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The increase in Brazilian household income and its impact on CO_2 emissions: Evidence for 2003 and 2009 from input–output tables

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ABSTRACT

In recent years, Brazil has experienced economic growth and a recovery of income that has had a positive impact on the consumption of goods. In this paper, we evaluate the impact of Brazilian household consumption on the CO_2 emissions for 2003 and 2009 using input–output tables from the World Input–Output Database. We used a semi-closed model with eight household groups in order to apply the hypothetical extraction method in the consumption structure of each group. Further, we use the result from the hypothetical extraction to evaluate the impacts of the structure consumption of each household group in terms of CO_2 emissions. We find that there is a trade-off between the households' greater satisfaction from consumption and the increasing setback in emissions from the restructuring and modification of the consumption basket. Thus, this study contributes to the research on emissions by mapping the recent behavior of the Brazilian economy in terms of increased income, changes in the consumption structure, and their impacts on emissions. The paper's aggregated results by income and consumption structure based on the intensity of the emissions and their systemic effects add to the discussions on less-polluting production processes, more conscious consumption of goods, and more rational uses of energy and transportation.

1. Introduction

The increasing levels of greenhouse gas (GHG) have existed since the beginning of industrialization. Therefore, the concentration of these gases in the atmosphere and the problems surrounding that concentration have increasingly become the focus of attention. In this context, an extensive literature has discussed the issues related to the emission of these gases. The focus has been on two different aspects: (i) assignment of the responsibility for the emissions to producers and (ii) the assignment of the responsibility to consumers.

In line with these aspects, two important questions have motivated recent studies: (i) How is responsibility for the emissions to be assigned? (ii) What economic agent is to be blamed? Wyckoff and Roop (1994), Schaeffer and De Sá (1996), Lenzen (1998), Machado et al. (2001), Munksgaard and Pedersen (2001), Peters and Hertwich (2004), Lenzen et al. (2004b), Gallego and Lenzen (2005), Hoekstra and Janssen (2006), Peters and Hertwich (2006), Turner et al. (2007), Wiedmann et al. (2007), Peters (2008), Davis and Caldeira (2010), Davis et al. (2011), Wiebe et al. (2012), and Carvalho et al. (2013) are some of the numerous studies that have made significant contributions to these areas.

Applying the input–output method, most of these authors have shown the importance of considering international trade in an environmental and energy use approach due to the significant amount of pollution embodied in international trade. Therefore, most of the recent literature highlights the importance of considering these pollutions in GHG abatement policies and point out that policymakers should consider the impact of international trade on emissions.

In line with the discussion on the allocation of responsibility for GHG emissions, there is a great deal of debate on the issues inherent to the relation between household consumption and emissions. As discussed by Weber and Perrels (2000), lifestyle influences the consumption of goods and energy and how "time" is spent, which in turn directly influences the pattern of emissions.

The attention paid to household consumption is primarily due to the fact that private consumption represents a major proportion of the final demand in most economies (Hertwich, 2011; Weber and Perrels, 2000). Thus, household consumption plays an important role in the diversity and volume of the produced commodities. In addition, as discussed by Weber and Perrels (2000), a detailed model of the pattern in household consumption offers increased possibilities to account for the effects of

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non-economic[2] influences on the direct and indirect use of energy that are related to household emissions.

Recently, many studies have linked the consumption choices of households to energy use through integrated input–output models: Lenzen (1998), Mukhopadhyay and Chakraborty (1999), Wilting et al. (1999), Munksgaard et al. (2000), Wier et al. (2001), Lenzen and Dey (2002), Lenzen et al. (2004a), Lenzen et al. (2006), Kerkhof et al. (2009a), Kerkhof et al. (2009b), Druckman and Jackson (2009, 2010), Washizu and Nakano (2010), and Das and Paul (2014). Further, Cohen et al. (2005) present important questions: "What is the relationship between energy intensity and household expenditure?" "Does the average household consume more energy directly through the purchase of energy itself than indirectly through the purchase of goods and services?"

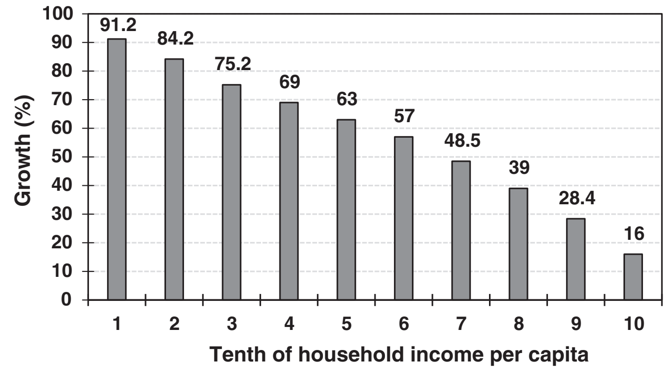
While the contributions of this literature are as diverse as possible, its main focus has been on the direct and indirect energy requirements and CO_2 emissions quantification of households for different countries and cross-country. In terms of results, as demonstrated by Hertwich (2005), there are large differences among countries in terms of goods and services contribution to total energy use and CO_2 emissions. Further, the majority of the works have shown that household characteristics, expenditure, and behavior have a significant influence on CO_2 emissions. Although there are some significant contributions, the empirical evidence needs more work to explain how a structural change in income impacts GHG emissions, particularly in a recent scenario of increase in income such as in Brazil.

In recent years, Brazil has experienced economic growth and the recovery of income. The increase in income has had a positive impact on the consumption of goods. Furthermore, this increase in consumption has had positive multiplier effects on the economy because the economy has had to offer more goods to meet the new and growing demand. On the one hand, structural change creates a favorable environment for the consolidation of a strong economy. This change in consumption and consequently the production process is often coupled with a higher level of pollution. Although seemingly unrelated issues, the evaluation of the impacts of variations in income on the level of emissions is correlated.

In Brazil, as discussed by Neri and Souza (2012), nominal income growth between 2001 and 2011 is evident.[3] Fig. 1 shows the growth of household income per capita divided into deciles of income. This figure shows that the lower income classes had higher growth in nominal income per capita. This growth was greater than 50% up to the sixth decile.

Fig. 2 shows the evolution of the average income for a period of 16 years. The average income grew mainly from 2003 to 2011.

Thus, given the evident variation in income levels in Brazil across income groups and in those related to household consumption and emissions, this study aims to assess the impact of household consumption on GHG, more specifically on the emissions of carbon dioxide (CO_2). The households are divided into eight consumption intervals based on the data from the Household Budget Survey (POF) and into eight income classes based on the National Household Sample Survey (PNAD).[4] These data provide the basis for the disaggregation of the consumption vector of the households and the vector of wages in the input–output table. The input–output tables are used for the years 2003 and 2009 in order to harmonize with the POF.



Source: Neri and Souza (2011) based on the data from National Household Sample Survey (PNAD).

Fig. 1. Growth of household nominal income per capita (2001–2011).

Because we seek to assess the impact of household consumption on GHG levels, we use a hypothetical extraction method on the expenditure structure. The use of such a method is justified to allow for the quantification of the interdependence between the sectors of the economy in terms of CO_2 emissions.

The main idea behind this method is that hypothetically extracting one household income group makes it possible to check how the products change and, therefore, how the emissions change. Because we have different income classes and therefore different preferences in consumption for a time horizon, the extraction of each one shows the relative importance of each consumption structure for emissions in Brazil.

Therefore, the method used aims to provide arguments on the weight of the consumption preferences for each household on pollution in a systemic input–output environment. In other words, in the extreme case, if there is no consumption by a particular income class, how much of a reduction in emissions would be achieved? Answering this question could identify the relative importance of each income class to the pollution process and the relation between consumption and pollution.

Besides this introduction, the paper is organized as follows: the second section provides a description of the methods and the database, the subsequent section presents the results, and the fourth section presents the final remarks.

2. Methods and database

2.1. Hypothetical extraction method[5]

According to Miller and Blair (2009) the objective of the hypothetical extraction method is to quantify how the total output of an economy with n sectors might change (e.g., decrease) if a particular industry or sector, the jth, is removed from the economy. This extraction can be performed in three ways: (a) the total extraction of an industry (or an agent)—columns and rows, (b) extraction of the consumption structure (backward linkages)—extraction of the columns, and (c) the extraction of the sales structure (forward linkages)—extraction of the rows. We are interested in the extraction of the consumption structure.

Consider the general case of a closed input–output model for households with n productive sectors and m households. In this model with endogenous households, the matrices have the following dimensions: $(n+m)x(n+m)$.

The model is given by

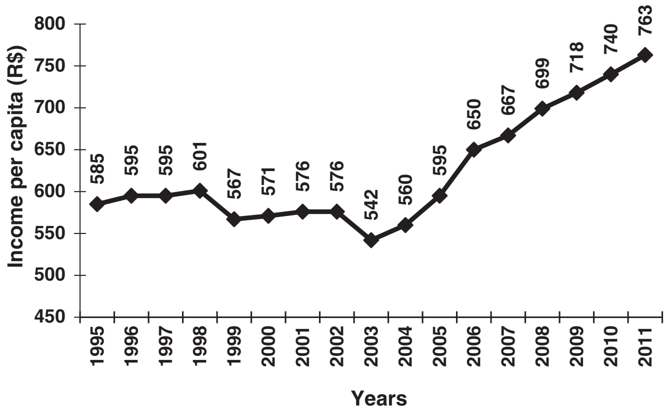
$$x = A^{*}x + f^{*} \quad (1)$$

[2] This means that lifestyle factors (i.e., cultural climate, societal values and norms, habit formation, expenditure patterns of money, and time) can lead to different structures of household consumption. However, we do not take these factors explicitly into account.

[3] Nominal income growth patterns by income class can be different from real income growth patterns since, for example, the inflation rates for those products especially important for lower income groups is higher than average. In other words, the structure of consumption basket and inflation rates by products can lead to a different pattern between nominal and real side.

[4] POF—Pesquisa de Orçamento Familiar. PNAD—Pesquisa Nacional de Amostra Domiciliar. Further details can be found in the next section.

[5] The hypothetical extraction method (HEM) is used to measure the CO_2 emissions inter-sector linkages in other studies, but not to assess the impact of household consumption on GHG. See studies of Australia (Temurshoev, 2009), China (Wang et al., 2013), 33 WIOD countries (Temurshoev and Oosterhaven, 2014), Italy (Ali, 2015), and South Africa (Zhao et al., 2015).



Source: Neri and Souza (2011) based on the data from PNAD.

Fig. 2. Average income (R$).

where x is a column vector of output with $(n + m)$ elements, A^* is a matrix $(n + m)x(n + m)$ of input coefficients, and f^* is a column vector of final demand with $(n + m)$ elements and without household consumption.

The solution to Eq. 1 is

$$x = (I{-}A^*)^{-1} f^* \tag{2}$$

where $B^* = (I - A^*)^{-1}$ is the Leontief inverse matrix. Eq. 2 induces the impacts of the hypothetical extraction of a particular agent. In this paper, we extract the consumption structure of each household group. Thus, generically, the jth household group does not acquire inputs from the productive sectors; that is, we extract the backward linkages.

The new matrix A^* is represented by $\bar{A}^*_{(cj)}$, which is the hypothetical extraction of the jth column from matrix A.

Therefore, the solution to this problem is

$$\overline{X}^*_{(cj)} = \left[I{-}\overline{A}^*_{(cj)}\right]^{-1} f^* \tag{3}$$

Comparing Eqs. 2 and 3, we can calculate the impacts of the extraction of the backward linkages from $i'x^*{-}i'\overline{x}^*_{(cj)}$, that is, a measure of the total backward linkage for the sector j. The result can also be disaggregated by sectors in which each element of the vector $x_i{-}\overline{x}^*_{(cj)i}$ shows the backward dependence of the sector or agent j relative to sector i.

2.2. Impact on emissions

The hypothetical extraction method provides the impact on production from the extraction of the households' consumption structure. The method's results can be interpreted as the change in the output of the economy due to that extraction. Therefore, to verify the impacts on emissions, it is necessary to interpret the decrease in production in terms of emissions. To do this, we use the following emission intensity vector (e_i),

$$e_i = \frac{E_i}{X_i} \tag{4}$$

where E_i is the vector with $(n + m)$ elements of CO_2 emissions, including sectorial, and household emissions and X_i is the vector with $(n + m)$ elements of total output.

The impact of the extraction of each household group on emissions is

$$\text{Emissions}_i^I = \text{diag}(e_i) * \left(x_i^I{-}\overline{x}^{*I}_{(cj)i}\right) \tag{5}$$

where Emissions_i^I is the total CO_2 emissions for each household extraction I, sector i, $\text{diag}(e_i)$ is the diagonal matrix of e_i, and $(x_i^I{-}\overline{x}^{*I}_{(cj)i})$ is the backward dependence of sector j relative to sector i. The impact on sectorial output is the extraction of household group I.

It is important to note that in this paper, we have $I = 1,\ldots,8$ and $i = 1,\ldots,23$ (15 productive sectors and 8 households).

Table 1
Household's consumption structure by percentiles of income.

Consumption data—POF (R$ per capita and per month)		
Household group	Year: 2003 Intervals	Year: 2009 Intervals
Household 1	Below 96.00	Below 186.70
Household 2	[96.00, 158.87)	[186.70, 297.00)
Household 3	[158.87, 227.66)	[297.00, 422.43)
Household 4	[227.66, 310.41)	[422.43, 570.02)
Household 5	[310.41, 432.50)	[570.02, 767.91)
Household 6	[432.50, 641.23)	[767.91, 1095.55)
Household 7	[641.23, 1156.46]	[1095.55, 1833.58]
Household 8	Above 1156.46	Above 1833.58

Source: the authors based on data from POF.

2.3. Database

We use the data from the WIOD (World Input–Output Database[6]). It consists of input–output tables covering 40 countries (27 countries of the European Union and 13 other major countries) plus the "Rest of the World" for the period from 1995 to 2011.[7] A model for the "Rest of the World" is provided in order to have a complete value-added decomposition of final output. The input–output tables contain data for 35 industries covering the overall economy. The range of sectors comprises agriculture, mining, industries (i.e., construction, utilities, 14 manufacturing industries), and services (i.e., telecom, finance, business services, personal services, eight trade, and transport service industries and three public service industries)—see Appendix Table A1. These world input–output tables (WIOT) have been constructed by national input–output tables that are connected with each other by bilateral international trade data (Timmer et al., 2015), following the conventions of the System of National Accounts (SNA). Furthermore, the WIOD database has environmental satellite accounts (WIOD environmental accounts), including CO_2 emissions data for the same range of countries and sectors of input–output tables, but only from 1995 to 2009.[8]

Thus, to assess the impact of Brazilian household consumption on GHG levels, we use two input–output tables at current price on Brazil for 2003 and 2009. We use these years in order to harmonize the input–output data set with the disposable information from the POF. Furthermore, we use atmospheric CO_2 emissions (in tons) for the same country and the same range of time and the same sector.[9]

The emissions information used in this paper refers mostly to emissions from the WIOD environmental account of energy use. Less than 7% of the CO_2 emissions are non-energy produced. From this database,CO_2 emissions were reported according to the intermediate use by industry and final use by households. Other types of emissions reported in both

[6] For more details about the WIOD project, see Dietzenbacher et al. (2013) and Timmer et al. (2015).

[7] Brazil has official input–output matrices for 1995 to 2000 and 2005, however, it does not have them for 2003 and 2009. It has only the supply and uses tables for these two years, which means that it is necessary to estimate them. Thus, it is not possible, from the available official data, to assess the impact of Brazilian household consumption on GHG levels for a more recent period that reflects the increase in the Brazilian household income. Therefore, since the WIOD database is compatible with official macroeconomic accounts and has been constructed by national input–output tables that are connected with each other by bilateral international trade data, following the conventions of the SNA, we have used input–output tables on Brazil for 2003 and 2009 from this database. Another motivation to use these matrices comes from the fact that the WIOD database has the Brazilian CO_2 emissions for the same range sectors and years, which minimize problems upon new reconciliations.

[8] For more details about the WIOD environmental and socioeconomic accounts, see Timmer (2012) and Genty et al. (2012).

[9] For more details about the sectors, see the appendix (Table A1).

Table 2
Nominal income growth rate between 2003 and 2009.

	HH1	HH2	HH3	HH4	HH5	HH6	HH7	HH8
Nominal Income Growth Rate between 2003 and 2009	73.55%	43.84%	22.87%	26.16%	38.50%	36.57%	27.47%	19.88%

Source: the authors based on data from the POF.

the WIOD database and the national emissions inventory of 2010 were not considered in this work, such as emissions from change in land use and forestry, materials use, and other products. The national emissions inventory refers to the Second National Communication of Brazil to the Convention—United Nations Convention on Climate Change (MCTI, 2010), whose most recent information was reported for the year 2005. Information on energy emissions from the WIOD database was compiled from the energy balance of the IEA (2011). Additional information and parameters were used to bridge between territory and residential principles and accommodate the structured data in the IEA accounts to the classification and concepts of the WIOD structure. The complete methodology of estimating the procedure of the emissions of the environment satellite account of the WIOD is described in detail by Genty et al. (2012).

Despite the sectorial structure of the WIOD tables, we aggregate the sectors into 15 new sectors to better identify a household consumption structure. To do this aggregation, we follow the structure proposed by Jorgenson et al. (2013). Table A1 in the appendix contains our typology.[10] Furthermore, we use income data for Brazil from the PNAD[11] for 2003 and 2009 and consumption data for the POF[12] for 2000 to 2003 and 2008 to 2009.

It is also important to consider the reconciliation of the data from the POF with the data from WIOD input–output tables. The first step is to match the POF products with the goods and services that make up the household consumption's column vector (1×35) in the input–output tables. We create a translator that collapses the 10,360 products in the POF with the 35 products in the WIOD input–output tables. The second step after the aggregation of the expenditure items is to build a matrix that distributes the spending of 35 different products in eight household groups that are based on the income module of the PNAD. Therefore, we disaggregate the household group (consumption units) into eight types by income per capita (percentiles of income). Further, we weight each yield by the respective sample expansion factor to acquire the universal data. Table 1 shows the intervals.

The final aggregation into the 15 productive sectors is as we described in the previous section. The aggregation is available in the appendix (Table A1).

3. Results

Given the focus of this study, the behavior of the income in each household group in terms of variation between the years 2003 and 2009 is important.

Table 2 shows the nominal income growth rate between 2003 and 2009 of each household group (HH1 to HH8). The table shows that there is growing nominal income for the lowest group, as expected. The nominal income growth rate of the lowest household group is 73.55%, and for the highest is 19.88%. The result for the lowest household group is due to the recent Brazilian income policy of transfer, including “Bolsa Família,” “Bolsa-Alimentação,” “Bolsa-Escola,”[13] and an increase in the minimum wage.

In Fig. 3, we observe the household's consumption structure in Brazil by income group for 2003 and 2009. The mapping of the consumption structure enables us to observe that the consumption structure differs among the household groups. Furthermore, it is possible to observe changes in the consumption structure between 2003 and 2009 for all of the groups. The household groups with lower income (HH1 to HH4) are becoming less concentrated, which means that there is a diversification in the consumption basket of these groups.

For illustrative purposes, Table 3 shows the distribution of the CO_2 emissions between intermediate consumption and the household consumption. The distribution illustrates a stable structure. The data show that households were responsible for approximately 22% of the emissions in 2003 and 2009. Although there are no significant changes in the period under review, the results indicate the importance in the study of the relationship between household consumption in an income growth environment and the amount of CO_2 emissions. This is due to household consumption's significant share in the economy.

With regard to sectorial emissions, Figs. 4 and 5 present the distributions of the emissions for each household group (HH1 to HH8) within the industry structure for the years 2003 and 2009, respectively. In other words, these figures show the share of each sector in the total CO_2 emissions in 2003 and 2009.[14]

In general, the sectorial structure of the emissions by household group is similar when a comparison is made between the years 2003 and 2009. The main changes can be observed for HH1 and HH8, respectively. For the lowest income class there is a loss of participation in the clothing and shoes sector in terms of emissions, from 52.63% in 2003 to 37.55% in 2009. This loss of participation is mainly because of the increased consumption of this household group relative to the other sectors, which can be seen through the percentage increase of all of the other sectors in relation to the emissions.[15] Similarly, for the highest household group, Household 8, we can also observe a loss of participation in the Clothing and Shoes sector, but at a lower rate (31.08% in 2003 and 26.87% in 2009). This loss of participation is mainly because of the increased participation in the personal services sector, which has an increase from 11.30% in 2003 to 17.57% in 2009. The participation of the transportation services sector for HH8 is approximately 11% and 10% for 2003 and 2009, respectively, and is significant. For HH1 to HH6 the participation is approximately 4% and is 6.13% for HH7 in 2003. However, it is 2% for HH1 to HH5 and 4% for HHs 6 and 7 in 2009.

Just as in the transportation services sector, for the personal services sector, we also observe a significant difference in terms of participation among the different household groups. For HH1 to HH7 the largest

[10] The final typology considers the representative structure of household consumption, with a lower number of sectors than the WIOD, however, without generality loss. The main idea of using this typology is to show and discuss the results in a more comprehensive form.

[11] The PNAD is a survey by the Brazilian Institute of Geography and Statistics (IBGE—Instituto Brasileiro de Geografia e Estatística) of a sample of Brazilian households. It provides information on various socioeconomic characteristics of Brazilian society, such as population, education, labor, income, housing, social security, migration, fertility, marriage, health, nutrition, among others. In this work, we use the income module to capture the income received from work, retirement, pension, permanent allowance, rent, and other income.

[12] The POF is a sample survey also conducted by the IBGE that aims to study the pattern of consumption and expenses of the Brazilian population by monitoring households for 12 months. The POF provides information about individuals (e.g., age, level of education, and income), households (e.g., existence of sewage, walls, and vehicles), and different records for each type of expenditure carried out.

[13] Both of these programs are funded by the Federal Government and this consists of cash transfer to poor families in order to decrease the income inequality in Brazil.

[14] The share in Figs. 4 and 5 is calculated as follow: $share_{ia} = E_{ia} / E_a$, where E_{ia} is the CO_2 emissions of the productive sector i in the year $a$and E_a is the total CO_2 emissions in the year a.

[15] Sectorial emissions are directly and proportionally related with the structure of consumption, given the method we use in this paper.

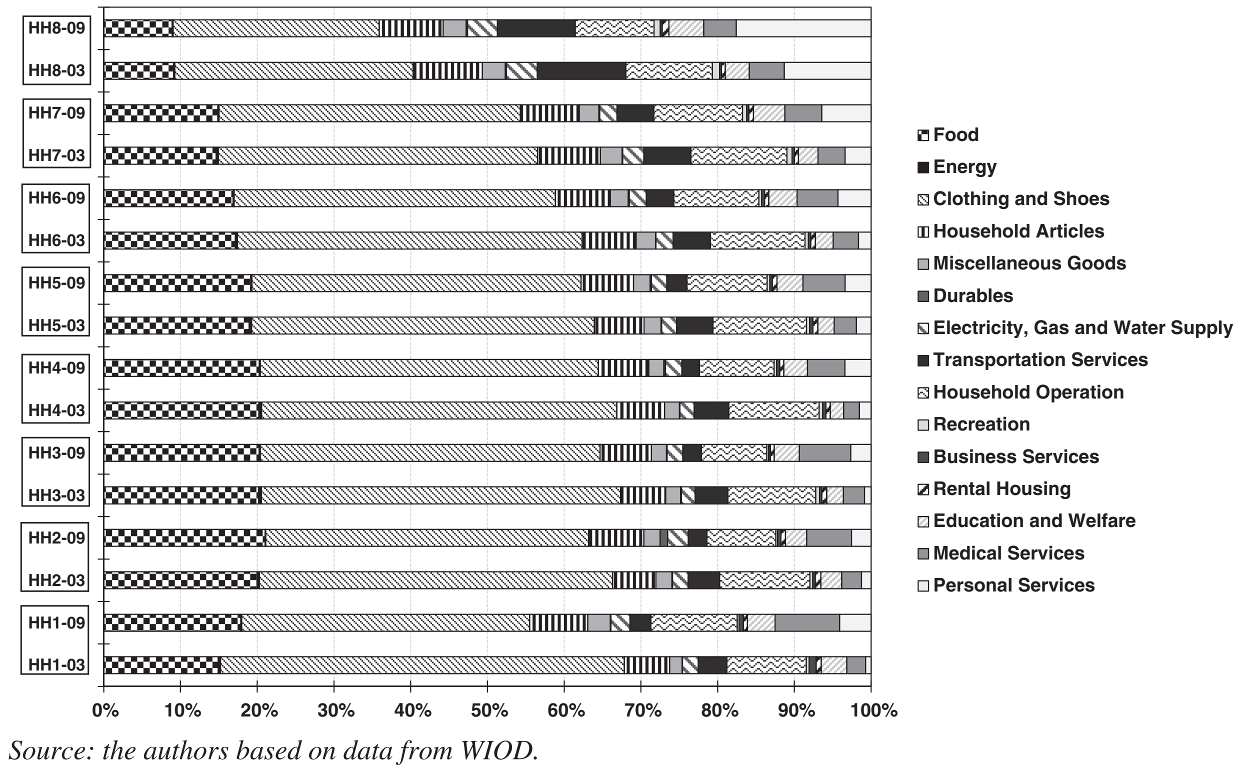


Fig. 3. Household consumption structure in Brazil by income group—2003 and 2009.
Note: The changes in consumption by sectors might be greatly influenced by variations in sectoral inflation rates since the shares are calculated based on nominal values.

share is 3.38% in 2003 and 6.43% in 2009, whereas for HH8, this participation is 11.30% and 17.57% for 2003 and 2009, respectively.

From this point, we analyze the main results. We present the disaggregated results in sectorial terms and by household group. These results illustrate the correlation between income, consumption, and emissions in the Brazilian economy.[16]

Fig. 6 shows the intensity coefficients of the CO_2 emissions by sector and income class. These coefficients (e_i) evaluate the impacts with regard to emissions. They also allow for the measurement of the sectorial losses in the total output of the emissions, $Emissions_i^l$ (see Eq. 5). Thus, the coefficients are important because they have a direct relation with the result of the environmental impact.

Fig. 6 also shows that the intensity of the CO_2 emissions is lower in 2009 than in 2003 for all of the productive sectors, and in particular for the coefficients of the transportation services, electricity, gas and water supplies, and energy sectors. We also observe the same pattern for all eight of the income classes. Although it is possible to observe lower intensities in 2009 compared to 2003, these results do not necessarily indicate that the production processes of these sectors have lower emissions. We observe that in 2009, for the households with the larger income (HH4 to HH8) there is a slight decrease in the intensity coefficient. In other words, this demonstrates that the consumer baskets tend to become less energy-intensive as income increases for those groups of income class. This result is in line with Lenzen et al. (2006).

Fig. 7 shows the proportion of the impact on emissions according to the eight household income classes considered in 2003 and 2009. Given the impact in terms of CO_2 emissions derived from the extraction of each income class, we sum the impacts and then calculate the relative proportion of each class in each year separately. The figure shows that the highest income class (HH 8), when removed from the analysis, produces the most negative impact on the CO_2 emissions compared with the other classes: −65.53% in 2003 and −63.78% in 2009. Although the results are still concentrated in the class with the higher income, there is a small structural change in 2009 compared to 2003. By 2009, the increased participation of the seven classes has larger negative effects on the CO_2 emissions than those produced in 2003, even though these are in small proportions.

Overall, these results capture the increase in income experienced by the Brazilian economy and the increase's major impact in terms of CO_2 emissions. On the other hand, if the income growth implies a shift of consumption patterns toward sectors with higher emission intensities, we could also see an increase of emissions intensity by household group. This result is in line with the direct requirement analysis made by Cohen et al. (2005), showing a continuous increase in this requirement from the lowest to the highest income class.

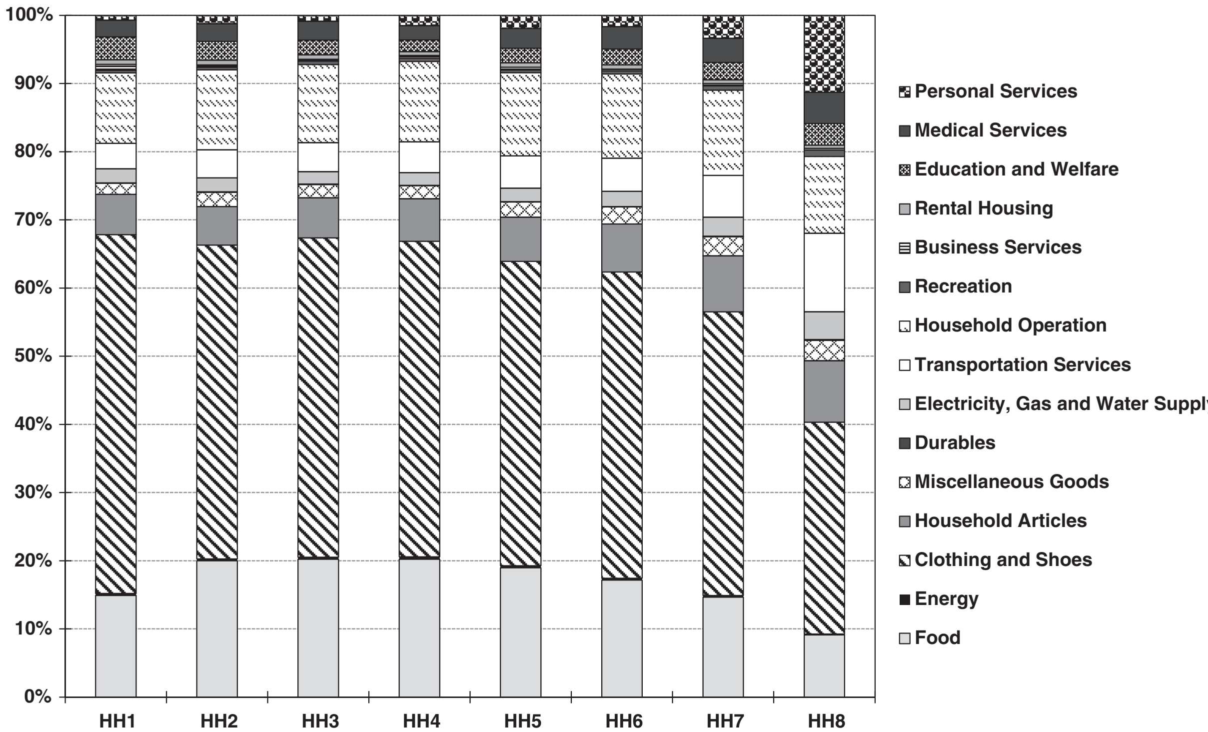
In order to capture the changes and to measure the effect of income growth within the income class, Fig. 8 presents the growth rates of the impacts generated by the hypothetical extraction. In other words, it shows the growth of the impact of the household hypothetical extraction between 2003 and 2009 on the emissions for each household. The figure shows that HH3 has the highest growth rate at 59.84%, followed by HH5 at 49.47%, and HH4 at 49.17%. However, the higher income class (HH8) has the lowest growth rate at 27.70%.

Table 3
The share of intermediate and household Brazilian consumption emissions in the WIOD database.

	1995	2000	2003	2005	2009
Intermediate consumption	76.3%	77.3%	77.9%	78.1%	77.9%
Household consumption	23.7%	22.7%	22.1%	21.9%	22.1%

Source: the authors based on data from WIOD.

[16] For a large country like Brazil, it is important to say that there are differences in terms of consumption baskets by region. Thus, the evolution of tastes can be related to income and location. However, as we are working with national input–output matrices, we will not deal explicitly with these differences, but they are endogenous in the household vectors.

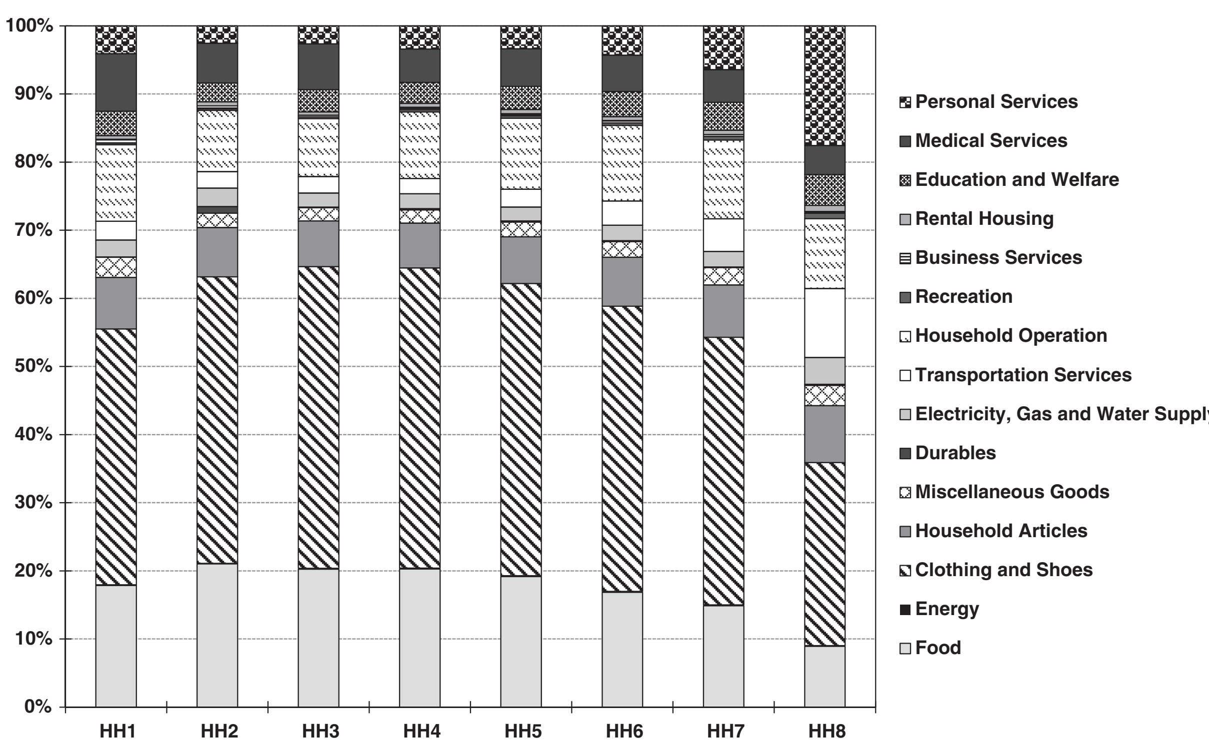


Source: the authors based on data from WIOD.

Fig. 4. Sectorial share of Brazilian CO_2 emissions—2003.

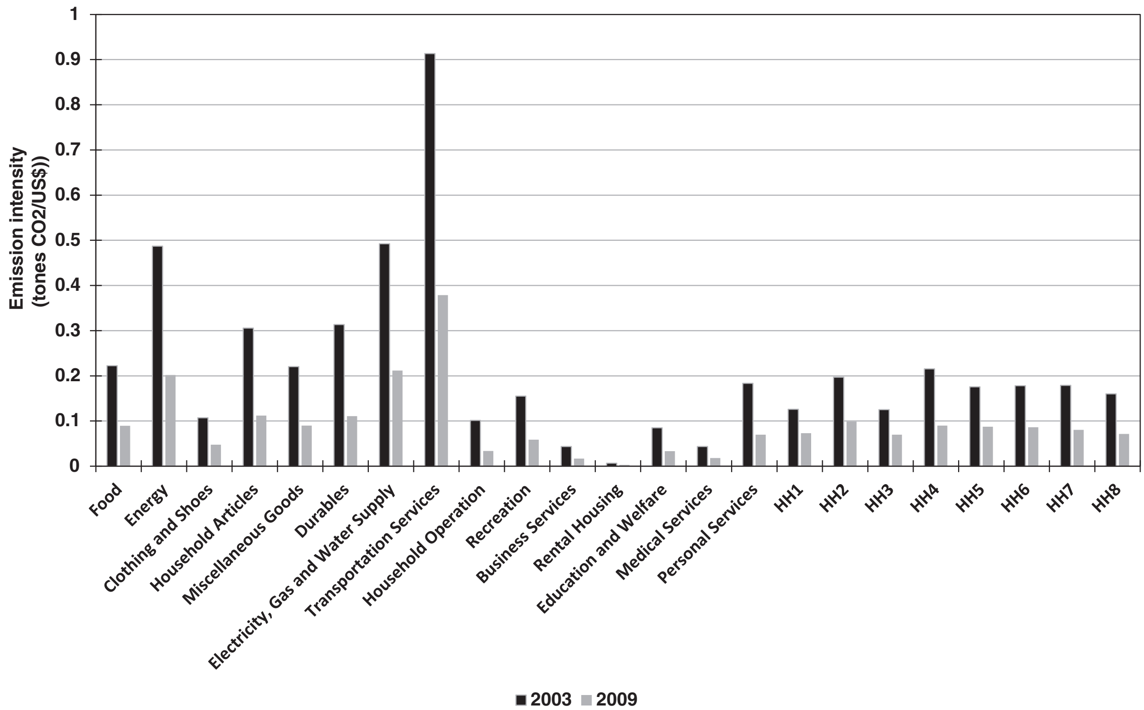
Thus, this result shows how the income growth of the lower income classes affects CO_2 emissions. However, there is no direct relation because the class with the highest growth rate in income is not the one with the highest growth rate in terms of its impact on CO_2 emissions, which can be explained by the different structure of consumption between the classes.

Furthermore, the total emissions by household increase by around 23% during the period 2003 to 2009, which is due to the increase in



Source: the authors based on data from WIOD.

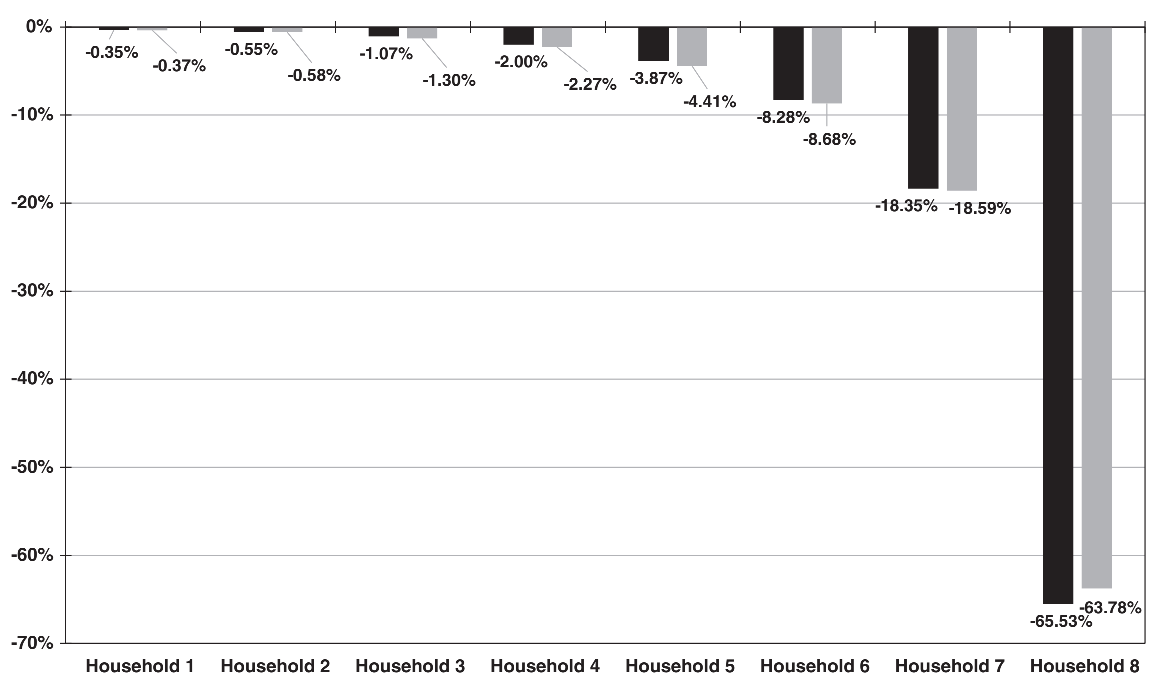
Fig. 5. Sectorial share of Brazilian CO_2 emissions—2009.



Source: Authors' calculations based on data from WIOD.

Fig. 6. Intensity coefficients of CO_2 emissions (2003 and 2009).

consumption linked to an increase in the household income. This results shed light on the necessity for an in-depth analysis of CO_2 emissions from the household side. We implemented an impact analysis through the extraction and observed that the major impact is from HH8. On the other hand, in Fig. 8, the analysis of growth rate shows us that we also need to consider the household with the smallest income. There is no consensus about the best mechanism to reduce emissions as part of a climate policy. Among other mechanisms, we can highlight government regulations, taxes, carbon trade, market mechanisms, subsidies, cap-and-trade, and carbon tax. However, we can affirm that, in



Source: Authors' calculations.

Fig. 7. Share of the impact on emissions according to the household groups.[17].

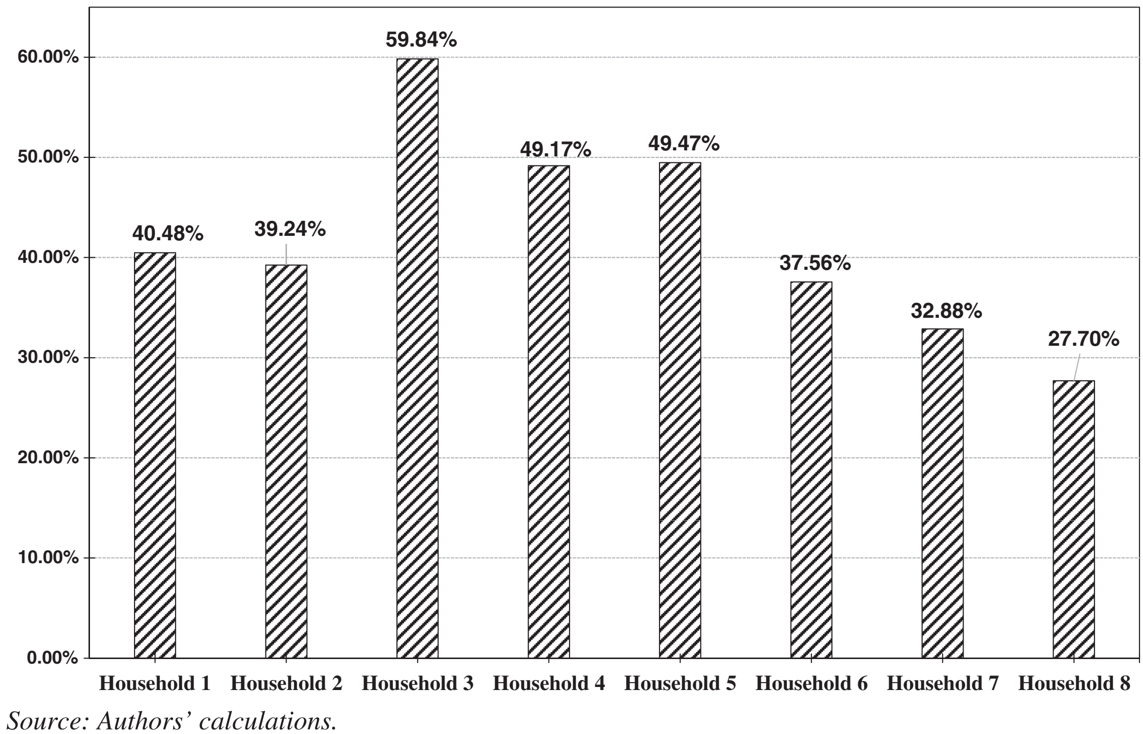


Fig. 8. Growth rate of the impact within the same income class.

terms of a policy perspective, the feasibility of these mechanisms are not high.

Thus, in order to observe these results in terms of sectors, Fig. 9 shows the proportion of the impact on sectorial emissions according to the household income classes. Observing the figure, we verify how much of the consumption structure and the income of each household group systemically affects the production and, consequently, the sectorial emissions.

Fig. 9(a) shows the results for the lowest income group (HH1). In this case, the consumption structure and income of this household group affects the economy such that the transportation service, food, durables, energy and electricity, and gas and water supplies sectors are the most negatively impacted in terms of emissions in 2003 and 2009. This is the expected result because the household groups of lower income tend to have a structure of spending that more intensively mobilizes the inputs related to the food production chain, transportation, and the provision of basic services. The withdrawal of this household group produces obvious but major negative effects on the production and emissions from these sectors.

As we observe the results for the other income classes in ascending order of income, Fig. 9(b) to Fig. 9(h), there is a change in the pattern of the proportion of the most affected sectors. The transportation sector, for example, has two peculiarities in this process, especially in 2003. The first is that the household groups with higher levels of income mobilize the economy more strongly, including the transportation sector. Thus, the higher the income level of the household group the higher the effect on the transportation sector tends to be.[17] The second peculiarity is that the Transportation sector has one of the highest emission intensity ratios (see Fig. 6) of that year. Thus, it follows that these two coupled effects play an important role in the Transportation sector in terms of reducing emissions.

Another important result is the significant change of the impacts in the Food sector among the different income classes. The negative impact is much higher for the lowest income class. On the one hand, for HH1, the impact is approximately 20% in 2003 and 17.3% in 2009. However, for the highest income group (HH8), the impact is approximately −14% and −13.8% for 2003 and 2009, respectively. Moreover, when withdrawing in the order of increasing income levels, the effects tend to be less concentrated. The sectors such as energy and durables, for example, now have a greater contribution to the fall in emissions.

The results presented by the durable goods, energy, and transportation sectors imply that the increase in income in the Brazilian economy leads to higher consumption of these goods. However, what this study shows is that there is a "price" in terms of CO_2 emissions. Therefore, the results show that there is a trade-off between the greater satisfaction that the household groups find in consumption and the increasing setbacks in emissions from the restructuring and modification of the consumption basket.

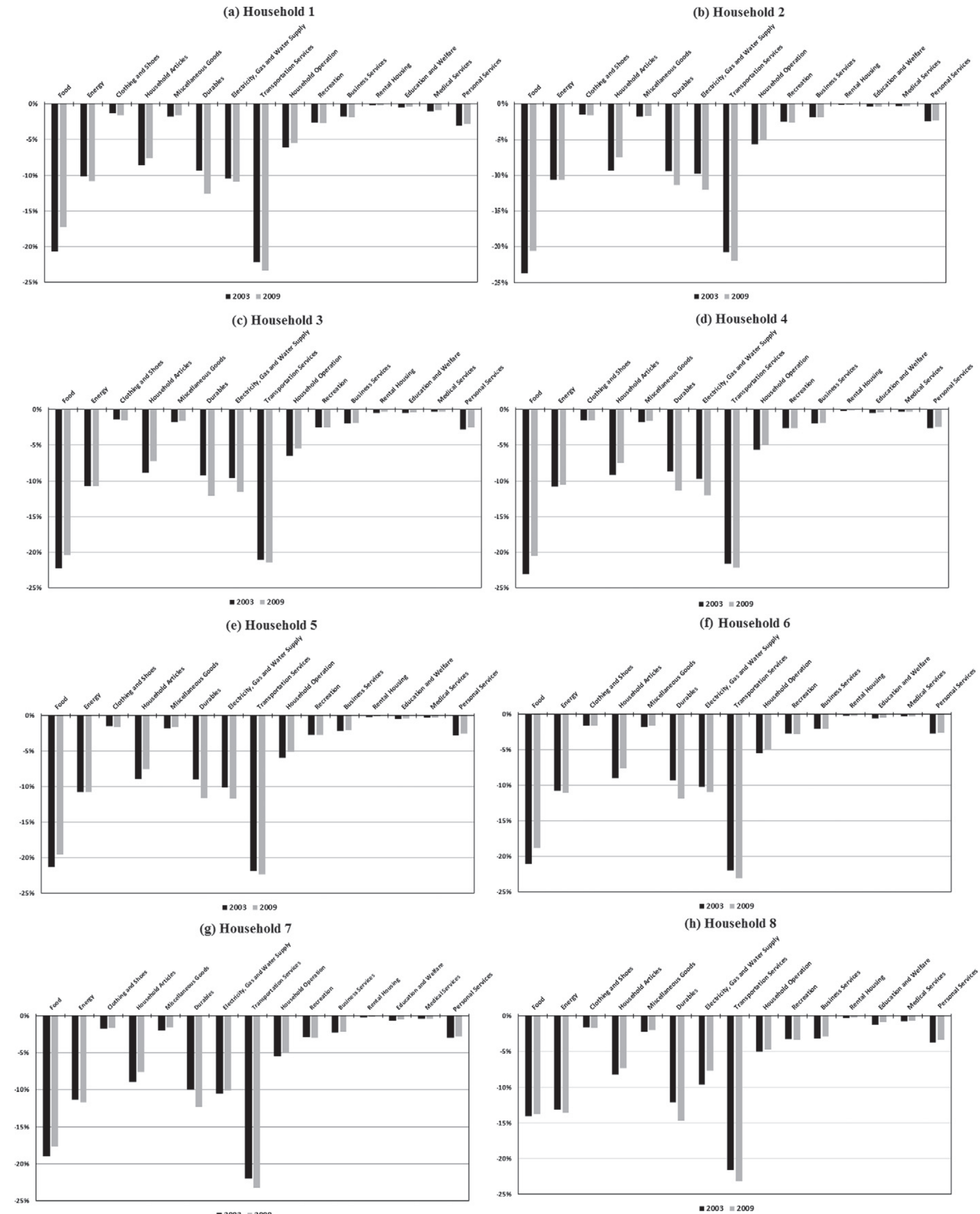
The apparent differences in the impact on emissions between 2003 and 2009 are due to two effects when a household group is withdrawn from the analysis: the systemic effect on production and the effect on the emission coefficients. In 2009, there are major changes in the intensity of the emission coefficients in relation to 2003. The standard deviation of the emission coefficients in 2009 is equal to 0.0798, while the standard deviation of the coefficients in 2003 is equal to 0.1940. Therefore, the variability of emission intensity coefficients in part explains the difference in the results between 2003 and 2009.

Furthermore, as affirmed by Lenzen et al. (2004a) the environment pressures and resource depletion is linked to the activities related to households. These are, for example, consumption of fuels, and energy. Thus the sectorial analysis presented in this paper helps to address the sources of environmental pressures from the perspective of household consumption.

4. Concluding remarks

This study evaluates the impact of household consumption on CO_2 emissions. By implementing the hypothetical extraction method, we

[17] This result is in line with Cohen et al. (2005).



Source: Authors' calculations.

Fig. 9. Proportion of the impact on sectorial emissions according to the household groups.

verify how the extraction of each household group (divided into eight groups) affects the sectorial output of emissions in the Brazilian economy. The input–output structure highlights the impacts in their systemic form. Therefore, the structure contributes to the results in terms of sectorial interdependence. By longitudinally evaluating the emission process, the results show that there was a reduction in emissions in 2009. This outcome is of great importance in our context.

From the hypothetical extraction of each household income class, we find some interesting results: the Transportation sector has the greatest negative impact over the period analyzed for all household income groups. The food industry, like most other sectors, decreases its emissions and is more pronounced in the lower consumption classes. In addition, the service sector has the least impact. These results are in line with the arguments that consider the evaluation of emissions, with particular attention to household consumption, important. This is the most significant component of the final demand in most countries and therefore plays a key role in the growth multiplier effect. In this paper we report the logic of consumption (or non-consumption—given the extraction of consumption vectors) to account for the effects of the influence of lower consumption in favor of the evaluation of the emissions.

The analysis should consider that because the consumption levels of the highest income classes are large, they should generate more emissions, and a small variation in the consumption could have a significant impact on emissions. Looking at the structure of household consumption, we observe that for 2003 the consumption of HH8 is around four times that of HH7. For 2009, it is 4.5 times greater than the consumption of HH7. These numbers strengthen the idea that, from the consumption perspective, the higher level income groups are much more important. Even with the income growth being higher for the low-income group, it would not be enough to change the contribution/impact of the highest level.

It is also necessary to consider at this point the direction of consumption arising from additional income. The consumption pattern has changed over the years and the level of energy intensity in most products consumed from additional income drives the identification parameter of the impacts on emissions. Again, the income groups have different patterns of consumption, and this is an important part of the explanation of the results.

Thus, the study contributes to the research agenda in the area of emissions by mapping the recent behavior of the Brazilian economy in terms of increased income, changes in consumption structure, and their impact on emissions. Furthermore, the paper demonstrates the extent to which households are important to emissions and shows that emissions are strongly correlated with income and that, in general, lower income, more vulnerable households, tend to have lower than average CO_2 emissions. On the other hand, in 2003 the richest household group (HH8) emitted eight times the amount of (HH1 to HH5) households. For 2009 they emitted seven times more.

It is not the aim of the paper to provide an ample discussion on mitigation processes. However, as the paper shows, the aggregated results by income and by consuming structure are partly due to the intensity of the emissions and the systemic effects. Thus, it is possible to discuss less-polluting production processes, more conscious consumption of goods, more rational uses of energy and the transportation system. There are many options to motivate behavioral changes in household consumption, such as coercion, communication with the people about their attitudes, economic measures, and institutional changes.

Furthermore, the picture presented in this paper leads us to affirm that the policy implications of our results are not easy to discuss, because there are several factors that influence the distributional impacts of some policies, or groups of policies. We can think about what is the overall implementation cost of a policy, which types of household are most likely to benefit and which are the ways the costs are recovered (i.e., per unit of energy, per customer, via taxation). In addition, a prerequisite for fostering pro-environmental behavior appears to be allowing participation, that is, enabling the consumer to find their own strategies and procedures to mitigate the emissions.

As a future research, the decomposition of the changes in emissions over time in Brazil in three components – sectorial emission coefficient changes, consumption pattern changes, and income changes – could be interesting and would introduce another point of view about the relationship between household consumption and emissions.

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Appendix A

Table A1
Sector typologies.

WIOD Code	WIOD Sectors	Typology I	Typology II	Typology III	Our Typology
1	Agriculture, Hunting, Forestry and Fishing	Non-durables	Food	Food	Food
2	Mining and Quarrying	Non-durables	Energy	Fuel-Coal	Energy
3	Food, Beverages and Tobacco	Non-durables	Food	Beverages and Tobacco	Food
4	Textiles and Textile Products	Non-durables	Consumer Goods	Clothing	Clothing and Shoes
5	Leather, Leather and Footwear	Non-durables	Consumer Goods	Shoes	Clothing and Shoes
6	Wood and Products of Wood and Cork	Durables	Consumer Goods	Household Articles	Household Articles
7	Pulp, Paper, Paper , Printing and Publishing	Non-durables	Consumer Goods	Miscellaneous Goods	Miscellaneous Goods
8	Coke, Refined Petroleum and Nuclear Fuel	Non-durables	Energy	Gasoline and Oil	Energy
9	Chemicals and Chemical Products	Non-durables	Consumer Goods	Household Articles	Household Articles
10	Rubber and Plastics	Non-durables	Consumer Goods	Household Articles	Household Articles
11	Other Non-Metallic Minerals	Durables	Durables	Durables	Durables
12	Basic Metals and Fabricated Metal	Durables	Durables	Durables	Durables
13	Machinery, Nec	Durables	Durables	Durables	Durables
14	Electrical and Optical Equipment	Durables	Durables	Durables	Durables
15	Transport Equipment	Durables	Durables	Durables	Durables
16	Manufacturing, Nec; Recycling	Durables	Durables	Durables	Durables
17	Electricity, Gas and Water Supply	Non-durables	Energy + Water Supply	Electricity, Gas and Water Supply	Electricity, Gas and Water Supply
18	Construction	Durables	Durables	Durables	Durables

(continued on next page)

Table A1 (*continued*)

WIOD Code	WIOD Sectors	Typology I	Typology II	Typology III	Our Typology
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	Consumer Services	Transportation	Transportation Services	Transportation Services
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	Consumer Services	Household Operation	Other Household Services	Household Operation
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	Consumer Services	Household Operation	Domestic Service	Household Operation
22	Hotels and Restaurants	Consumer Services	Miscellaneous Services	Recreation	Recreation
23	Inland Transport	Consumer Services	Transportation	Transportation Services	Transportation Services
24	Water Transport	Consumer Services	Transportation	Transportation Services	Transportation Services
25	Air Transport	Consumer Services	Transportation	Transportation Services	Transportation Services
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	Consumer Services	Transportation	Recreation	Recreation
27	Post and Telecommunications	Consumer Services	Household Operation	Communication	Household Operation
28	Financial Intermediation	Consumer Services	Miscellaneous Services	Business Services	Business Services
29	Real Estate Activities	Consumer Services	Housing	Rental Housing	Rental Housing
30	Renting of M&Eq and Other Business Activities	Consumer Services	Household Operation	Business Services	Business Services
31	Public Admin and Defense; Compulsory Social Security	Consumer Services	Miscellaneous Services	Welfare	Education and Welfare
32	Education	Consumer Services	Miscellaneous Services	Education	Education and Welfare
33	Health and Social Work	Consumer Services	Medical	Medical Services	Medical Services
34	Other Community, Social and Personal Services	Consumer Services	Consumer Services	Personal Services	Personal Services
35	Private Households with Employed Persons	Consumer Services	Consumer Services	Personal Services	Personal Services

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