         |       |
| South           | 4,510                                  | 4,312–4,707\(^b\) | 4,738 | 4,597–4,880\(^b\)                       |         |       |
| Midwest         | 5,052                                  | 4,864–5,240\(^b\) | 5,641 | 5,471–5,812                            |         |       |
| **Total**       | 4,489                                  | 4,407–4,572 | 4,765 | 4,695–4,836                            |         |       |

gCO\(_2\)e, grams of carbon dioxide equivalent. CI95%: 95% Confidence Interval.

\(^a\) p < 0.05 for dichotomous variables and p for linear trend < 0.05 in the case of ordinal variables.

\(^b,c,d,e\) p < 0.05 in the Bonferroni test for two-by-two comparisons of macroregions and when macroregions do not share the same superscript letter.
Table 3. Carbon footprint of food consumption according to Federative Units. Brazilian population aged 10 and over, 2008 to 2009 (n = 34,003).

| Federative Unit   | Carbon footprint |               |               |
|-------------------|------------------|---------------|---------------|
|                   | (gCO₂e/person/day) | CI95%         |               |
|                   | Average          |               |               |
| Acre              | 5,673            | 4,887–6,458   |               |
| Amapá             | 5,219            | 3,881–6,557   |               |
| Amazonas          | 4,390            | 4,100–4,680   |               |
| Pará              | 5,556            | 5,240–5,872   |               |
| Rondônia          | 4,733            | 4,385–5,080   |               |
| Roraima           | 5,319            | 4,472–6,166   |               |
| Tocantins         | 6,133            | 5,338–6,929   |               |
| Alagoas           | 3,522            | 3,212–3,833   |               |
| Bahia             | 4,781            | 4,386–5,177   |               |
| Ceará             | 3,812            | 3,538–4,087   |               |
| Maranhão          | 4,506            | 4,260–4,751   |               |
| Paraíba           | 4,025            | 3,633–4,416   |               |
| Pernambuco        | 4,655            | 4,373–4,936   |               |
| Piauí             | 4,967            | 4,655–5,278   |               |
| Rio Grande do Norte | 4,049          | 3,786–4,313   |               |
| Sergipe           | 5,331            | 4,872–5,790   |               |
| Paraná            | 4,763            | 4,412–5,115   |               |
| Rio Grande Do Sul | 4,319            | 4,043–4,595   |               |
| Santa Catarina    | 4,442            | 4,024–4,861   |               |
| Espírito Santo    | 4,243            | 3,883–4,603   |               |
| Minas Gerais      | 4,007            | 3,822–4,192   |               |
| Rio de Janeiro    | 4,171            | 3,903–4,439   |               |
| São Paulo         | 4,456            | 4,201–4,711   |               |
| Distrito Federal  | 4,303            | 3,786–4,820   |               |
| Goiás             | 4,912            | 4,638–5,186   |               |
| Mato Grosso       | 5,482            | 5,051–5,914   |               |
| Mato Grosso do Sul | 5,598           | 5,300–5,896   |               |

95%CI: 95% confidence interval.
DISCUSSION

Based on data from two 24-hour dietary records obtained in 2008 and 2009 from a probabilistic sample of the Brazilian population aged 10 years and over (n = 34,003), the average carbon footprint of the Brazilian diet was estimated at 4,489gCO2e/person/day. This footprint was greater in the diet of men, people between 20 and 49 years of age, residents of the North and Midwest regions, and people with a higher level of income or education. Adjusting for differences in the amount of food consumed did not substantially change the relationship of the diet footprint with sociodemographic variables, except for a reduction in the relative excess of the footprint among men and an increase in the relative excess of the footprint in the Midwest region, which would then be the diet with the largest carbon footprint in the country.

When compared to other countries, the carbon footprint of the diet per person/day estimated for Brazil (4,489gCO2e) can be considered of intermediate intensity, as it is much higher than that estimated in Peru\(^1\) (2,036gCO2e), slightly higher than that of France\(^2\) (4,090gCO2e), slightly lower than that of the United States\(^3\) (4,700gCO2e) and much lower than that of Argentina\(^4\) (5,480gCO2e). The carbon footprint of the Brazilian diet exceeds by 30% the value of 3,288gCO2e/person/day, which corresponds to the estimated footprint of a diet that simultaneously fulfills all the nutritional requirements of a healthy diet\(^5\) and corroborates with the containment of average temperature of the planet\(^6\).

The relative excess of the dietary carbon footprint of male representatives observed in our study has also been described in several countries, such as the Netherlands\(^7\), Ireland\(^8\) and China\(^9\). In the Swedish population, similarly to what we found in Brazil, diets with larger carbon footprints were observed among young and intermediate-age adults\(^10\). The literature does not show a clear pattern of the relationship between the diet’s carbon footprint and people's income or education level. For example, in the United States\(^3\) no differences were observed in the carbon footprint of diets according to socioeconomic variations. In Ireland\(^8\), the largest carbon footprint was found in the diet of people with intermediate education, while in Sweden\(^10\), as in Brazil, people with university education had the diets with the largest carbon footprint.

It is worth mentioning that, in Brazil, the higher the level of education, the greater the concern with climate risks\(^11\). However, this concern was apparently not reflected in the diet’s carbon footprint. Relatively low environmental impacts observed in the diets of developing countries have been attributed to the low purchasing power of the population and the consequent restriction to purchase foods with greater environmental impact, such as meat\(^3\). A study comparing higher and lower income Peruvian populations concluded that in the city of Lima, where the population’s purchasing power is greater, it would be possible to reduce the carbon footprint of the diet by 6% without compromising its nutritional quality, while in Cajamarca, where there are the poorest, the improvement in the nutritional quality of the diet would lead to an 18% increase in its carbon footprint\(^13\).

The largest carbon footprints of the Brazilian diet were found in the North and Midwest regions. Although it is beyond the scope of this study to analyze the impact of specific foods on the carbon footprint of the Brazilian diet, which will be the subject of a future study, it should be noted that, in the two regions where the carbon footprint of the diet is higher the consumption of beef is also higher: 58.6g/person/day in the North region and 80.7g/person/day in the Midwest region, consumption much higher than the average consumption recorded in Brazil, which is 50.2g/person/day\(^9\).

A previous study carried out with the same database estimated the carbon footprint of the Brazilian diet at 6,761gCO2e/person/day\(^23\), therefore, about 50% higher than our estimate. It should be noted that this study considered only adults and excluded foods and beverages that did not have an environmental footprint, which represented about 15% of the total calories consumed. In addition, it did not take into account the form of food consumption.
which can lead to errors and inconsistencies in estimating the environmental impact of diets. For example, the carbon footprint of cooked rice, one of the most consumed foods in Brazil, is 2.3 times smaller than the footprint of an equivalent amount of raw rice.

Another important difference between the two studies, which is probably the most important to explain the difference found regarding the magnitude of the carbon footprint of the Brazilian diet, concerns the coefficient used to quantify the carbon footprint of beef: 60 kg CO₂e/kg in the previous study and 26.3 kg CO₂e/kg in our study. The coefficient used in our study corresponded to the average of values found in the international literature and was close to the coefficient calculated by Clune et al. and used in studies carried out in Argentina and Peru (28 kg CO₂e/kg), while the coefficient used in the previous study was calculated based on a single study that considered zootechnical parameters of extensive cattle raising and emissions from pastures, which have low feed conversion and high methane emissions.

Among the limitations of our study, we highlight the fact that, although we used estimated environmental impact coefficients for foods and culinary preparations reported by POF 2008-2009 participants, due to the scarcity of studies carried out in Brazil, the estimates were often based on studies carried out in other countries. Another important limitation of this study is due to the fact that the coefficients for many industrialized foods come not from published studies, but from statements of environmental performance of products.

The strengths of our study are linked to the representativeness of the studied sample and the methodological procedures adopted. Adjusting the environmental footprint coefficients according to how food is consumed reduced the possibilities of errors and inconsistencies. In addition, the calculation of the environmental impacts of diets by fixed amounts of calories provided an adequate comparison between dietary patterns by controlling the effects of differences in the amount of food consumed.

CONCLUSION

The carbon footprint of the Brazilian diet, estimated by our study at 4,489 g CO₂e/person/day, exceeds by about 30% the human diet footprint that could simultaneously meet the nutritional requirements of a healthy diet and the global target to contain the increase of the planet’s average temperature. The pattern of association between sociodemographic variables and dietary carbon footprints described in this study can help identify priority targets for public actions aimed at reducing the environmental impacts of food consumption in Brazil.

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