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Carbon footprint of Brazilian families based on the Household Budget Survey and input-output analysis

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Abstract: This study aims to comprehensively assess the carbon footprint of Brazilian households using data from the 2008 and 2018 Household Budget Survey (POF). Employing a hybrid Life Cycle Assessment methodology, our analysis reveals noteworthy insights. In 2008, households within the lower income bracket emitted approximately 4.04 tCO_2e/year, decreasing to 3.81 tCO^2e/year by 2018. Conversely, higher-income households emitted significantly more, with emissions of around 28.73 tCO_2e/year in 2008, decreasing to 25.94 tCO_2e/year by 2018 - almost seven times the emissions of their lower-income counterparts. Intriguingly, although constituting merely 2.47% of all families in 2018, the wealthiest households were responsible for 8.31% of total emissions, while the poorest, representing 24.25%, contributed to 11.97% of emissions. The imperative for affluent families, who exert a disproportionate environmental impact, lies in reconsidering consumption habits and actively seeking low-emission alternatives to curtail their carbon footprint.

Keywords: Carbon Footprint. Sustainability. Input-output model. Family Budget Survey. Social Disparity.

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Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), between 1850 and 2019, human activities caused, approximately, 1°C of global warming (IPCC, 2021a). There is a high degree of scientific confidence that human-induced climate change has caused widespread and severe damage to humans and natural systems by increasing the frequency and/or intensity and/or duration of extreme weather events, including droughts, wildfires, land and sea heat waves, and cyclones (IPCC, 2021a). If the reduction of carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions is not achieved, climate change is expected to trigger global negative effects on nature and society. Thus, society should move beyond existing global agreements, if we want to limit global warming (SKÖLD et al., 2018).

Human activities spanning from 1750 to 2019 were responsible for emitting a total of 2,560 $GtCO_2$ (IPCC, 2021a). To curtail global warming to a 1.5°C increase by 2100, the remaining additional CO_2 mass permitted in the atmosphere from 2020 to 2100 must be capped at 500 $GtCO_2$ (IPCC, 2021a). Since the dawn of the industrial era, emissions have consistently risen, peaking at 35.2 $GtCO_2$ during the last decade (2010-2019) (IPCC, 2021a). Given that 44% of the emitted CO_2 lingers in the atmosphere, addressing the climate crisis necessitates maintaining the emission levels witnessed in the previous decade over a span of only 32 years.

Within the time frame from 2010 to 2019, Brazil's average annual emissions stood at 1.9 $GtCO_2$ (SEEG, 2019). Despite contributing a modest 5% to the global emissions pool, Brazil's emissions play a role in elevating atmospheric CO_2 levels. As a participant in the Paris Agreement, under the United Nations Framework Convention on Climate Change (UNFCCC), the country is obligated to drive emission reductions.

Economic disparity and climate change have surged to the forefront of the global political agenda, yet progress in addressing these issues remains sluggish (MILLWARD-HOPKINS; OSWALD, 2021). It's estimated that over 72% of the GHG emissions stem from worldwide household consumption. Nonetheless, crucial gaps persist concerning emission patterns and their underlying determinants (DUBOIS et al., 2019; MINX et al., 2013).

Carbon emissions are intrinsically linked to household income, both within nations and across them (BOUCHER, 2016). One of the challenges in mitigating carbon footprints is disconnecting consumption growth from income expansion and favoring consumption of less carbon-intensive goods and services (BOUCHER, 2016). Consequently, delving into the concept of the carbon footprint, which encapsulates the cumulative consumption-driven emissions of individuals, groups, or families (ABNT, 2021), becomes indispensable.

The analysis of global carbon footprints indicates large differences between the footprints of the poorest and the richest. The World Bank classifies families in developing countries into four categories, with the most modest consumption range, which is below $2.97, in purchasing power parity (PPP), corresponding to half of the families. On average, for this lowest-income range, the carbon footprint is 1.6 tons of carbon dioxide equivalent (tCO_2e) per year, while the average carbon footprint for the highest-income people, the top 10% of the population, with income greater than $23.03 PPP per capita per day, is 17.9 tCO_2e per year (HUBACEK et al., 2017a).

In 2017, globally, the richest (people from any part of the planet with an income greater than 23 USD per day) represented about 10% of the population but were responsible for 36% of GHG emissions due to the consumption of goods and services and emissions along global supply chains. The poorest (people with an income of less than USD 2.97 per day) represented 50% of the global population but were responsible for 15% of total GHG emissions (HUBACEK et al., 2017b).

Although some developed countries have reduced GHG releases to the atmosphere, they are still the main responsible for global warming, as they have not reduced their consumption. The pursuit of growth at any cost, especially in northern countries, with higher levels of consumption, must be questioned to ensure environmental sustainability (MARTÍNEZ-ALIER, 2012). Moreover, analyzing GHG emissions, considering only the location of goods production, accounts for direct emissions and ignores supply chain emissions triggered by household consumption (IVANOVA et al., 2017).

Industries have changed their plants, following a dynamic allocation of production units according to the comparative advantages of each location (country, region, province, state), as well as the socio-environmental externalities that characterize these allocation processes (IVANOVA et al., 2017). Products can accumulate a significant burden of environmental impacts, along their global production chains, before they reach final consumers and such effects are ignored from a purely territorial perspective of impact precursors (IVANOVA et al., 2017).

Finally, few studies have assessed the differences in the carbon footprint associated with domestic consumption in low- and middle-income countries, such as Latin American countries (ZHONG et al., 2020). In addition, the formulation of targeted and effective policies to reduce the carbon footprint of households depends on a thorough understanding of prevailing consumption patterns and their environmental consequences, therefore, it is crucial to investigate and compare household behaviors and lifestyle-induced carbon footprints (FROEMELT; WIEDMANN, 2020).

Thus, the aim of this article is estimating carbon emissions from the perspective of household consumption in Brazil, quantifying the mass of GHG emissions (directly and indirectly) released by income class in the country in 2008 and 2018.

Methods and materials

Carbon footprints (CF) of Brazilian families result from the sum of their direct (DE) and indirect (IE) GHG emissions (see Equation 1), calculated through the average consumption of each income class (IC), and these values are recovered from the Household Budget Survey (POF) of the Brazilian Institute of Geography and Statistics (IBGE). The unit of measurement was the metric ton of CO_2e per year, so emissions were multiplied by 12, because POF has provided monthly consumption records.

$$Equation\ 1: PCCR = ED_{CR}\ x\ 12 + EI_{CR}\ x\ 12$$

The ICs were divided according to the tabulation of data made available by the IBGE in its Automatic Recovery System (SIDRA) and the division corresponds to the current minimum wage in the respective years (see Table 1). Dollarized values were adjusted by purchasing power parity according to the Organization for Economic Co-operation and Development (OECD)'s reference data (OECD, 2023). It is worth mentioning that in 2008 the nominal minimum wage was BRL 830.00 and in 2018 the value was BRL 1,908.00, and the IBGE divided the income classes according to family income both in 2008 and in 2018.

Table 1 – Income classes according to their monthly income

Income class	Household income in 2008	Household income in 2008 (USD)	Household income in 2018	Household income in 2018 (USD)	Household income as minimun wage (MW) values
E	Up to R$ 830	Up to US$ 504,23	Up to R$ 1.908	Up to US$ 1.162,26	Up to 2 MW
D2	above R$ 830 to R$ 1.245	Above US$ 504,23 to US$ 756,34	Above R$ 1.908 to R$ 2.862	Above US$ 1.162,26 to US$ 1.743,42	from 2 to 3 MW
D1/C2	above R$ 1.245 to R$ 2.490	Above US$ 756,34 to US$ 1.512,68	Above R$ 2.862 to R$ 5.724	Above US$ 1.743,32 to US$ 3.486,85	from 3 to 6 MW
C1	above R$ 2.490 to R$ 4.150	Above US$ 1.512,68 to US$ 2.521,13	Above R$ 5.724 to R$ 9.540	Above US$ 3.486,85 to US$ 5.811,40	From 6 to10 MW
B2	Above R$ 4.150 to R$ 6.225	Above US$ 2.521,13 to US$ 3.781,69	Above R$ 9.540 to R$ 14.310	Above US$ 5.811,40 to US$ 8,717,10	from 10 to 15 MW
B1/A2	Above R$ 6.225 to R$ 10.375	Above US$ 3.781,69 to US$ 6.302,81	Above R$ 14.310 to R$ 23.850	Above US$ 8.717,10 to US$ 14.528,52	from 15 to 25 MW
A1	Above R$ 10.375	Above US$ 6.302,81	Mais R$ 23.850	Above US$ 14.528,52	Above 25 MW

Source: elaborated by the authors based on (DIEESE, 2021; IBGE, 2019a; IPEA, 2020; MENEZES, 2021; OECD, 2023).

The calculation of the carbon footprints of Brazilian families is done according to the GHG Protocol (FGV; WRI, 2008), in which scope 1 refers to direct GHG emissions from direct fossil fuels burning - gasoline and liquefied petroleum gas (LPG); scope 2 refers to emissions due to electricity consumption by households; and scope 3 corresponds to indirect emissions calculated based on data from the Brazilian input-output model (IOM). The Brazilian input-output model is part of the IBGE's System of National Accounts (SCN). It is a matrix composed of the technical coefficients, representing the economic flows between each pair of economic sectors for a given year. It is worth noting that to calculate Scope 3 emissions, a relationship was established between the expenses described in POF and the economic activities of the SCN-IBGE. Thus, the applied method follows a hybrid life cycle assessment, which combines the environmental repercussions of economic chains, through an input-output model, extended with CO_2 emissions, with emissions estimated based on direct consumption of energy carriers.

Direct emission calculations (scope 1 and 2)

Brazilian households' direct emissions were calculated using monthly fossil fuels expenditures (the direct use of biofuels was considered emission-neutral) and electricity. The monetary value spent on a given POF category ($) was divided by its average retail market price on the survey date ($\bar{p}$). In this way, the quantity of the product consumed in month (Qm) was found, according to Equation 2. The average price values collected were the following: BRL 2.50/l (2008) and BRL 4.20/l (2018) for gasoline (TREVIZAN, 2021); BRL 2.13/kg (2008) and BRL 5.33/kg (2018) for LPG (MANFREDINI, 2019); BRL 0.25/kWh (2008) and BRL 0.55/kWh (2018) for electricity (ANEEL, 2022).

$$\text{Equation 2: } Qm = \frac{\$}{\mathrm{P}}$$

Emission factors (Ef), which are the ratio between the amount of emissions generated and the amount of raw material transformed or burned, corresponding to CO_2e from fossil fuels and electricity, considered in this assessment, were the following: 1.7 kg/l (2008) and 1.6 kg/l (2018) for gasoline (BRAZIL, 2015; EPE, 2021; IPCC, 2006); 0.003 t/kg for LPG (EPE, 2021; IPCC, 2006); 0.000025 t/kWh (2008) and 0.000074 t/kWh (2018) for electricity (MCTIC, 2021). The share of ethanol in gasoline, which is regulated by the government, was considered (BRAZIL, 2015), thus reducing its Fe. In 2008, a 25% share of ethanol was applied, and, in 2018, a 27% share of ethanol was applied (BRAZIL, 2015).

To find DE values for the Brazilian families, the Qm values were multiplied by the Fe of each item.

Indirect emissions of Brazilian households (scope 3)

Quantification of the IE of Brazilian households was based on three data sources, which were used to build the IOMs:

- tabulated data from POF 2008 and 2018, retrieved from IBGE's SIDRA (IBGE, 2019a).
- Leontief 2010 matrix from the National Accounts Systems (SCN) of IBGE (IBGE, 2020) and Leontief 2018 matrix retrieved from the Center for Regional and Urban Economics of the University of São Paulo (NEREUS) (GUILHOTO; SESSO FILHO, 2005, 2010; NEREUS, 2020).
- CO_2e emissions inventory, based on the National Energy Balances (BEN) 2009 (EPE, 2009) and 2019 (EPE, 2019).

For household consumption data, two footprints were calculated: energy and carbon. The cumulative energy demand was the starting point for calculating CO_2e emissions from energy use in economic activities. The EI are the result of multiplying the Leontief matrix (L), the column vector of income class expenses (F_{IC}) (POF data) and the column vector of emission coefficients (Ce). The result was expressed for each IC, according to Equation 3.

$$Equation\ 3: EI_{CR} = L \times C_e \times F_{CR}$$

Matrix (L) was created from an intersectoral matrix. The intersectoral matrix demonstrates the intersectoral economic flows of a given economy, in other words, how much each economic activity consumes monetarily from another, or from itself. In 2010, the Brazilian matrix (L) was made available in 3 dimensions: 12, 20 and 67 (IBGE, 2015). In this work, the dimension 67 matrix referring to the years 2010 and 2018 was used.

Energy and emission coefficients calculation

In this section, the calculation of the coefficients of the input-output models to quantify the Brazilian household carbon footprints was demonstrated. It is worth mentioning that the input-output model was consolidated by Wassily Leontief in the late 1930s, and the input-output analysis is one of the most widely applied methods in economics and since the late 1960s the method has been expanded by several researchers to quantify the environmental pollution associated with inter-industrial activity.

Energy coefficients

The calculation of energy consumption coefficients was based on data from the National Energy Balance (BEN) of 2009 and 2019. BEN consumption data are divided into several economic sectors, namely: air transport, agriculture, food and beverages, product manufacturing ceramics, commercial, pig iron and steel manufacturing, water transport, mining and pelletizing, non-ferrous and other metallurgy manufacturing, pulp and paper manufacturing, public sector, chemical manufacturing, residential use, rail transport, road transport, textile production, energy sector, cement manufacturing, ferroalloy manufacturing and other industries (EPE, 2019).

Consumption coefficients were calculated for the following energy sources: diesel oil, electricity, firewood, mineral coal, natural gas (NG), others (coal gas, fuel oil, gasoline, LPG, and kerosene), petroleum coke and products of sugarcane (EPE, 2019). To calculate the energy coefficients, the total volume of energy consumption of each activity was divided by the production value of the respective economic activity, and the GHG emission associated with energy conversion for each type of source was determined.

Carbon dioxide emissions coefficients

GHG emissions of each activity were calculated by adding energy, industrial and agricultural processes (including livestock and forest production activities). The emission values were calculated in mass of CO_2e, considering the Global Warming Potential (GWP) (IPCC, 2021b).

Energy related CO_2e emissions were prepared by multiplying the consumption of each energy vector by their respective emission factors, described in the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

The National Emissions Inventory (MCTIC, 2017) was used to determine emissions from industrial processes (manufacture of pig iron and steel, ferroalloys, chemical industry, non-ferrous and other steelworks, cement and mining and pelletizing) as well as emissions from agriculture (livestock and forest production). Emissions from agriculture came from enteric fermentation of livestock, handling animal waste, growing rice, burning agricultural waste, and cultivating agricultural land.

Equation 4 shows the sum of the emission coefficients. Each coefficient is the ratio between the total CO_2e emission in each activity divided by the production value of the respective activity.

$$Equation\ 4: Cet_{at} = Cee_{at} + Cep_{at} + Cea_{at}$$

Where:

- Ce_{at}:Total CO_2e emission coefficient for each activity.
- Cee_{at}: CO_2e emission coefficient for energy use in each activity.
- Cep_{at}: CO_2e emission coefficient for industrial process in each activity (some activities, such as production of non-metallic minerals).
- Cea_{at}: CO_2e emission coefficient for agriculture in each activity (only in activities: agriculture, livestock, and forest production).

Limitations and adjustments of the input-output model

Fugitive GHG emissions (CO_2e emissions from pressurized equipment, which occur due to leaks and other involuntary releases of gases) were not considered. The use of diesel oil in road transport comes from the consumption of two segments: cargo and passengers. The latter should not be quantified in an IOM because it is related to household's consumption (GENTY; ARTO; NEUWHAL, 2012). In this way, CO_2e emissions in the land transport activity were estimated considering the 52% share of cargo transport in road transport (SEEG, 201).

A relationship was elaborated between the economic sectors of BEN and the economic activities. However, the classification of each agency does not follow the same system. Information in the Methodological Manual (EPE, 2021) was used to correlate BEN's data to the economic sectors from IBGE. In cases where the energy consumption of a given sector had to be divided, because there are two or more economic activities of the SCN included in the same BEN's sector, the energy consumption was considered proportional to the economic product of the activity.

Thus, activities with greater economic product were responsible for greater energy consumption.

The analysis of POF microdata allows for a more robust and detailed study on the carbon footprint of Brazilian families, however, we opted for an analysis by division of minimum wages, limiting the research results to ranges delimited by the number of minimum wages.

Household expenditures survey (POF)

POF 2008 surveyed a sample of 55,970 households in all Brazilian states between 2008 and 2009 (IBGE, 2011), whereas POF 2018 surveyed a sample of 57,920 households (IBGE, 2019b). The research did not address the family carbon footprint, but investigated family expenditures for distinct income classes, thus allowing the use of the IOM, created this research, to determine the carbon footprint, as well as the calculation of direct emissions. Thus, the research has determined the structure of consumption, expenses, and income of Brazilian households. Sampling was designed to yield results at different regional levels (IBGE, 2011). The 2008 POF was carried out between 2008 and 2009, and its results were published in 2009. Therefore, the Leontief matrix made available in 2010 was used without any adjustments.

Consumption expenses correspond to expenses incurred by households to purchase goods and services used to meet their personal and family needs. The surveyed categories were food; housing; clothing; transport; personal hygiene and care; health care; education; recreation and culture; smoke; personal services; and miscellaneous expenses (IBGE, 2011).

The household expenditures survey was carried out by filling out forms. Depending on the form, it was filled out individually or collectively. The survey forms used in the POF 2008 and POF 2018 were as follows:

- POF 1: household and residents characteristics questionnaire (form completed through the head of the household or any other resident).
- POF 2: Collective acquisition questionnaire (form completed through the head of the household or any other resident).
- POF 3: Collective acquisition booklet (form completed through the head of the household or any other resident).
- POF 4: individual acquisition questionnaire (individual form completed by all residents of the household over 18 years of age).
- POF 5: individual work and income questionnaire (individual form completed by all residents of the household over 18 years of age).
- POF 6: assessment of living conditions and (form completed through the head of household or any other resident).
- POF 7: personal food consumption block (individual form completed by all residents of the selected household over 18 years old, it is not necessary to fill in all residents).

According to IBGE (2019b), home was the sampling unit of POFs, consisting of a research and analytical unit for characterizing the living conditions of families.

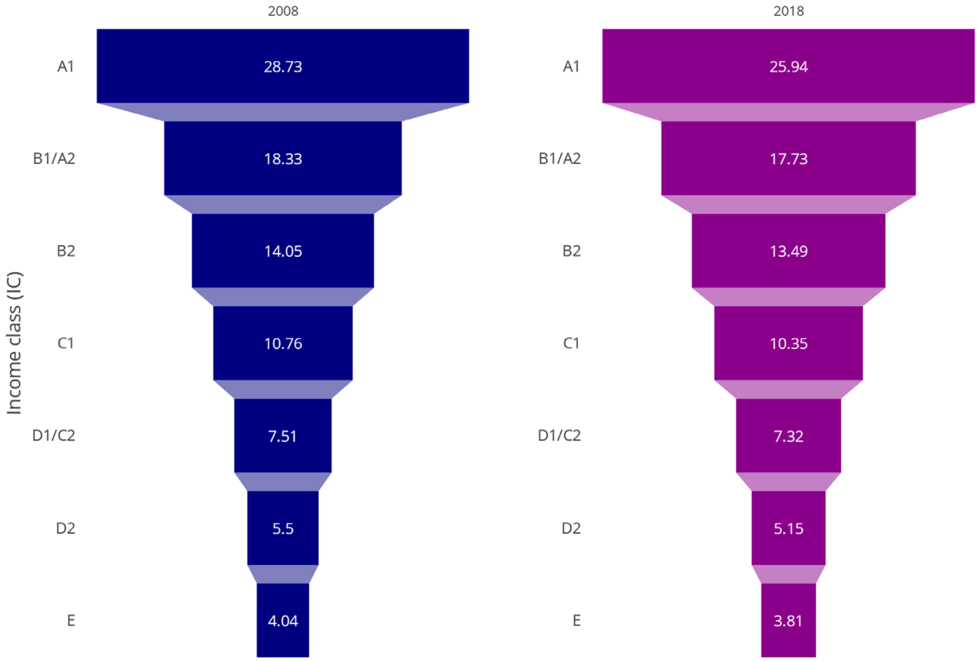
Results and discussion

Figure 1 shows the quantification of the household carbon footprint for the years 2008 and 2018. The "cup" of Brazilian household emissions can be seen. The poorest families (class E) emitted 4.04 tCO_2e in 2008 and 3.81 tCO_2e in 2018, while the richest families (class A1) would emit 28.73 tCO_2e in 2008 and 25.94 tCO_2e in 2018, about 7 times more than the poorest families (both in 2008 and in 2018). The average emission of Brazilian households was 8.7 tCO_2e in 2008 and 7.7 tCO_2e in 2018.

Compared to the study by Jones and Kammen (2011), the richest Brazilian class has emitted less carbon than the average of North American households, which emitted 48 tCO_2e/year in 2005. However, the richest, both in 2008 and 2018, emitted more than the average for Norwegian households (22.30 tCO_2e/year in 2012) (STEEN-OLSEN; WOOD; HERTWICH, 2016). Compared to German households, the richest in Brazil emitted less when compared to 2008 values (approximately 30 tCO_2e in 2008 emitted by households in Germany (MIEHE et al., 2016) versus 28.73 tCO_2e for the richest in Brazil).

A large portion of household carbon footprints occurred indirectly (ranging between 85% and 91% of the household carbon footprint, depending on the year of the IOM and IC), that is, in the production chain of goods and services. In 2018, the scenario remained the same as in 2008, with the richest emitting considerably more than the poor.

Figure 1 - Household carbon footprints per income class in 2008 and 2018



Source: prepared by the authors based on (EPE, 2009, 2019; IBGE, 2010; IPCC, 2006; MCTIC, 2017; NEREUS, 2020).

The tendency of the rich to emit more GHG than the poor (HUBACEK et al., 2017a) is also predominant in Brazil. There is a disparity in the CO_2e emissions of Brazilian families. While the poorest families (class E), which represented more than 20% in 2008, emitted about 10% of total emissions due to domestic consumption, families with income above 6,302.81 USD, adjusted by the PPP in 2008 (class A1) emitted 12.52% of total domestic emissions and represented only 3.81% of households in 2008. Figure 2 illustrates this result.

In 2018, the carbon inequity remained, but there was a decrease in disparity, with the richest decreasing their share in total emissions by domestic consumption and the poorest increasing their share. Class A1 families represented 2.47% of all families and emitted 8.31% of GHG emissions by domestic consumption in 2018. The poorest families (class E) represented, in 2018, 24.25% of households and induced 11.97% of GHG emissions (see Figure 2).

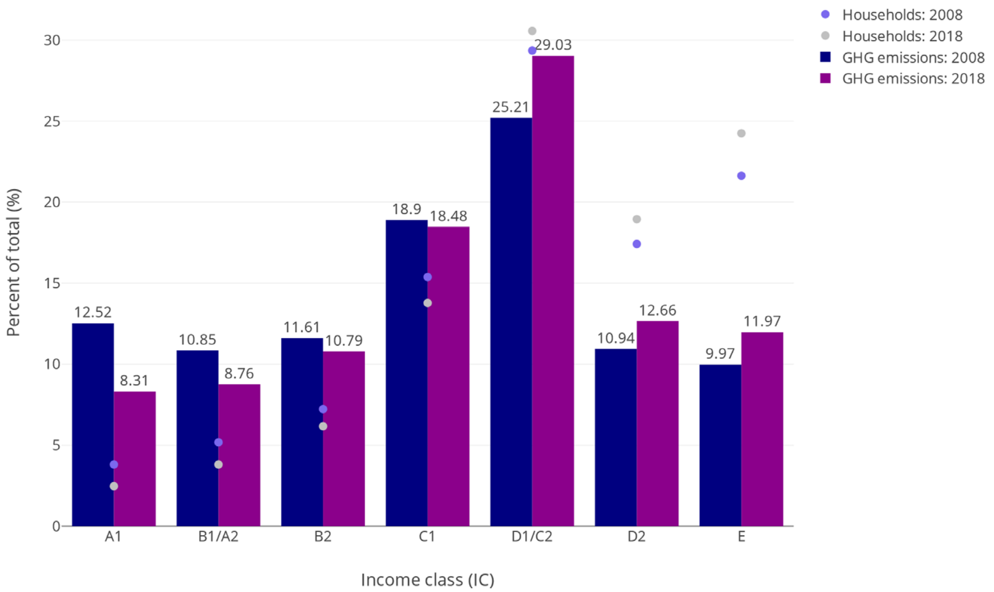
Continuing the analysis of Figure 2, the D1/C2 class almost equaled its percentage of households with its share of inducing emissions. In 2008, the D1/C2 class represented 29.36% of the families and was responsible for 25.21% of the total GHG emissions by domestic consumption. In 2018, the D1/C2 class represented 30.57% of families and was responsible for 29.03% of total GHG emissions by domestic consumption. Class C1 also practically remained the same in terms of participation by households and issues

(15.38% of households and 18.90% of issues in 2008, 13.78% of households and 18.48% of issues in 2018).

It is worth mentioning that in December 2018 the ideal minimum wage, according to the Inter-Union Department of Statistics and Socioeconomic Studies (DIEESE), was equal to BRL 3,960.57 (DIEESE, 2022). The nominal income of families in income classes E and D2 were lower than this value. That is, about 43% of Brazilian families earned less than the ideal to survive and were responsible for almost 25% of household carbon emissions in Brazil.

Between 2008 and 2018, there was a decrease in the share of families in the richest ICs (A1, which represented 3.81% in 2008, increased to 2.47% in 2018, B1/A2, which represented 5.18% in 2008, increased to 3. 81% in 2018, B2 which represented 7.23% in 2008 increased to 6.17% in 2018), however, the variation of Gross Domestic Product (GDP) per capita between 2008 and 2018 grew 3.62% (in 2008 the Brazilian per capita GDP was USD 8,831.18 and in 2018 per capita GDP was USD 9,151.38 (WORLD BANK, 2022), adjusted by the PPP (OECD, 2023) these values correspond respectively to USD 10,729.88 and USD 20,370, 97 USD). Thus, there was a decrease in the share of families in the richest ICs, but per capita GDP practically doubled if we consider values in USD PPP.

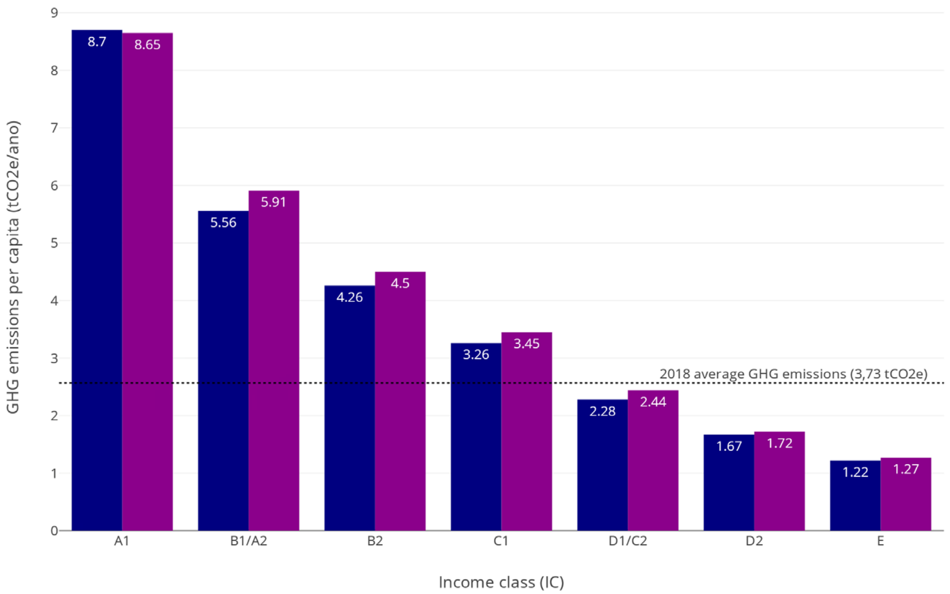
Figure 2 – Shares of households and GHG missions by income class in 2008 and 2018



Source: prepared by the authors based on (EPE, 2009, 2019; IBGE, 2010; IPCC, 2006; MCTIC, 2017; NEREUS, 2020).

Considering the average values of people per family (BRAZIL, 2021), the per capita carbon footprint was calculated for the Brazilian Ics (see Figure 3). The averages of all ICs (except the average of class E for the year 2008) were higher than the average Chinese carbon footprint (1.70 tCO_2/cap (WIEDENHOFER et al., 2017)). When compared to the average Australian per capita emission (27 tCO_2e/year (TUKKER et al., 2014)) the average of all Brazilian ICs was lower (both in 2008 and in 2018). When compared worldwide, the averages of class E (1.22 tCO_2e/year in 2008 and 1.27 tCO_2e/year in 2018) follow the trend of lower income (1.6 tCO_2e/year (HUBACEK et al., 2017a). Compared to the richest people, the highest Brazilian class, class A, emitted less carbon than the global average (8.65 tCO_2e/year in 2018 in Brazilian families against the global average of 17.9 tCO_2e/year (HUBACEK et al., 2017a)).

Figure 3 – Consumption driven per capita GHG emissions in Brazil, in tCO_2e



Source: prepared by the authors based on (EPE, 2009, 2019; IBGE, 2010; IPCC, 2006; MCTIC, 2017; NEREUS, 2020).

According to Figure 4, food was the most relevant category, which induced GHG emissions, both in the highest income class (A1) and in the lowest income class (E). To address food related emissions, Brazilian agriculture has goals for more sustainable agriculture, which are established by the agriculture sectoral plan (ABC Plan). The ABC plan promotes the adoption of sustainable technologies that conserve natural resources (EMPRABA, 2018). However, despite sustainable improvements in agricultural management, behavioral changes in consumers are fundamental to achieve sustainable development (KALBAR et al., 2016).

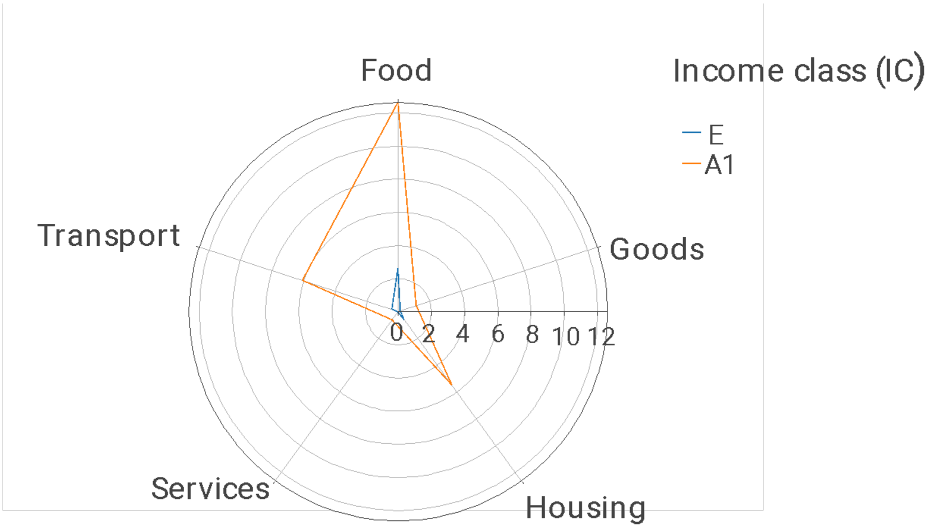
Reducing households carbon footprint through food consumption demands a change in behavior, which might come through alternative diets, such as substituting vegetables for meet, which yields ancillary benefits to health, besides GHG emissions reduction (ESTEVE-LLORENS et al., 2021). However, completely reducing animal protein consumption at the lowest ICs may do more harm than good. An entirely vegetarian diet could lead to some nutritional deficiencies (HERRMANN; SAUERBORN; NILSSON, 2020) and low-income people are likely to experience food insecurity, worry or uncertainty, and even lack or deprivation of food (TAVARES; LIMA, 2021). Food insecurity can also cause nutritional deficiencies (TAVARES; LIMA, 2021), thus, the reduction of animal protein in low-income families could further accentuate a situation of food insecurity and malnutrition.

Figure 4 shows that the contribution of the transport category stands out in the Brazilian household carbon footprints. For the construction of low carbon scenarios and reduction of CO_2 emissions, the use of bioenergy is an alternative usually considered. Brazil is a reference in the world bioenergy market, making the expansion of the use of ethanol in light vehicles is a viable option for low-carbon transport. In addition, electric vehicle technology, which already exists in the foreign market, might provide a fleet of new green vehicles in the future to serve the population of large Brazilian cities (CAMARGO; SIMÕES; PACCA, 2019). However, due to the high price of these vehicles (around BRL 100,000 in 2021), the lower income classes will not have immediate access to them (VICENZO, 2021), but the higher income classes certainly will, and being those that emit the most, it becomes fair for high-income families to purchase electric vehicles.

Compared to the carbon footprint of North American households, there is a difference between the importance of activities when compared to the Brazilian models of 2008 and 2018. In the North American model by Jones and Kammen (2011), the most relevant category for carbon emissions induction was transport, followed by housing and food. In the Brazilian models, however, there is an inversion, with the main induction category being food, followed by housing and transport. In the model by Steen-Olsen et al. (2016), the main categories follow the trend of the model by Jones and Kammen (2011), with transport being the main induction category, followed by housing, food, and recreation. In the model by Miehe et al. (2016), there is a change and the main category that drives carbon emissions is housing, followed by transport and food.

In contrast to the findings presented in the study conducted by López et al. (2016), the size of consumption is not the only factor that influences the carbon footprint of Brazilian families. While food accounted for around 68% of carbon emissions in class E (in 2018), the share of representation in this category drops to around 45% in class A1 (also in 2018). In 2018, the transport category accounted for around 6% of emissions in class E, while in class A1 it was around 15% (see Figure 4). So, there is a difference in representation.

Figure 4 - GHG emissions per consumption category in tCO_2e



Source: prepared by the authors based on (EPE, 2009, 2019; IBGE, 2010; IPCC, 2006; MCTIC, 2017; NEREUS, 2020).

Despite the significant value of GHG emissions, individual choices, changes in consumption habits and lifestyle are providing consumers with more transparent relationships with products and the impacts they cause on the environment. Some products such as Praya beer (first beer to offset its carbon emissions) and Nude hazelnut milk (first carbon neutral vegetable milk on the market) show how creating products with less carbon can help create a more sustainable relationship between brands and individuals (GOMES, 2021). In this way, consumers of products with high carbon intensity will tend to choose products with less emissions in the future.

Nevertheless, persuading individuals or families to choose more sustainable products demand public policies and information on the benefits of such consumption (BRAVO et al., 2013). For example, a public campaign in the United Kingdom led to a significant increase in awareness of the link between individual behavior and the environment (JACKSON; MICHAELIS, 2003). There are other studies that have shown that informative and normative policies are more effective than economic stimuli in producing behavioral changes (BRAVO et al., 2013). In Brazil, there are currently several carbon calculators that quantify emissions and help individuals to save or offset carbon. Some examples are the carbon calculators of the Bradesco bank (BRADESCO, 2021) and of the non-governmental organization SOS Mata Atlântica (SOS MATA ATLÂNTICA, 2021). But it is worth noting that families are still not willing to make drastic decisions regarding the reduction of their consumption (SKÖLD et al., 2018).

Conclusions

In Brazil, carbon emissions are very uneven, and the richest are the largest contributors (class A1 emitted almost 7 times more than class E, both in 2008 and in 2018). Changes in the lifestyle of wealthy families become a good alternative for mitigating climate change, although the quality of life of the poorest needs to improve. So, it's worth thinking about climate mitigation policies targeting the richest. It would be necessary to change eating habits, with a reduction in food of animal origin, a change in the way of getting around, changing individual transport for public transport, or fuel type (from gasoline to ethanol, for example), and the preference for short trips with active transport. The taxation of CO_2 emissions should target the consumption of the richest.

However, Brazilian household carbon footprints were mostly induced by diets, being smaller than the North American, Australian, and German household carbon footprints. In these countries, the carbon footprints were greater than in Brazil, and was driven by different categories. In any case, Brazilian household carbon footprints (for the most part) are smaller than those of high-income countries, which are shown to be the main responsible for carbon emissions, and consequently for climate change.

The footprints of the poorest must increase and their consumption must grow to meet appropriate levels of human well-being. Income transfer programs, such as *Bolsa Família*, and liquefied petroleum gas (LPG) cylinder rebate programs, such as the one carried out by Petrobras in 2022, are initiatives that help to reduce the ills of social, economic and carbon disparity in Brazil, but do not eradicate the problem.

Finally, results support the search for public policies, guided by environmental justice, aligning the balance of emissions, between income classes, with climate change mitigation.

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SciELO

Emissões de carbono das famílias brasileiras por meio da POF e da matriz de insumo-produto

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Sérgio Almeida Pacca

São Paulo. Vol. 26, 2023
Artigo Original

Resumo: O objetivo deste trabalho foi analisar a pegada de carbono das famílias brasileiras com base na Pesquisa de Orçamentos Familiares (POF) de 2008 e 2018. A metodologia utilizada neste artigo foi uma Avaliação de Ciclo de Vida híbrida. Segundo os nossos resultados, as famílias da classe de renda inferior emitiram cerca de 4,04 tCO_2e/ano em 2008 e 3,81 tCO_2e/ano em 2018, em contrapartida, as famílias da classe de renda mais alta emitiram cerca de 28,73 tCO_2e/ano em 2008 e 25,94 tCO_2e/ano em 2018, quase 7 vezes mais do que as famílias da classe de renda inferior. Enquanto as famílias mais pobres, que representavam 24,25% do total de famílias brasileiras em 2018, foram responsáveis por 11,97% do total de emissões, as famílias mais ricas foram responsáveis por 8,31% do total de emissões, embora representassem apenas 2,47% do total de famílias em 2018. Os mais ricos devem considerar uma mudança no seu padrão de consumo e buscar alternativas que impliquem em menos emissões para diminuir suas pegadas de carbono.

***Palavras-chave*:** Pegada de Carbono. Sustentabilidade. Modelo Insumo-produto. Pesquisa de Orçamento Familiar. Disparidade Social.

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Emisiones de carbono de las familias brasileñas a través del POF y la matriz insumo-producto

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São Paulo. Vol. 26, 2023
Artículo Original

Resumen: El objetivo de este trabajo fue analizar la huella de carbono de las familias brasileñas a partir de la Encuesta de Presupuestos Familiares (POF) de 2008 y 2018. La metodología utilizada en este artículo fue un Análisis de Ciclo de Vida híbrido. De acuerdo con nuestros resultados, las familias de menor ingreso emitieron alrededor de 4,04 tCO_2e/año en 2008 y 3,81 tCO_2e/año en 2018, en cambio, las familias de mayor ingreso emitieron alrededor de 28,73 tCO_2e/año en 2008 y 25,94 tCO_2e/año en 2018, casi 7 veces más que las familias de la clase de ingresos más bajos. Mientras que las familias más pobres, que representaban 24,25% de todas las familias brasileñas en 2018, fueron responsables del 11,97% del total de emisiones, las familias más ricas fueron responsables del 8,31% del total de emisiones, aunque representaron solo el 2,47% del total de emisiones. familias en 2018. Los más ricos deberían plantearse un cambio en su patrón de consumo y buscar alternativas que impliquen menos emisiones para reducir su huella de carbono.

Palabras-clave: Huella de Carbono. Sustentabilidad. Modelo de entrada-salida. Encuesta de Presupuestos Familiares. Disparidad Social.