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Demographic change in Brazil and its impacts on CO_2 emissions

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ABSTRACT

In recent years, the debate about demographic changes and its impacts on the economy has increased. The growth in the relative share of elderly people in the age pyramid may occur in the coming decades in many parts of the world, and their effects on the composition of consumption, notably on energy demand and emissions, are not yet known. This article estimates the changes in the pattern of consumption in Brazil due to the changes projected in the age pyramid in 2050 and the consequences of these changes on CO_2 emissions. For this, projections will be made using an input–output model for the Brazilian economy for the year 2010 considering 67 productive sectors and six age groups. The results suggest that emissions grow less than proportionally to population growth and that the participation of sectors such as fuels and transport shows a small decrease in the consumption vector for 2050.

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1. Introduction[1]

In the past few decades, researchers have shown growing interest in studying issues related to demographic changes and their impacts on the economy. According to Park and Hewings (2007), studies have largely been focused on whether economic growth is limited by, promoted by, or independent of population growth. The pessimistic perspective, such as of Ehrlich (1968), indicates that fast population growth is a threat to limited resources, since much of the investment needs to be used to serve growing populations. The more optimistic, such as Kuznets (1967) and Simon (1981), believe that a larger population promotes technological innovation and facilitates economies of scale.

However, it is not only population growth that matters but also the age structure. The relative share of elderly people in the age pyramid may grow in the coming decades in many parts of the world, and it is important to consider the impacts of these changes on the structure of production and consumption. Bloom et al. (2001), Fougère et al. (2007), Dalton

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et al. (2008), Kronenberg (2009), and Albuquerque (2015) have examined the impacts of age distribution on economic growth.

A country with a high proportion of elderly people may experience lower economic growth because a large proportion of the resources will have to be allocated to serve a less productive population (Bloom et al., 2001). Also, the consumption patterns of younger and older people are different (Albuquerque & Lopes, 2010; Dewhurst, 2006; Fougère et al., 2007). This change in consumption patterns and the resulting multiplier effect across the economy will reveal opportunities for expansion for some sectors and contraction in others (Dewhurst, 2006).

According to Kronenberg (2009) the current pattern of consumption is unsustainable, and the debate focuses on the instruments that can be used to change it. But as mentioned before, the patterns are already changing because of the aging population. Most studies on this topic find that as the population ages, the importance of health sector rises and the importance of education sector decreases (Albuquerque & Lopes, 2010; Dewhurst, 2006; Fougère et al., 2007; Lefèbvre, 2006; Lührmann, 2005). Besides that, the expenditure share for food, furniture and energy can increase with age, and the shares spent on leisure, clothing and transport can decline substantially (Lührmann, 2005).

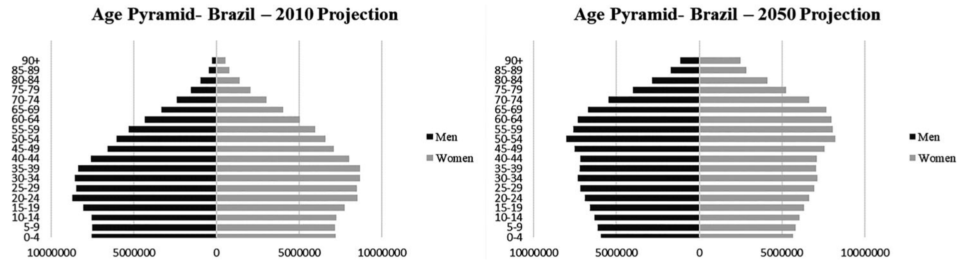
Those changes in consumption patterns would affect the energy requirements in the economy (Bin & Dowlatabadi, 2005) and, hence, would also affect greenhouse gas (GHG) emissions. Statistical analyses of historical data suggest that affluence, consumption per capita and population growth has been the main drivers of emissions growth in recent years (Arto & Dietzenbacher, 2014; Cole & Neumayer, 2004; Dietz & Rosa, 1997; Fan et al., 2006; Malik et al., 2016). O'Neil et al. (2010) affirmed that families can affect emissions directly through consumption or indirectly through the effects on the sectors of the economy via the production chain. Kronenberg (2009) states that older people generally consume more heat energy and less gasoline than young people because they tend to be more sensitive to cold, and use the car less often.

Therefore, changes in consumption, both directly and indirectly, can affect economic growth, energy use and consequently GHG emissions, representing an important vector of emissions. And despite population growth, all else being equal, contributing to the increase in GHG emissions by increasing total consumption, it is necessary to remember that demographic change also includes population aging (Kronenberg, 2009). Accordingly, since the elderly consume less of emissions-intensive sectors, the aging population will tend to reduce emissions, neutralizing part of the positive effect of population growth on emissions.

Brazil has a large population and is still advancing in the age transition, unlike the developed countries that started this transition long ago. It is possible to predict that the population of the elderly (over 65 years) will increase at an accelerated rate (2–4% per year), while the young population will decrease (Nasri, 2008). The 5 to 9 year age group declined from 14% to 12% between 1970 and 1990 (IBGE, 2010). On the other hand, the age group of people over 65 years old increased from 3.5% in 1970 to 5.5% in 2000. By 2050, this age group is expected to account for about 19% of the Brazilian population (IBGE, 2010). These facts will lead to a change of pattern in the Brazilian population pyramid. Figure 1 illustrates the change in the 2010 Brazilian age pyramid projected to 2050.

Figure 1 shows an increase in the participation of older people in the total population of Brazil. This projected demographic change affects the final demand, which, in

Figure 1. Age pyramid in 2010 and projection of age pyramid in 2050 for Brazil. Source: IBGE (2019).



turn, generates repercussions on the production structure, energy use and emissions, by changing the participation of some sectors in total production. As Brazil leads the participation of developing countries' movement in the global effort to reduce GHG emissions,[2] it is relevant to evaluate how the change of the Brazilian age pyramid will affect its future emissions.

This article seeks to estimate the changes in the pattern of consumption in Brazil due to projected changes in the age pyramid in 2050 and the consequences of these changes on GHG, notably on CO_2 emissions. This study focuses on CO_2 emissions because it is one of the major GHG and the energy from the combustion of fossil fuels is the main source of it. Although Brazil has a strong presence of renewable sources in its energy matrix, demand for fossil fuels accounted for 55.1% of total energy demand in 2016 (MME, 2017).

For this, projections will be made using an input–output model for the Brazilian economy for the year 2010. An input–output model is an adequate tool because the goal of this study is to present the changes in specific consumption patterns by age group and their impacts on various sectors of the economy. This method has the advantage in capturing systemic effects on the economy and consequently on CO_2 emissions resulting from a final demand shock by calculating the direct and the indirect effects via inter-sectoral linkages of the population aging. It should be noted, as pointed out by Dewhurst (2006), that the method has some limitations because it does not incorporate the effect of new technologies, changes in relative prices, and changes in behavioral patterns. However, this is an unprecedented study for Brazil; it is the first attempt to assess the impact of an aging population on consumption patterns and CO_2 emissions.

2. Evidence from literature

Some studies have tried to evaluate how population aging could affect the pattern of consumption, and the composition of the different goods in the economy. Sastry et al. (1989) study the interrelations between income and age for U.S., and found that the higher level of elderly household expenditure on labor intensive goods and services signals a further shift towards a service-intensive economy.

A different age structure may affect energy use and consequently GHG emissions. Some studies have suggested that the consumption of elderly households is more energy intensive (Kronenberg, 2009; Yamasaki & Tominaga, 1997). This section presents the insights

[2] It has already tabled several proposals for voluntary targets, such as the National Plan on Climate Change (PNMC, 2008).

of some studies about the effects of demographic changes on consumption patterns. Afterwards, results of studies evaluating how demographic changes can affect GHG emissions are presented.

Most industrialized countries are facing the phenomenon of population aging, and this change will probably induce shifts in the sectoral composition of final demands (Fougère et al., 2007). The authors evaluated the impact of aging in Canada from 2000 to 2050 using a computable general equilibrium model with overlapping generations. Considering both the supply-side and the demand-side channels, they find some important sectoral shifts due to changes in final demand. For example, sectoral participation of health and insurance in total GDP is expected to increase while education and construction is expected to decrease.

On a consumption-base approach using an input–output model, Dewhurst (2006) analyzed the effects of population aging in Scotland for 2016, disaggregating the household income column into three subsectors: (i) younger families (head of household under 65 years); (ii) mature families (head of household between 65 and 74 years); and (iii) older families (head of 75 years or older). He also finds that an increase in older families and a decrease in younger families would reduce the final demand for education but increase for health and insurance services. In the same line, for Portugal from 2005 to 2060, Albuquerque and Lopes (2010) also identify a rise in the health sector and a decline in education.

These changes in the sectoral composition of consumption affect emissions directly through household energy use and indirectly by industrial sectors producing non-energy commodities demanded by the households (Munksgaard et al., 2000). Thus, population growth, by stimulating the increase in consumption and production, could affect GHG emissions. On the other hand, an aging population, by changing the sectoral composition of final demand, can also alter energy use and consequently related emissions. In this sense, some studies have sought to understand how GHG emissions could change because of population growth and aging population.

O'Neil et al. (2012) reviewed several studies and presented evidences to show how CO_2 emissions can be affected by demographic factors such as population growth, urbanization, aging, and changes in household sizes. They noted that statistical analyses of historical data show that population growth causes a proportional increase in energy use and emissions. They also verified the results of studies that used future scenarios of demographic changes and found that urbanization and aging can produce effects in some regions of the world. However, they noted that only some studies incorporate variables such as age distribution.

With an econometric model and not considering the age distribution, Dietz and Rosa (1997) have estimated the effects of population, wealth, and technology on CO_2 emissions for 111 nations in 1989. Their results showed that affluence followed by population growth tends to aggravate CO_2 emissions. Corroborating Dietz and Rosa's (1997) findings, Cole and Neumayer (2004) estimate the relationship between CO_2 emissions and population growth for 86 countries from 1975 to 1998 and found evidence that population growth causes a proportional increase in emissions. Arto and Dietzenbacher (2014) and Malik et al. (2016) carried out a structural decomposition analysis (SDA) to decompose the changes in CO_2 emissions and their results showed the rise in emissions was also driven by affluence (consumption per capita), followed by population growth.

Fan et al. (2006) investigated the impact of population, wealth, and technology on CO_2 emissions of China and other countries with different income levels from 1975 to 2000.

Their results showed that globally, economic growth has the greatest impact on CO_2 emissions. Therefore, government policies aimed at offsetting the emissions growth may be needed because of increasing levels of individual wealth, but the literature does not offer any effective policies options to address this driver (Lenzen et al., 2013). That is why it is important to look at other drivers such as population growth and aging.

Considering population aging and the sectoral composition of final demand, some authors have analyzed the impact on emissions of a change in age structure. Kronenberg (2009) estimated the impact of demographic change in Germany on energy use and GHG emissions by 2030 using an environmental input–output model. The results suggest that, by 2030, demographic change will increase methane's share of total GHG emissions and will not help reduce energy use and emissions in Germany. Dalton et al. (2008) analyzed how the age composition of US households may affect energy use and CO_2 emissions using a dynamic computable general equilibrium model with multiple heterogeneous families, showing that population aging can contribute to the reduction of emissions in the long term by almost 40% in a scenario of low population growth.

In general, these studies suggest the health and food sectors can increase, and education and transport sectors can decline. However, most studies analyze only developed countries that are already at an advanced stage of demographic transition. The differential of the present article is to evaluate a developing country with a large population, which is in the initial stage of transition. Moreover, studies that sought to analyze the sectoral effects of income on energy requirements in Brazil, have identified that utilities, mobility and shelter were the most important (Cohen et al., 2005). And unlike developed countries, the transport sector increases its share of total energy requirements as income increases and age is correlated with expenditure and has a positive influence on energy (Lenzen et al., 2006).

Although the methodology used by Kronenberg (2009) was replicated in this study, the results are not comparable. The author assessed the impact on GHG emissions due to demographic change up to the year 2030 in Germany. Our focus is to analyze the impacts of the change in the age pyramid up to the year 2050 in Brazilian consumption patterns and CO_2 emissions.

The input–output model fits in studies on emissions and demographic changes because it is able to project the systemic effects of a final demand shock, making it possible to capture the direct and indirect effects on CO_2 emissions caused by the change in the age structure. This research does not consider changes in consumption behavior within each group. But even so, its results will contribute to show the relative importance of sectoral emissions resulting from the population aging on a consumption-based approach. An input-output framework will only reflect demand considerations and cannot reflect supply side adjustments (Dewhurst, 2006).

3. Research Approach

An input–output model was used to project the impact of Brazilian population aging on GHG emissions. This model consists of an analytical framework of general equilibrium[3]

[3] Input–output models are general equilibrium models that adopt assumptions of (i) constant technological coefficients (Leontief function), (ii) constant returns to scale, (iii) exogenous final demand, (iv) perfectly elastic supply, and (v) rigid prices.

with the representation of existing relations in an economy, where productive activity responds to the exogenous variations of the final demand. The input–output model represents the national economy with intersectoral flows of goods, where the production of the sectors changes to satisfy the final demand. In matrix terms, the solution of the model[4] can be presented as

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{1}$$

where $\mathbf{x}$ is a vector of total output by sector; $(\mathbf{I} - \mathbf{A})^{-1}$ is the total impact matrix, the Leontief Inverse matrix; and $\mathbf{y}$ is the vector of final demand by sector. The model considers five components of final demand, namely, household consumption, government consumption, exports, investment (gross fixed capital formation), and inventory changes.

An environmental input–output approach is used by incorporating sectoral CO_2 emissions data to analyze the environmental impacts of changes in consumption and production. This is a method widely used in the literature (e.g. Carvalho et al., 2013; Carvalho & Perobelli, 2009; Kronenberg, 2009; Perobelli et al., 2015; and Lixon et al., 2008).

3.1. Projection of the impacts of aging on CO_2 emissions

To reach the objectives of this study, the first step was to make a projection of the final consumption of households by sector and by age group. The Family Budget Survey data for the years 2008/2009 (POF 2008/2009) were used to map the composition of consumption considering different age groups, and then classify this consumption within the sectors of the input–output model. Next, we estimated household consumption by considering the demographic projections of the Brazilian Institute of Geography and Statistics (IBGE) until 2050. Then, this projection of consumption by sector and age group was incorporated into the input–output model, making it possible to project production and emissions. Appendix 1 presents the demographic projections of IBGE in greater detail.

Following the method proposed in Kronenberg (2009), household consumption was disaggregated into six groups according to the age of the head of household. The families within each group are assumed homogeneous, while the composition of consumption of each group is considered constant over time. Only changes in group sizes occur, such as growth of the older group relative to the younger group.

Thus, the average household consumption would be

$$\mathbf{C} = \mathbf{S}\hat{\mathbf{h}} \tag{2}$$

where $\mathbf{C}$ is the household consumption matrix by sector and age group. $\mathbf{S}$ is the share matrix of the total expenditure by sector and age group. $\hat{\mathbf{h}}$ is the diagonal matrix of $\mathbf{h}$, the vector of total consumption of the household by age group.

Then, total consumption matrix by sector and age group would be

$$\mathbf{H} = \mathbf{C}\hat{\mathbf{n}} \tag{3}$$

where $\hat{\mathbf{n}}$ is diagonal matrix of $\mathbf{n}$, the vector of the number of households by group.

[4] For more details, see Miller and Blair (2009).

The share of consumption by sector and age group, **S**, is considered constant over time. The estimated vector that is going to change is **n** through the demographic projection. This assumption is in line with the goals of the article, which intends to estimate, in isolation, the changes in CO_2 emissions that could occur due to demographic changes. It is known that both **S** and **h** can change over time because of, for example, the substitution effect of changes in relative prices, income effect, or even a change in consumption patterns. However, this article intends to capture the possible impact on emissions from a change in the Brazilian age pyramid. Finally, **H** is the total consumption matrix by sector and age group.

The demographic and consumption projections for 2050 will be considered the final demand of the model $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$. Then, the resulting CO_2 emissions, and the direct and indirect effects are calculated. However, an emission intensity vector byector is first calculated.

$$\mathbf{e} = \hat{\mathbf{x}}^{-1}\mathbf{m} \tag{4}$$

where **m** is the CO_2 emissions vector that includes the sectors of the input–output model and $\hat{\mathbf{x}}$ is the diagonal matrix of **x**, the vector of total output. The impact of age pyramid change on emissions is then

$$\mathbf{EM} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{H} \tag{5}$$

where **EM** is emissions matrix that represents the impacts of aging on CO_2 emissions.

4. Database

This research uses the input–output matrix produced by IBGE for the year 2010, which presents 67 sectors of the Brazilian economy to estimate the changes in consumption pattern in Brazil due to demographic changes and the consequences of these changes on CO_2 emissions. We also use data from the POF (2008/2009), as well as data from the National Energy Balance (BEN) – EPE (2009). The first step in the preparation of the data was to aggregate the sectors of the three bases.

The POF data were used to map the composition of consumption by age group. This survey is carried out by IBGE every five years. The main objective of this survey is to measure the consumption structures, the expenditures, and income of the families, as well as the perception of the living conditions of the population, according to the characteristics of the households and people. In addition, the data are used to subsidize the construction of the National Consumer Price Index (INPC).

The 2008/2009 survey contains information on the population living in urban and rural areas in Brazil. The sample is representative of the 27 units of the Federation and 9 metropolitan areas, as well as for the whole country. The sample size included 190,159 individuals residing in 55,970 households. Data collection is carried out through six questionnaires, five of which are organized according to the type of expenditure: (1) characteristics of households and residents; (2) collective expenses on durable household goods (3) collective expenses on food and cleaning, (4) individual expenses; and (5) individual earnings and wages. The last questionnaire investigates the perception of living conditions (IBGE, 2004).

The disaggregation procedure of the consumption vector, considering age groups, requires that the products and services available in the POF are compatible with the input–output matrix. In the compatibilization procedure,[5] the first step was to organize approximately 7000 POF items and distribute them according to the classification of the 127 products and 67 sectors of the input–output matrix. For this, the translator[6] elaborated by the IBGE was used to associate each POF product with a product of the System of National Accounts (SCN), which is the database of the input–output matrix. In the SCN, household consumption expenditure is estimated from the structure calculated by the POF (IBGE, 2010).

The aggregation adopted was aimed to preserve, as much as possible, the information provided by the input–output matrix and the Family Budget Survey (POF data). It is noteworthy that this modification changes only the composition of the matrix, not modifying its structure in terms of value, maintaining the consistency of the original IBGE matrix.

As the focus of this work is directed toward the effects of demographic changes on consumption, the next step was to map a specific consumption profile considering the age of the household head.[7] Six age groups were thus defined: (1) younger than 30 years; (2) between 30 and 39 years; (3) between 40 and 49 years; (4) between 50 and 59 years; (5) between 60 and 69 years, and (6) above 70 years.[8] This disaggregation helps verify the difference in consumption pattern between the components of families with older and with younger household heads.

Households of different age groups do not differ only in terms of energy consumption, but also in other aspects. Although consumption is not directly related to energy use and GHG emissions, it may be related to production. Thus, a shift between healthcare consumption and education can indirectly affect energy use and GHG emissions (Kronenberg, 2009; Lührmann, 2007; Santiago, 2014).

Analyzing Table 1, we note that the food share remains practically constant for age groups up to age 59 (on average 13% of the budget) and increasing for the older groups (14.2% for 60–69 years and 16.7% for 70 years or older). Older age groups (60–69 years and 70 years or older) tend to allocate a relatively large share of their total expenditure on healthcare (6.9% and 8.9%), and services (27.8% and 25.9%). In relation to services, one of the explanatory hypotheses is the provision of care services for the elderly that may imply higher expenses. Younger groups tend to allocate a significant portion of their spending on textile and clothing, transport, and other industries. For example, in this group, about

[5] In the compatibilization procedure of Family Budget Survey data and input–output matrix we use as a basis the work of Lührmann (2005), Lefèbvre (2006), Dalton et al. (2008), Kronenberg (2009), Santiago (2014). Other approaches adopted in literature, such as in the work of Min & Rao, Narasimha, 2017; Steen-Olsen et al., 2016, are interesting and can be implemented in future work.

[6] The IBGE translator excludes expenses that are not considered final consumption, such as taxes, transfers, and gross capital formation. Available in: < http://www.ibge.gov.br/home/estatistica/economia/contasnacionais/2009/default_SCN.shtm > .

[7] When we choose this approach, we adopt the assumptions of collective choice models (Chiappori, 1988, 1992; Browning & Chiappori, 1998, 2009), where the utility function of the family is a weighted sum of individual utilities and the resulting choices are Pareto efficient. The model is based on the principle that the more an individual's preferences prevail in family choice, the greater the bargaining power of that individual within the family. As the head of the household, according to IBGE (2014), is the person responsible for the family business and, in most cases, the most important source of income, we are adopting the hypothesis that the head has a greater bargaining power and, therefore, becomes responsible for household consumption choices.

[8] The number of observations of the six age groups is: (1) younger than 30 years (7,617); (2) between 30 and 39 years (12,164); (3) between 40 and 49 years (12,065); (4) between 50 and 59 years (9,322); (5) between 60 and 69 years (6,669), and (6) above 70 years (5,152).

Table 1. Distribution of families' expenditures by type of domicile in Brazil, aggregated for 15 products (in % change).

	Age Groups					
Products	≤ 29	30–39	40–49	50–59	60–69	70+
Food	13.7%	13.3%	13.0%	12.4%	14.2%	16.7%
Textile and Clothing	4.7%	4.1%	4.1%	3.4%	3.3%	3.0%
Fuels	2.3%	2.6%	2.7%	2.7%	2.6%	2.0%
Ethanol	0.7%	0.8%	1.0%	1.0%	0.8%	0.5%
Transport	4.4%	3.6%	3.6%	3.3%	2.9%	2.5%
Healthcare	3.4%	3.6%	5.0%	4.6%	6.9%	8.9%
Durables	6.5%	6.3%	5.8%	5.4%	5.0%	3.9%
Other Industry	4.9%	4.3%	3.9%	3.4%	3.6%	3.6%
Energy	2.0%	2.1%	2.3%	2.3%	2.6%	3.0%
Water	0.9%	0.8%	0.9%	0.8%	1.1%	1.3%
Education	2.3%	2.8%	3.6%	3.4%	2.1%	0.9%
Financial Intermediation and Insurance	4.2%	5.7%	6.6%	8.7%	11.1%	14.0%
Services	24.6%	27.7%	27.8%	29.5%	27.9%	25.9%
Accommodation and Food Services	7.0%	6.4%	5.7%	5.6%	4.5%	3.7%
Real State and Rental Services	18.5%	15.8%	14.1%	13.4%	11.5%	10.2%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Input–output matrix (IBGE, 2016) and Family Budget Survey – POF 2008/2009 (IBGE, 2004).

4.7% of the budget is allocated for the acquisition of textile and clothing, while its share is only 3% for the group above 70 years.

From the matrix aggregation, the second stage of the work was to convert the energy coefficients (in 1000 toe) into CO_2 emissions (in gigagram (Gg) = 1,000 tonnes) caused by the use of fuels by various sectors of the economy. Thus, the conversion coefficients found in Economy and Energy (2002) were applied.[9]

5. Analysis and discussion of the results

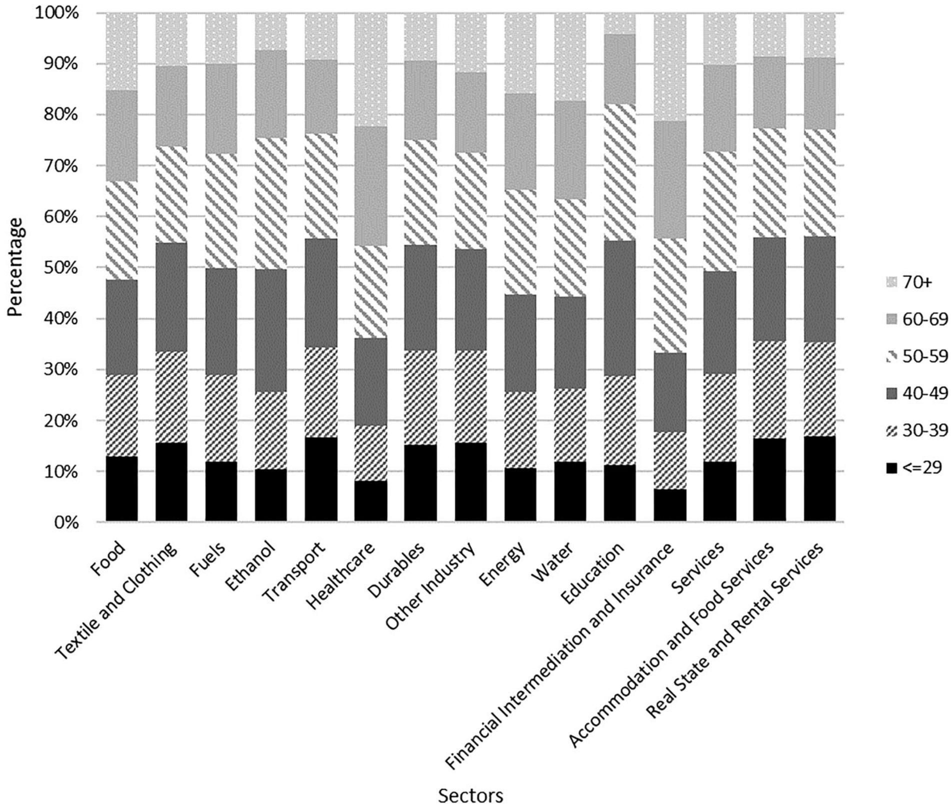
This section identifies and analyzes the main results obtained from the implementation of the method proposed on Section 3. To facilitate the perception and understanding of the results, we decided to aggregate the results into 15 sectors.[10] The aggregation was defined based on degree of homogeneity of the activities, according the classification of IBGE (2016). It is worth mentioning that two energy sectors – fuels and energy – have been kept disaggregated as they are sectors that can change their CO_2 emissions due to demographic changes, according to the literature (Kronenberg, 2009; O'Neil et al., 2012).

5.1. Sectoral emissions intensity and household footprint

The first result presented in this section is the distribution of the total impacts on CO_2 emissions caused by household type in each expenditure category in 2010 (Figure 2). It is noted that the total emissions in textile and clothing, fuels, transport, ethanol and education, sectors are mainly due to the expenses of groups up to 49 years old. On the other hand, for sectors such as healthcare, financial intermediation and insurance, and services, the total emissions are mainly caused by the consumption of groups aged 50 and over. We

[9] The method used to disaggregate the BEN sectors is the one proposed by Montoya et al. (2014).
[10] The disaggregated results for the 67 sectors can be seen in the supplementary material.

Figure 2. Household footprint by expenditure category in 2010 – in share of total CO_2 emissions.



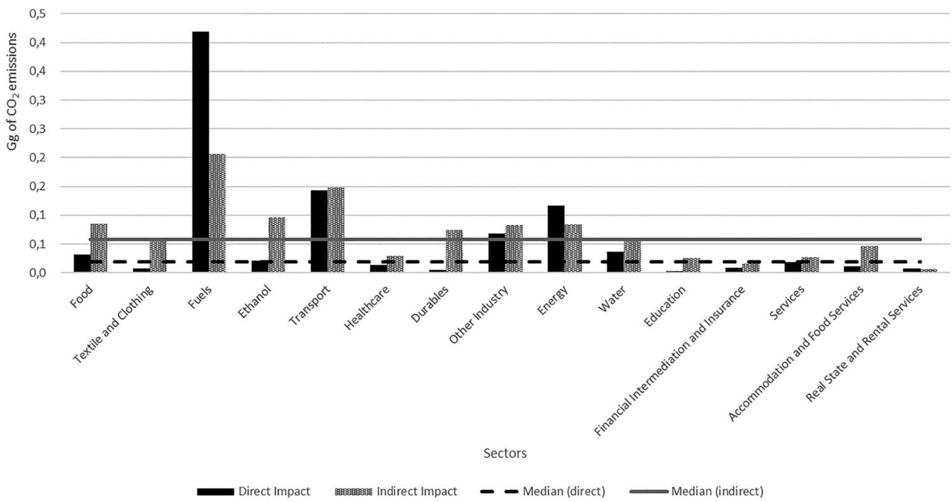
also note that in groups over 70 years of age, for example, there is a small participation in the total emissions of CO_2-intensive sectors, such as transport and fuels.

In addition to the results of participation in total emissions by age group in each sector, it is important to identify the activities that most contributes to increase the CO_2 emissions, both directly and indirectly. That is, the increase in emissions generated to directly meet the final demand of the sector and the indirect increase caused by the increase in demand from the other sectors. Understanding this dynamic will be important in explaining the effects of demographic changes on production and, consequently, on CO_2 emissions. These results can be observed in Figure 3.

Figure 3 shows that fuels and transport sectors will have the greatest impact, with around 0.6 and 0.3 Gg of CO_2 emissions for each increase in final demand of R$ 1 million, respectively. Followed by energy and other industry, they are the sectors that generate the most increase in emissions due to an increase in final demand.

In relation to the fuels sector, about 70% of the increase in its CO_2 emissions is generated directly when an increase in the final demand takes place. Other sectors increase their emissions indirectly due to the acquisition of inputs from the other sectors to meet the final demand. Durables stand out (on average 93% of the increase in their emissions occurs indirectly), as do education (92%) and clothing (89%). As the sectors are highly aggregated, the indirect effect is more intense across all.

Figure 3. Direct and indirect impacts on CO_2 emissions (in Gg) of an increase by R$1 million in final demand.



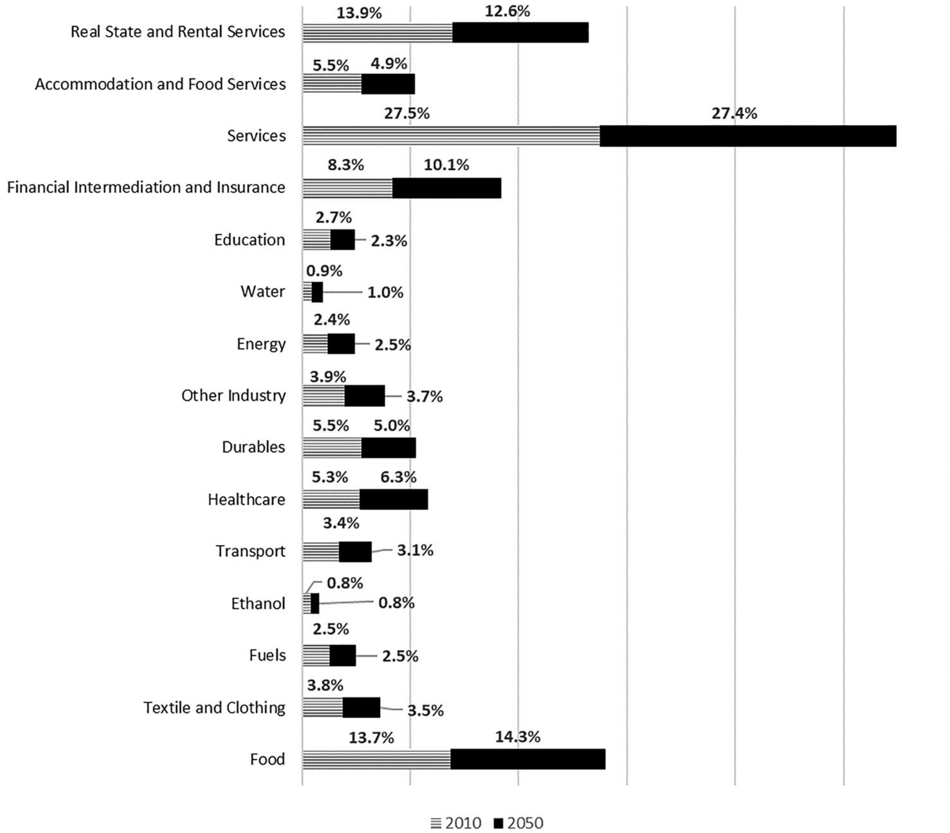
5.2. *Impact on the CO_2 emissions of the productive sectors due to the change in the age pyramid*

Figure 4 presents the results for changes in the composition of household consumption due to the change in the age structure of the population, comparing the years 2010 and 2050. Figure 4 shows that textile and clothing, transport, other industry, durables, education, accommodation and food services, and real estate and rent sectors reduced their share in the consumption for 2050. The result is interesting because the sectors that increase the most emissions to meet the final demand would lose participation in the consumption vector due to the change in the age structure, although this loss is only marginal.

The less emissions-intensive sectors, such as healthcare and financial intermediation and insurance, expand their share of the 2050 consumption vector. The only emissions-intensive sector with an increase in the composition of the 2050 vector is energy. Overall, the results seem to indicate that the change in the age pyramid moves the consumption toward activities that incorporate fewer emissions into their production process.

To better evaluate the impacts of the age structure change in the productive sectors, Table 2 shows the results on emissions. With the projections of demographic change, there has been an increase in household spending, from R$1918 million in 2010 to R$3397 million in 2050, corresponding to a 77% increase, considering the projected consumption structure. Total emissions increase from about 160,000 of Gg to 280,000 of Gg in 2050, representing a nearly 75% increase, showing that population growth can increase GHG emissions, which corroborates Dietz and Rosa (1997) and Cole and Neumayer (2004) findings. However, the results indicate that the emissions would not increase proportionally to the expenses, as found by these studies. Our result shows the importance of the composition effect due to the increase in the participation of less emissions-intensive sectors in the 2050 consumption vector.

Figure 4. Change in the composition of consumption vector (expenditure) by sector from 2010 to 2050.



However, it should be remembered that the model does not consider any technological change in the period, only the impact that a change in the age pyramid would cause in the emissions of productive activities if all the technical coefficients remained the same as in 2010. It also does not consider substitution via prices. In this way, keeping the 2010 technology constant, the model captures the increase in emissions that the increase in consumption would cause (directly and indirectly) due to the changes in the age structure of the Brazilian population. And still, the results have shown that the percentage increase in emissions is not linear with population growth. Thus, population growth, given the changes in age structure, may not pressure resources in the same proportion.

In this case, we can observe that sectors that are emissions-intensive, such as fuel, transport, and durables, lose a small share in the composition of emissions from 2010 to 2050 as a result of aging population. Although this reduction is small, we can state its importance in the results because the fuel and transports sectors are the activities with the most CO_2 emissions embodied. However, sectors such as food and energy, which have a high total impact on emissions when final demand increases, show a gain in the composition of emissions in 2050.

Table 2. Household spending impact on CO_2 emissions (Gg) by year and demographic change impact on CO_2 emissions (in Gg) by sector.

	2010				2050			
Sectors	Direct Impact	Indirect Impact	Total Impact	Emissions Share	Direct Impact	Indirect Impact	Total Impact	Emissions Share
Food	8622	23,836	32,457	20.2%	15,910	44,048	59,958	21.4%
Textile and Clothing	306	3762	4068	2.5%	533	6223	6756	2.4%
Fuels	20,404	10,028	30,433	19.0%	34,944	17,175	52,119	18.6%
Ethanol	326	1512	1838	1.1%	541	2511	3051	1.1%
Transport	9274	10,023	19,297	12.0%	14,960	16,129	31,089	11.1%
Healthcare	1419	3018	4437	2.8%	3089	6479	9567	3.4%
Durables	411	7226	7637	4.8%	676	11,828	12,504	4.5%
Other Industry	2744	5893	8637	5.4%	4668	9995	14,664	5.2%
Energy	5267	3782	9049	5.6%	9997	7180	17,177	6.1%
Water	669	995	1663	1.0%	1293	1923	3216	1.1%
Education	110	1284	1394	0.9%	166	1945	2112	0.8%
Financial Intermediation and Insurance	1399	2496	3895	2.4%	3005	5358	8363	3.0%
Services	10,970	16,879	27,849	17.4%	18,694	29,062	47,756	17.0%
Accommodation and Food Services	1115	4913	6027	3.8%	1772	7806	9578	3.4%
Real State and Rental Services	459	1159	1618	1.0%	721	1856	2577	0.9%
Total	63,494	96,807	160,300	100.0%	110,969	169,518	280,487	100.0%

Table 3. CO_2 emissions in 2010 and projected CO_2 emissions in 2050 resulting from demographic change, by age group.

	2010		2050	
Age Groups	Emissions Intensity	Emissions Share	Emissions Intensity	Emissions Share
< 29	20,923	13%	14,546	5%
30–39	26,730	17%	24,450	9%
40–49	32,183	20%	38,281	14%
50–59	33,832	21%	54,916	20%
60–69	27,439	17%	71,635	26%
70+	19,194	12%	76,659	27%
Total	160,300	100%	280,487	100%

5.3. CO_2 emissions impact by age group

The change in consumption due to demographic changes induces significant changes in the composition of total emissions by different age groups. The results are presented in Table 3. Due to population aging, in 2050, the age groups that present a more emissions-intensive consumption vector are the 60 to 69 years group, as well as the groups above 70 years. Younger groups, under 29 years and between 30 and 39 years old, represent only 14% of the total in 2050, and the group under 29 years old accounted for almost the same percentage in the composition of the emissions in 2010. This behavior can be explained by demographic projections, where the highest growth occurs for the group over 60 years. While these age groups increase the share of consumption in less emissions-intensive sectors, the effect of the group growth is greater on emissions.

6. Conclusion

The results indicate that demographic change has an impact on the structure of household consumption expenditure when considering different age groups. The most important impacts are observed in the healthcare and transport sectors. Household energy use is also significantly affected. In addition, population growth, when considering the change in age structure, does not appear to cause a proportional increase in emissions. We obtain this result mainly due to the reduction of participation in the consumption vector for 2050 for sectors such as fuels and transport. Thus, changes in the number of individuals in each group do not generate significant changes in the structure of emissions in the sector, but they generate a change in the composition of emissions by age group.

This composition effect is shown to be important and corroborates O'Neil et al.'s (2012) work. However, Kronenberg (2009) notably used a similar method and found evidences to show that the change in the age structure of Germany until 2030 does not seem to contribute to a reduction of CO_2 emissions. This result seems to be associated with the fact that Germany is in a more advanced stage of age transition than Brazil is, which means the changes of the shares of elderly groups are larger in Brazil. Therefore, more studies should assess how changes in the age pyramid will affect energy use, and thus emissions, in developing countries, such as Brazil, India, and China. These countries, in addition to having a large population, are increasingly contributing to total global emissions. Therefore, understanding how this process will affect emissions is important.

This article was not intended to establish definitive projections of demographic change and CO_2 emissions. Notably, the changes in the consumption patterns of each 2050 age group were calculated by considering only the population projection. In fact, the pattern of consumption within age groups is expected to change over a long period due to increased incomes, price changes, or cohort effects, for example. In addition, the input–output analysis was based on the technical coefficients of the 2010 matrix. In fact, these coefficients may be affected by technological change or substitution effects. Future research, however, could incorporate such effects into a computable general equilibrium (CGE) model.

But even if the model assumes constant emission coefficients, the model manages to capture the effects on emissions that would result only from the change in the age structure for 2050. Furthermore, the model captures the direct and indirect effects of the change in the structure of final demand, which would not be possible through a partial equilibrium model. Thus it achieves its main goal by indicating the relative changes in the sizes of the sectors of the economy, as well as suggesting that the growth in CO_2 emissions will be less than proportionally to the population increase due to the changes that will occur in the Brazilian age pyramid.

Finally, our results show that, unlike most developed countries, the change in the Brazilian age structure can influence the pattern of emissions. Thus, the demographic characteristics as well as the economic activities structure are relevant to the impacts of aging on the consumption pattern and emissions. However, the demographic change is not enough, reinforcing the need of policies aimed at reducing emissions. Among the instruments that can mitigate the degree of emissions we can highlight the adoption of best practice for industrial production, the improvement at transport system and the promotion of energy efficiency and renewable energy sources.

We can affirm that some policies are too difficult to implement in a developing country. In that way, our study can contribute to this issue since aging is a reality in Brazil. Our results, mainly for population over 60 years, could help the policymakers, for example, by focusing in the adoption of best practice for activities that are growing in the age groups that most contribute to the emissions. On the other side, aging is related to healthcare, thus policies that encourage a healthy diet with reduced consumption of animal protein may also be an option.

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