GHG Emissions Associated with Food Diets Eaten in the State of São Paulo, Brazil

Danilo R. D. Aguiar and Giovanna T. C. Simões[1]

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Abstract

The purpose of this paper is to measure the emissions of Greenhouse gas (GHG) related to the diets eaten in the state of São Paulo, Brazil, by different groups of consumers, as well as to examine whether the taxes currently applied to food products are consistent with the environmental damages caused by them. We found that from 73% to 87% of the diet-related GHG emissions come from only two types of foods: beef and dairy. Rice is the main emitter among the foods of plant origin. The results also show that the diets of low-income individuals emit significantly less, while the diets of residents of countryside and small towns emit more than the diets of residents of São Paulo capital and the metropolitan area. Regarding the relationship between the existing taxes products and the hypothetical environmental taxes, we found that the existing taxes are too low for GHG-intensive foods and too high for less GHG-intensive foods, a pattern that tends to restrict the consumption of eco-friendly food items, as well as to stimulate the consumption of foods with high carbon footprints. A review of the tax policy applied to food products taking into account their GHG intensity is highly recommended, but the impact of such policy on nutrition and health should also be considered.

Keywords: climate change, food consumption, environmental taxes.

JEL codes: D12 Consumer Economics: Empirical Analysis; Q5 Environmental Economics.

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[1] Danilo R. D. Aguiar is a professor and Giovanna T. C. Simões is a postgraduate student in the Department of Economics, School of Management and Technology, Federal University of São Carlos, Sorocaba, Brazil. E-mail: danilo@ufscar.br for correspondence. The authors thank São Paulo Research Foundation for financial support.

1. Introduction

Food security has been a major preoccupation worldwide, as estimates suggest that around 800 million people are still suffering the effects of hunger across the globe (von Grebmer et al., 2015; FAO, IFAD and WFP, 2015). Moreover, since the world's population is projected to reach 9.6 billion people by 2050 (FAO, 2009), food shortage might become even worse in the future if food production does not increase considerably.

The task of increasing food supply may be challenging, however, as the global food system is a major cause of greenhouse gas (GHG) emissions, emitting mainly methane, originated from enteric fermentation in ruminant livestock, nitrous oxide from soil management practices and nitrogen fertilisers application, and carbon dioxide from the use of fossil fuels in all stages of the food system (Garnett, 2011). Also, as production technology varies from product to product, some foods have been target for generating more emissions than others, being meat (especially beef and lamb) and dairy the largest GHG emitters according to several studies[2].

Considering the necessity of feeding a growing population and simultaneously reducing food-related GHG emissions, many authors[3] endorse the consumption approach, warning that if Western-style diets based on animal-source foods continue to spread across the world, it will be impossible for supply to meet demand without large increases in GHG emissions. The consumption approach asserts that consumers should change their eating habits towards climate-friendly diets, what would induce the food system to move in the same direction.

Despite the extensive literature on diet-related GHG emissions[4], almost all studies have been done in high-income countries. In Brazil, the only study investigating GHG emissions from food diets was carried out by Carvalho et al. (2013) and was restricted to emissions from meat consumption in the city of São Paulo. Consequently, there is a lack of broader studies considering other foods, other localities and individuals from different social classes, which could provide useful information to consumers concerned about the impacts of their diets, and to Brazilian policy-makers seeking to design emission-cutting policies. Although policies like these have not been adopted in Brazil yet, examples from other countries have

[2] See, for example, Garnett (2014a), Garnett (2016), Macdiarmid et al. (2012) and Scarborough et al., 2014).

[3] Garnett (2014a), Garnett (2014b), Bajzelj et al. (2014), Caillavet et al. (2015), Garnett (2015), Garnett (2016), etc.

[4] Joyce et al. (2014), Auestad and Fulgoni (2015) and Niles et al. (2017) bring good reviews of international literature.

ranged from consumer education programmes to taxing GHG-intensive foods, but any policy requires information on consumers' behaviour to be properly designed.

In this context, the purpose of this paper is to measure GHG emissions linked to food diets consumed in the state of São Paulo, Brazil, by individuals from different social classes residing in different locations, as well as to examine whether the existing taxes are consistent with the environmental damages caused by each food item. About the latter, it is not our goal to recommend environmental taxes, but only to check whether the existing tax policy inhibits consumption (and production) of foods with high GHG footprints. This article also tests two hypotheses: first, diets of richer individuals emit more GHG because they usually have plenty of animal-based foods; and second, the existing tax system has not inhibited diet-related emissions, since this issue has not been raised in Brazil yet.

The paper is organised in five sections. In the next section we explore the economic concepts behind GHG emissions and the effect of taxing. In section 3 we detail our data and method. In section 4 we report and discuss our empirical results. Section 5 brings our conclusions.

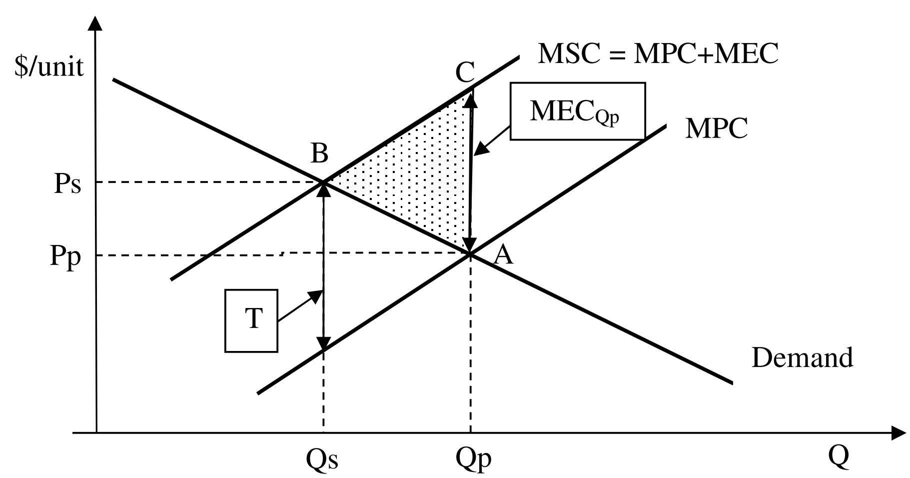
2. Economics of GHG emissions

GHG emissions are a classic example of negative externality because they are generated from someone's activities and harm someone else. They can also be considered a case of transboundary pollution (Hanley et al., 2007) as they not only have local but also worldwide effects. The direct effect of GHG emissions is global warming, which harms the ecosystems triggering droughts, floods, instability of agricultural production, loss of biodiversity and other kinds of damage in different parts of the world. Since producers do not take into consideration the external costs generated from their emissions when deciding how much to produce, they tend to produce more (and emit more GHG) than the socially optimal.

Given that GHG emissions are a negative externality, producers would cut their production and consequently reduce their GHG emissions if their marginal external cost of production (externality cost) was incorporated into their explicit production cost. A tool that can be used with this purpose is tax policy, by taxing foods according to their GHG intensity. Such tax, known as Pigouvian Tax (named after the British economist Arthur Cecil Pigou), should match the marginal external cost, inducing producers to incorporate the externality into their decision-making process.

Figure 1 highlights the welfare loss caused by GHG emissions and illustrates how a Pigouvian tax could be used to prevent such loss. Without any government intervention, the hypothetical market represented in Figure 1 would reach the private equilibrium at point A, with quantity Qp and price Pp, where the private supply (the Marginal Private Cost, MPC) meets demand. The marginal external cost originated from the production of the last unit (Qp) is MEC_{Qp}, while the whole damage (welfare loss) caused by the externality (total external cost) is represented by the area of triangle ABC.

Figure 1 – Effects of GHG emission in a hypothetical market



$/unit = monetary value / unit; Q = quantity /time; Ps = social price; Pp = private price; Qs = social quantity; Qp = private quantity; MSC = marginal social cost; MPC = marginal private cost; MEC = marginal external cost; MEC_{Qp} = MEC at Qp.

Source: elaborated by the authors.

Applying a (Pigouvian) tax of $T per unit, the Marginal Social Cost (MSC) would be the new supply function, comprising the Marginal External Cost (MEC) plus the Marginal Private Cost (MPC), and the market equilibrium would move to point B, reaching the socially optimal output (Qs).

Figure 1 represents the consumption approach to mitigate GHG emissions, since cutting consumption/production is a requirement to reduce emissions[5]. According to this consumption approach, actions should be taken to reduce consumption from Qp to Qs, being the Pigouvian tax one of the possibilities. Despite the policy approach chosen to reduce

[5] Another possibility, not contemplated in Figure 1, would be the introduction of a new technology assigned to reduce GHG emissions. This possibility represents what can be referred to as "production approach to mitigate GHG emissions".

consumption/production of GHG-intensive foods, quantifying the damage caused by the emissions originated from each product would be crucial.

The determination of the proper tax value to reduce production from Qp to Qs can be done by means of estimates of price elasticities of demand. Another option is to use an estimate of the marginal external cost (the carbon price, considering the case of GHG emissions) at production level Qp, as done by Springmann et al. (2017). Assuming a constant marginal external cost, what means that each unit of production causes the same damage as the previous one, MSC and MPC would be parallel (as in Figure 1) and the Pigouvian tax (T) would be equal to the MEC_{Qp}.

3. Data and Methods

In this section we begin by describing our data and then we detail our method, since the latter is designed to overcome differences between consumption and emissions data.

3.1. Data

For consumption, we used data from the most recent Consumer Expenditure Survey (POF), carried out by Brazilian Institute of Geography and Statistics (IBGE, 2010), bringing information on the amount of food and beverages purchased by households for at-home consumption. For GHG emissions, we used Life Cycle Assessment (LCA) data provided by Brazilian Ministry of Science and Technology (MCT, 2014) reporting emissions originated from production systems of the most important agricultural products. MCT reports methane emissions generated by enteric fermentation of animals, animal waste management, rice cultivation and burning of agricultural residues, and nitrous oxide emissions from animal waste management, agricultural soil management and burning of agricultural residues. Because emissions of nitrous oxide from fertiliser use are reported by MCT in the aggregate, we use estimates of product-level nitrogen fertiliser application in 2008, provided by IPNI (2018)[6], in order to assign fertiliser-related nitrous oxide emissions to specific food products. According to IPNI data, Maize and Sugar Cane were the main users of nitrogen fertiliser in 2008, with shares of 33.7% and 26.9%, respectively, while the shares of rice, soya and beans totalled, respectively, 6.7%, 2.4% and 3.7%.

Twelve basic products were considered: (1) Rice; (2) Beans; (3) Maize; (4) Wheat; (5) Soya; (6) Cassava; (7) Sugar cane; (8) Beef cattle; (9) Pigs; (10) Poultry; (11) Eggs; and (12)

[6] As our consumption data refers to 2008, we used all other data referring to the same year.

Dairy. Each basic product was linked to several food items consumed by final consumers, such as flour, oil, dairy products (fluid milk, powder milk, milk cream, yogurt, cheese, etc.), different cuts of beef, chicken, and pork, and so on. Such food items are reported as consumer choices by POF, while GHG emissions are reported by MCT for basic products (cattle, poultry, pigs, maize, etc.).

3.2. Estimating GHG emission from food diets

As each of the two datasets refers to different product forms, we needed to connect one dataset to another. For example, as POF brings information on the consumption of cheese and MCT informs the amount of GHG emitted annually by a dairy cow, we needed to estimate how much emission occurs per litre of milk (based on dairy cow yields) and how much milk is required to produce a kilogram of cheese (using conversion factors).

To estimate GHG emissions from a basic product *i*, where i represents one of the 12 basic products, we first added together the annual emissions of methane (CH_4) and nitrous oxide (N_2O) originated from product *i*, after having converted such emissions to carbon dioxide equivalent (CO2eq) according to Global Warming Potential (GWP)[7]. Then, using production data provided by IBGE (2017a) and IBGE (2017b), we divided our annual emission estimates by product *i*'s average production and found GHG emissions per kilogram of either agricultural product or live weight of livestock in CO2eq per year:

$$E_{un}^{i} = \frac{CH_4^i + N_2O^i}{Q^i} \quad (1)$$

where E_{un}^{i} is the total annual emission per kg of basic product *i*, CH_4^i is the annual emission of methane from product i (in CO2eq), N_2O^i is the annual emission of nitrous oxide from product *i* (in CO2eq), and Q^i is the production of product *i* in 2008.

Among the 12 basic products included in this study, the only one for which we followed a different approach is wheat because this product is mostly imported and, consequently, MCT does not report emission data for it. Considering that Brazilian imports mostly come from Argentina, we relied on emission data referring to the latter, provided by FAO (Food and Agriculture Organization) (FAOSTAT, 2017).

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[7] A limitation of our data is that they do not include emissions of carbon dioxide from transport and other activities of the food chains. So our emissions are restricted to methane and nitrous oxide.

Based on POF information, the 12 basic products were split into 50 food items consumed either by humans or by livestock[8] (Chart 1). To connect food items to basic products, we used technical coefficients of transformation provided by FAO (FAO, 2000) to estimate conversion factors. The conversion factor of a given food *j* derived from basic product *i*, $f_{j,i}$, shows how much of product *i* is required to produce one kg of food *j*.

The conversion factors estimated for each food item (Chart 1) are then multiplied by the emissions of their respective basic products, originating emissions per kg of food:

$$E_{un}^{j,i} = f_{j,i} E_{un}^{i} \tag{2}$$

where $E_{un}^{j,i}$ is the annual GHG emission from one kg of food *j* derived from basic product *i*, $f_{j,i}$ is the conversion factor linking them, and E_{un}^{i} is the annual emission per kg of product *i*.

The last step is to estimate the annual amount of GHG emissions associated with the amount of food consumed by a given individual (*x*) from a household (*k*), using consumption information provided by POF:

$$E_{j,i}^{x,k} = \frac{q_j^k E_{un}^{j,i}}{N_k} \tag{3}$$

where $E_{j,i}^{x,k}$ is the average annual GHG emission due to the consumption of food *j* (produced from basic product *i*) by individual *x* (member of household *k*), q_j^k is household k's consumption of food *j*, $E_{un}^{j,i}$ is the annual GHG emission originated from a kg of food *j* produced from basic product *i*, and N_k is the number of people living in household *k*.

[8] Chart 1 brings two products (maize grain and soya meal) essentially used to feed animals (mainly poultry and pigs) which indirectly affect GHG emissions of animal products.

Chart 1 – Basic products, food items and conversion factors linking them

Basic Product or Food Item	**Conversion factor***	**Basic Product or Food Item**	**Conversion factor***
I. Rice		**VIII. Beef cattle**	
1. Rice without peel	1.18	*First class beef*	
2. Starch/Flour/Cereals	1.38	26. Without bone	2.47
II. Beans		27. With bone	1.75
3. Beans	1.00	*Second class beef*	
III. Maize		28. Without bone	2.47
4. Maize grain	1.00	29. With bone	1.75
5. Maize cereal	1.00	30. Edible offal	1.75
6. Maize oil	3.17	31. Processed	2.19
7. Maize flour	1.11	32. Oil/Fat	1.75
8. Maize Starch	1.31	**IX. Pigs**	
9. Canned corn	0.50	33. Meat	1.20
IV. Wheat		34. Processed	1.42
10. Wheat flour	1.35	35. Edible offal	1.20
11. Wheatgerm	1.35	36. Fat	1.20
12. Bread / Pasty	1.18	**X. Poultry**	
13. Macaroni	1.35	37. Meat	1.00
V. Soya		38. Edible offal	1.00
14. Soya grain	1.00	39. Processed	1.09
15. Soya oil	1.05	**XI. Eggs**	
16. Margarine	0.93	40. Eggs	1.00
17. Soya sauce / cream	0.29	**XII. Dairy cattle**	
18. Tofu	0.22	41. Whole milk	1.00
19. Soya meal/protein	1.05	42. Low-fat milk	1.08
VI. Cassava		43. Chocolate milk	1.00
20. Fresh Cassava	1.00	44. Powder milk	10.00
21. Flour/Starch	4.00	45. Cheese	10.00
22. Tapioca/Gum	3.57	46. Condensed milk	4.00
VII. Sugar cane		47. Milk cream	6.67
23. Sugar cane	1.00	48. Yogurt	1.25
24. Refined sugar	7.50	49. Fermented milk	1.25
25. Treacle/brown sugar lump	6.90	50. Butter	23.81

* conversion factors showing how many kilograms of basic products (or one kg of live weight in the case of beef cattle, pigs and poultry) are required to produce one kg of their respective food items.

Source: Estimated by the authors based on FAO (2000).

In our analysis, consumers were split into groups according to two parameters: per capita income and geographic location of the residence (Chart 2). Regarding income, we sorted the sample into 11 different income brackets after converting the households' monthly per capita incomes, originally quoted in Brazilian currency ("Real"), into number of minimum wages (MW). About the geographic location of the residence, consumers were split into four groups based on where they live.

Chart 2 – Consumer groups for individuals living in the state of São Paulo according to income and location of residence

Groups according to monthly per capita income, in number of minimum wages (MW)	**Groups according to location of residence**
Smaller than one MW	Capital
1 to 2	
2 to 3	
3 to 4	Metropolitan area
4 to 5	
5 to 6	
6 to 7	Small towns
7 to 8	
8 to 9	
9 to 10	Countryside
Larger than 10 MW	

3.3. Assessing tax policy effects

As food products are taxed at both federal and state level through several taxes, our first task was to identify the taxes applied to each food item consumed in the state of São Paulo, based on official documents such as MCC (2013) and SF (2017).

To represent the external damage caused by GHG emissions we used the explicit price of carbon, but instead of using a single estimate of it, such as Springmann et al. (2016) who used US$ 52 per metric tonne of CO2eq, we relied on price ranges proposed by the High-Level Commission on Carbon Prices (HLCCP, 2017). This commission asserts that the carbon price per ton (equivalent to 907.185 kg) CO2eq should be at least from US$ 40 to US$ 80 by 2020, and from US$ 50 to US$ 100 by 2030, to be consistent with achieving the temperature target settled by the Paris Agreement.

In order to enable drawing comparisons with Brazilian existing taxes, which are referred in percentages, we used the four carbon reference prices suggested by HLCCP (converted into Brazilian currency[9]) to estimate four hypothetical environmental taxes for each product as percentage of its average price:

$$HET_j(\%) = \frac{100(P_c^r E_{un}^{j,i})}{P_j} \qquad (4)$$

where $HET_j(\%)$ is the hypothetical environmental tax of food product j in percentage, P_c^r is each of the four carbon reference prices proposed by HLCCP (2017), P_j is the average price of food j (provided by IEA, 2017), and $E_{un}^{j,i}$ is the annual GHG emission from a kg of food j produced from basic product i.

4. Results and Discussion

In this section we report and discuss our results, beginning with the assessment of each food's contribution to GHG emissions. Then, we analyse the diets of different groups of individuals and finally we examine the impact of tax policy.

4.1. Emissions related to food items

Using GHG emissions of basic products and the conversion factors linking them to food items, we estimated GHG emissions per kg of each of the 50 food items (Chart 3). The results show that animal-based foods have the highest GHG footprints per kilogram, being butter, powder milk and cheese the largest emitters. Among the plant-based foods, rice and rice products are the most GHG-intensive items, although their emissions are quite low comparing with foods of animal origin. This result is rather important because rice and beans are both consumed in high quantity by Brazilians, but while the former is a considerable emitter, the latter produces a much lower level of emission.

The numbers reported in Chart 3 highlight the impact of a unit of each food item, but they do not allow making inferences on how much each food actually contributes to GHG emissions because consumers do not eat identical quantities of all foods. The real impact of each food will depend on consumers' diets, as we examine in the next section.

[9] The conversion to Brazilian currency was done by means of the annual average of the exchange rate published by BCB (2017).

Chart 3 – GHG emissions from the production of the food items consumed in the state of São Paulo, Brazil, in 2008/09 (kg of CO2eq per kg per year)

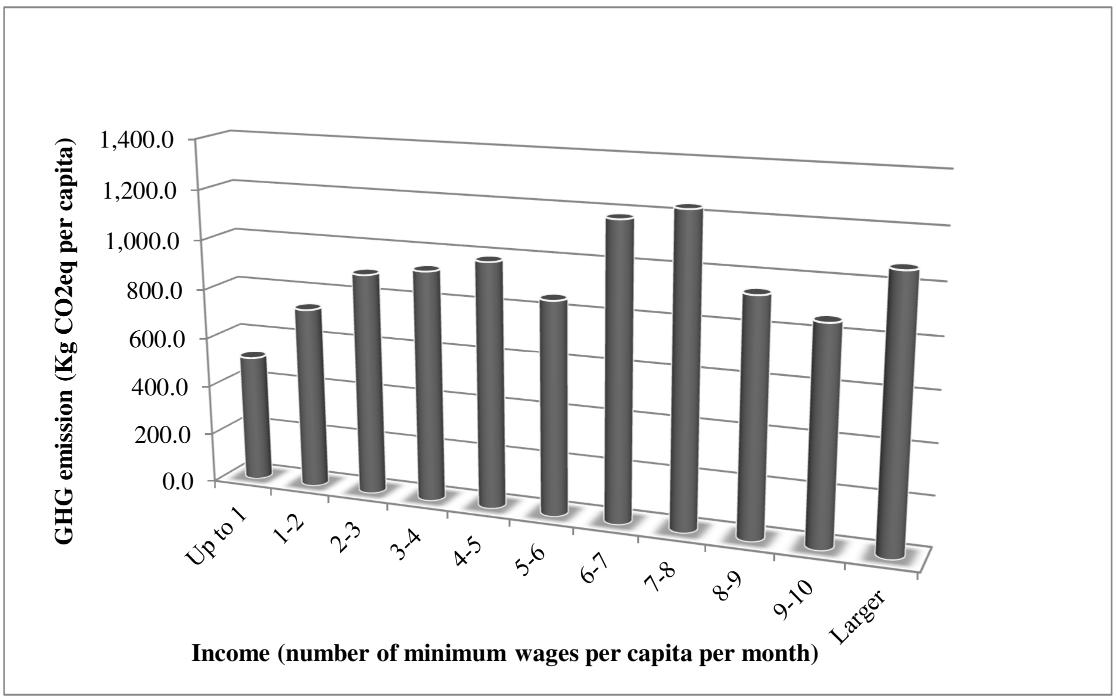
Basic Products and Food Items derived from them	Emission (Kg CO2eq/ Kg of food / year)	Basic Product / Food Items	Emission (Kg CO2eq/ Kg of food / year)
I. Rice		**VIII. Beef cattle**	
1. Rice without peel	1.15	*First class beef*	
2. Starch/Flour/Cereals	1.35	26. Without bone	21.45
II. Beans		27. With bone	15.23
3. Beans	0.33	*Second class beef*	_
III. Maize		28. Without bone	21.45
4. Maize grain and cereal	0.17	29. With bone	15.23
5. Maize oil	0.54	30. Edible offal	15.23
6. Canned maize grain	0.08	31. Oil/Fat	15.23
7. Maize flour	0.19	32. Processed	19.03
8. Maize Starch	0.22	**IX. Pig**	
IV. Wheat		33. Meat	3.19
9. Wheat flour	0.07	34. Processed	3.75
10. Wheatgerm	0.07	35. Edible offal	3.19
11. Bulgur	0.05	36. Fat	3.19
12. Macaroni	0.07	**X. Poultry**	
13. Bread and Pasty	0.06	37. Meat	4.34
V. Soya		38. Edible offal	4.34
14. Soya grain	0.08	39. Processed	4.72
15. Soya oil	0.09	**11.Eggs**	
16. Margarine	0.08	40. Eggs	1.90
17. Soya sauce/cream	0.02	**12. Dairy cattle**	
18. Tofu	0.02	41. Whole milk	2.74
19. Soya meal/protein	0.09	42. Low-fat milk	2.95
VI. Cassava		43. Chocolate milk	2.74
21. Fresh Cassava	0.08	44. Powder milk	27.44
22. Flour/Starch	0.09	45. Cheese	27.44
22. Tapioca/Gum	0.08	46. Condensed milk	10.98
VII. Sugar cane		47. Milk cream	18.30
23. Sugar cane	0.02	48. Yogurt	3.43
24. Refined sugar	0.25	49. Fermented milk	3.43
25. Treacle/brown sugar lump	0.13	50. Butter	65.34

Source: Estimated by the authors based on FAO (2000) and on MCT (2014).

4.2. Contribution of different consumer groups to diet-related GHG emissions

Beginning with the analysis of income brackets, Figure 2 indicates that GHG emissions linked to the food diets eaten in the state of São Paulo rise as income rises up to the bracket with monthly income in the range from 7 to 8 minimum wages per capita, decreasing afterwards. Moreover, the diets of low-income individuals, especially those who belong to households with per capita income lower than one minimum wage a month, emit significantly less than the diets of individuals from other social classes.

Figure 2 – Diet-related GHG emissions according to income (measured as number of minimum wages per capita) earned by residents of the state of São Paulo, Brazil, 2008/2009, in CO2eq per capita



Source: estimated by the authors.

An explanation for the decline of diet-related GHG emissions for people earning more than eight minimum wages per capita relies on the properties of our data, which are specific to at-home consumption. Considering that wealthier individuals are more likely to eat out, we can reason that they would eat less at home and, consequently, would generate lower estimates for at-home GHG emissions[10]. This pattern becomes even more evident when we look at food products (Chart 3) because the emissions related to plant-based foods decrease lightly or keep stable, while the emissions associated with the consumption of beef and pork decreases sharply for individuals with earnings beyond eight minimum wages a month. As it is most unlikely that high-income individuals would eat less beef and pork, we can infer that they are eating such foods away from home.

Chart 3 – GHG emissions related to basic food products for different income brackets, quoted at number of minimum wages (MW) per capita per month, in the state of São Paulo, Brazil, 2008/2009, in kg CO2eq per capita

Income brackets (in number of MW per capita)	GHG emission per product and total (in kg CO2eq per capita)												
	Rice	Beans	Maize	Wheat	Soya	Cassava	Sugar cane	Beef	Pigs	Poultry	Eggs	Dairy	Total
Up to 1	28.5	2.1	0.6	1.2	0.7	0.2	25.3	206.7	26.8	45.5	5.3	167.7	510.7
1-2	35.3	3.1	0.7	1.5	0.9	0.3	33.9	310.8	38.4	58.4	5.7	244.1	733.1
2-3	38.9	3.0	0.8	1.6	1.1	0.1	33.7	359.8	45.8	63.9	8.6	336.5	893.7
3-4	22.9	2.4	0.6	1.6	0.8	0.2	24.3	426.8	46.4	60.9	6.3	334.1	927.2
4-5	28.9	2.5	1.3	1.9	1.0	0.1	23.4	453.5	44.1	68.9	8.3	349.4	983.1
5-6	40.0	1.3	1.0	1.7	0.8	0.2	21.6	327.4	30.6	43.7	7.7	378.9	854.8
6-7	26.6	2.7	0.5	2.0	0.9	0.2	39.0	471.4	48.3	53.9	9.2	525.1	1,179.6
7-8	17.7	1.9	0.7	1.7	1.5	0.6	17.5	520.4	51.3	60.9	7.7	551.5	1,233.1
8-9	19.4	1.3	0.3	1.9	0.6	0.3	24.6	381.2	18.5	58.4	12.6	419.6	938.6
9-10	24.9	0.6	0.7	1.5	0.4	0.1	21.9	266.3	13.7	63.5	5.8	460.0	859.2
Larger	18.1	1.4	1.1	1.8	0.7	0.2	16.7	327.2	35.0	54.8	7.8	603.2	1,068.0
Average	31.4	2.5	0.7	1.5	0.9	0.2	28.8	331.4	38.2	57.2	6.8	304.9	804.7

Source: estimated by the authors.

[10] Caillavet et al. (2015) reached similar results and offered a similar explanation.

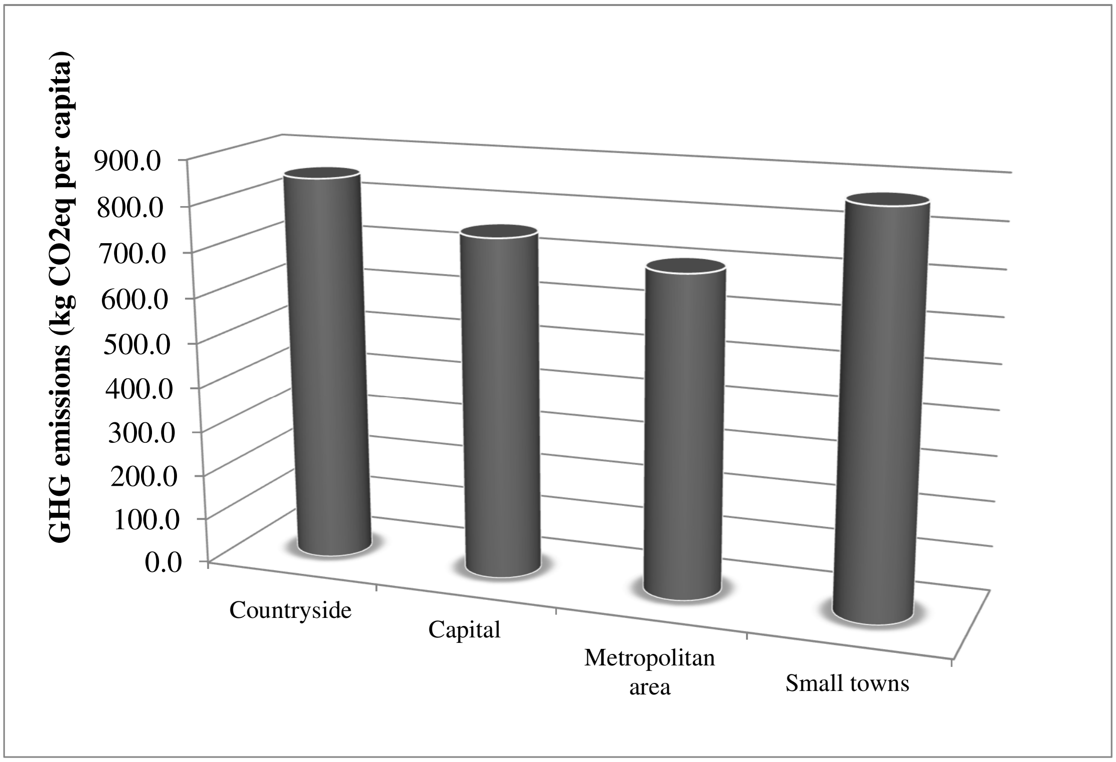
The numbers reported in Chart 3 also indicate that about 80% of diet-related GHG emissions come from only two basic products: beef and dairy. The share of these products increases with income, from 73% for consumers earning less than one minimum wage per capita to 87% for consumers earning more than 10 minimum wages per capita, as the share of rice decreases from 5.6% to 1.7% between those two income brackets.

The last column of Chart 3 indicates that the consumer group that emits the most emits a little bit above 1,200 kg CO2eq per capita annually. Despite the difficulty of contrasting results from different studies because their data and methods normally differ, our estimates are comparable to the results found for Sweden by Wallen et al. (2004), who estimated emissions of 1,100 kg CO2eq per capita, and for France, as Vieux et al. (2012) estimated for a French full diet (including consumption of food away from home) emissions of 1,496.5 kg CO2eq per capita. For the U.S., Heller and Keoleian (2014) found annual emissions of 1,825 kg CO2eq per capita, even though the same authors have cited other studies using economic input-output LCA data that found overall diet-related emissions slightly above 3,000 kg CO2eq per capita. Higher estimates have also been found by other authors, such as Hoolohan et al. (2013), who found that the current UK average diet emits 3,212 kg CO2eq per capita, including both food eaten and food wasted (post-purchase), and Hendrie et al. (2014), who found that the GHG emission of the average Australian food diet for adults was 5,292.5 CO2eq, being 2,920 CO2eq per capita originated from the consumption of red meat alone.

Therefore, diet-related GHG emissions in the state of São Paulo seem to be, in average, slightly below the findings for countries such as France and Sweden, and much lower comparing with the UK, the U.S. and Australia. In addition, as GHG emissions increase when income increases, we can conclude that the largest emitters in the state of São Paulo emit in the range of French to Swedish consumers, while the poorest individuals emit much less.

Regarding the geographic location of the residence (Figure 3), residents of small towns and countryside emit more diet-related GHG per capita than residents of other places. This pattern reflects the fact that residents of the capital and the metropolitan area are more likely to eat out because they normally commute longer to work, resulting that their at-home diets should emit less than the at-home diets of residents of countryside and small towns.

Figure 3 – Diet-related GHG emissions according to geographic location of the residence by consumers of the state of São Paulo, Brazil, 2008/2009, in kg CO2eq per capita



Source: estimated by the authors.

Looking at specific food groups, Chart 4 indicates that countryside individuals eat much more rice and beans, the main sources of energy in Brazilian typical diets, than individuals of other locations, what might be associated with the labouring activities carried out at countryside. It is also noticeable that residents of the capital and the metropolitan area eat less of almost all food items than the residents of other places, what might be related to the fact that they eat more away from home as mentioned previously.

Chart 4 – GHG emissions linked to per capita intakes of basic food products in the state of São Paulo, Brazil, 2008/2009, according to geographic location of the residence, in kg CO2eq

Location of the residence	GHG emission per product and total (in kg CO2eq per capita)												
	Rice	Beans	Maize	Wheat	Soya	Cassava	Sugar cane	Beef	Pigs	Poultry	Eggs	Dairy	Total
Countryside	52.1	4.1	2.6	1.5	1.2	0.6	49.3	385.3	41.0	55.0	7.6	252.4	852.9
Capital	23.9	1.8	0.6	1.6	0.7	0.1	24.0	308.5	25.7	47.9	6.0	309.7	750.5
Metropolitan area	32.1	2.6	0.6	1.3	0.5	0.2	21.1	277.1	40.3	60.9	7.0	260.8	704.5
Small towns	32.4	2.7	0.6	1.5	1.1	0.2	31.9	358.1	43.3	60.7	7.1	326.7	866.4
Average	31.4	2.5	0.7	1.5	0.9	0.2	28.8	331.4	38.2	57.2	6.8	304.9	804.75

Source: estimated by the authors.

4.3. Impact of tax policies

Chart 5 reports the taxes currently applied to some of the main food products consumed in the state of São Paulo as well as four hypothetical environmental taxes considering the proposals of the High-Level Commission on Carbon Prices (HLCCP, 2017) for 2020 and 2030. Four situations are apparent. First, for some products such as beans, maize and eggs, the real taxes are lower than the hypothetical environmental taxes, but the environmental taxes are quite small (especially for maize and beans). For a second group, which includes poultry and yogurt, the current taxes are between the minimum and the maximum environmental taxes (for poultry, the existing tax is inferior to the maximum environmental tax for 2030 only), what might suggest that the existing taxes are possibly adequate to induce consumers to eat the amount socially optimal (considering the environmental cost) of these products. A third group, including products such as cassava flour, soya oil, sugar and pork, has the existing taxes higher than the environmental taxes (for pork, the difference is not very large though), suggesting that the existing taxes might be inhibiting the consumption of these less GHG-intensive foods. And for a fourth group, composed by beef, cheese, milk and rice, the existing taxes are much lower than the hypothetical environmental taxes.

Such results suggest that cutting taxes for products such as cassava flour, sugar and soya oil, and raising taxes for rice, milk, cheese and beef, would help cutting diet-related GHG emissions in the state of São Paulo. However, before considering tax changes, other parameters should also be contemplated. Particularly, health and nutrition issues should be considered, as larger consumption of products like sugar may affect health negatively, while restricting consumption of rice (still the main source of energy in Brazilian diets) and products of animal origin may cause nutrient deficiencies if those products are not replaced properly.

Chart 5 – Current taxes, and minimum and maximum environmental taxes projected for 2020 and 2030, in percentage terms, for some of the main products consumed in the state of São Paulo, Brazil

Food item	**Current tax**	**Minimum environmental tax (2020)**	**Maximum environmental tax (2020)**	**Minimum environmental tax (2030)**	**Maximum environmental tax (2030)**
Rice	0%	5.9%	11.9%	7.4%	14.9%
Beans	0%	1.2%	2.5%	1.5%	3.1%
Maize	0%	0.2%	0.4%	0.3%	0.5%
Soya oil	7%	0.3%	0.7%	0.4%	0.8%
Cassava flour	7%	0.4%	0.8%	0.5%	1.0%
Sugar	7%	1.2%	2.4%	1.5%	3.0%
Beef	7%	8.6%	17.1%	10.7%	21.4%
Pork	7%	2.7%	5.4%	3.4%	6.8%
Poultry	7%	3.3%	6.6%	4.1%	8.2%
Eggs	0%	2.5%	5.0%	3.1%	6.3%
Milk	7%	14.1%	28.2%	17.6%	35.2%
Cheese	7%	13.6%	27.3%	17.0%	34.1%
Yogurt	7%	5.4%	10.8%	6.8%	13.5%

Source: estimated by the authors.

5. Final remarks

The results found for the state of São Paulo, Brazil, are consistent with the literature, as beef and dairy products are the main sources of diet-related GHG emissions. Moreover, as rice is a very important component of Brazilian diets and also a considerable GHG emitter, this food turns to be the largest emitter among all plant-based foods. We also found that diet-related GHG emissions increase with income, although this pattern keeps on until certain level of income beyond which consumers tend to eat more away from home and reduce at-home intakes and emissions.

Changing consumers' eating habits could cut significantly GHG emission, as low-income individuals emit significantly less GHG than the others. For example, if consumers earning from 7 to 8 minimum wages per month started eating like consumers earning from 1 to 2 minimum wages, there would be a 68% reduction in their per capita emissions. The desirability of such change, however, would also depend on the nutritional status of low-income individuals, as these individuals might not be obtaining all nutrients they need from their diets. Thus, although there is plenty of opportunity for reducing GHG emissions through diet changing, it is still necessary to evaluate whether the diets with low GHG emissions are nutritionally adequate, what was not done in this work.

A limitation we faced in this research, which is common to most of the international studies, is that our data refers to at-home eating only. Consequently, we probably underestimated the amount of GHG emissions associated with the diets of high-income individuals, as they tend to eat more away from home. Despite this limitation, we can conclude that GHG emissions would reduce if more individuals moved towards diets with less beef and dairy, like the diets of low-income individuals. Also, our results suggest that even in the case of actions following the "production approach", aiming to improve efficiency by means of new technologies, the focus should be the beef and dairy sectors as they are critical regarding GHG emissions.

We also found that there is no relation between the taxes currently applied to food products and the hypothetical environmental taxes. Existing taxes seem to be too low for most of GHG-intensive foods and too high for low-impact foods, what might be restricting the consumption of eco-friendly foods and boosting the consumption of foods with high carbon footprints. Future research should focus on reviewing the tax policy applied to food products considering the environmental damages caused by them, but also contemplating the impact such policy would have on nutrition and health.

Regarding our two hypothesis, both were not rejected. First, GHG emissions are positively correlated to income, at least up to a certain level (above of which, it is hard to draw conclusions because we used data for at-home consumption only). Second, the existing tax system not only fails to combat diet-related GHG emissions, but also induces the consumption of GHG-intensive foods and restricts the consumption of foods with low carbon footprints.

Finally, despite the limitations mentioned above, this paper brings brand new information about diet-related GHG emissions in Brazil, which may assist in the design of actions aiming to cut emissions. Although the adoption of climate-friendly diets by residents of the state of São Paulo would not be sufficient to produce substantial cuts in GHG emissions from food production, as a large part of Brazilian food production is destined for foreign markets, a new pattern of food consumption inside the country could join forces with similar trends taking place abroad and induce the food production system to move towards low-carbon foods.

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